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POWELL RIVER PROJECT

RECLAMATION GUIDELINES FOR SURFACE-MINED LAND

Revegetation Species and Practices

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Introduction

Establishing vegetation is an important activity in reclaiming mined lands. Revegetation encourages minesoil development, creates an aesthetically pleasing landscape, and contributes to productive postmining land use. Prompt and thorough establishment of vegetation after mining is essential to comply with the federal Surface Mining Control and Reclamation Act (SMCRA) by coal-mining operations.

This publication summarizes procedures for establishing herbaceous vegetation (grasses and legumes) on mined areas. The emphasis is revegetation to control erosion and establish hayland/pasture as a postmining land use. Powell River Project has developed a separate set of recommendations for revegetation to establish trees and shrubs for a forested postmining land use; these are reviewed in *Restoring Forests on Surface-Mined Land*, Virginia Cooperative Extension (VCE) publication 460-123, and *Establishing Groundcover for Forested Postmining Land Uses*, VCE publication 460-124.

Minesoil Selection and Placement Procedures

Successful revegetation of active surface mines begins well in advance of fertilization and seeding. The most important step, by far, in surface-mine revegetation occurs when the soil medium is selected and placed on the land surface. For optimum plant growth, the soil medium should be selected to provide physical and chemical properties suitable for the intended postmining land use.

Fertilization and, in some cases, liming are also important components of revegetation procedures. Minesoil selection, placement, and amendment procedures are covered in *Creation and Management of Productive Minesoils*, VCE publication 460-121.

Plant Species for Revegetation

When establishing vegetative groundcover on surface-mined sites, the two most important factors influencing species selection should be soil properties and postmining land use. Three general categories or types of plants are used for revegetation of mined areas: grasses, forbs, and trees.

Grasses are the most commonly seeded plants in revegetation programs. They belong to the Gramineae family, produce large amounts of biomass, and are adapted to initiate regrowth rapidly after mowing or grazing. Grasses have fibrous root systems that hold soil in place, thereby controlling erosion.

Forbs – herbaceous flowering plants – are generally used in mine revegetation in conjunction with grasses. Forbs usually have broad leaves, flowers, and a branching taproot system. Forbs can be further classified as legumes and nonlegumes.

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Legumes are forbs that belong to the Leguminosae family. Legumes are especially important for revegetating mined lands because they are capable of using nitrogen from the air to meet their nitrogen nutrition requirements, and they can transfer this "fixed" nitrogen to other components of the plant/soil system. A healthy population of legumes is essential to successful revegetation, especially on minesoils constructed from blasted overburden ("topsoil substitutes"), which are essentially devoid of native plant-available nitrogen (see VCE publication 460-121).

Nonleguminous forbs are also broad-leaved plants with showy flowers. Examples of nonleguminous plants used in revegetation are buckwheat (*Fagopyrum sagittatum*), sunflowers (*Helianthus spp.*), and Japanese fleeceflower (*Polygonum cuspidatum*).

Trees and shrubs are the final plant material category. They are used when forested or wildlife habitat land uses are desired after mining. The establishment of trees and shrubs on mined lands is not discussed in this publication (see VCE publications 460-123 and 460-124).

Grasses

Grasses are the most commonly seeded plants in mine-revegetation programs for several reasons:

1. Numerous grass species are available for seeding.

2. Seed of grass species adapted to disturbed areas can be obtained readily and at reasonable costs.

3. The grass family (when taken as a whole) is tolerant of a wide variety of environmental and soil conditions.

Several grasses are well-adapted to the infertile, droughty, and/or acidic sites often associated with mined areas; others are able to provide high-quality hay and forage. A healthy grass component is important to successful erosion control. Many species are capable of producing large amounts of biomass in a short time and responding quickly to fertilizer and management, while other species may be slower growing and persist on the site for long periods without management. For these reasons, a good revegetation program will always contain grasses as a major component of the seed mix.

Grass species commonly used in mine reclamation are listed in tables 1 and 2. For each, the most commonly used varieties and cultivars and other characteristics essential to successful use in reclamation are also summarized. The term "cultivar" is derived from the term CULTIvated VARiety. Some cultivars have distinguishing characteristics that make them better adapted to the environmental conditions on Appalachian mined areas. The plant's life cycle, season of growth, origin, seeding rate, and soil/site tolerances are also shown.

Grasses for Groundcover and Forage

Tall fescue is a cool-season grass that is grown throughout the eastern United States. The range of tall fescue extends from Florida to Canada; the species is common in Kentucky, Virginia, West Virginia, Ohio, and Pennsylvania. It is a deep-rooted, long-lived perennial that gradually develops into a uniform sod in older stands.

Well-established tall fescue provides excellent erosion control, and this species is widely used in mine reclamation throughout the eastern United States. It grows best in well-fertilized, loamy soils, but it is capable of persisting under a wide variety of soil and environmental conditions. Tall fescue grows well if the pH is 4.5 or above; the species is drought-resistant and cold-tolerant.

Tall fescue is an excellent reclamation species when a hayland/pasture postmining land use or rapid and thorough erosion control is intended. Due to infection by a fungus (*Acremonium coenophialium*), some varieties of tall fescue can cause problems for grazing animals at certain times of the year (see Smith et al. 2002; *Making the Most of Tall Fescue in Virginia*, VCE publication 418-050). Seeding endophyte-free tall fescue will help minimize problems for cattle if the area is grazed. However, endophyte-free tall fescue is less hardy, less insect-, disease-, and drought-resistant, and less persistent than the nonendophyte-free varieties.

Orchardgrass is a cool-season grass that can be grown successfully on acidic, disturbed soils in areas where lime and fertilizer have been applied. It grows from the Gulf States to southeastern Canada. Other than bluegrass (*Poa* sp.), it is probably the most common forage species in the Appalachian region. Orchardgrass is shade-tolerant, and it will persist on shallow, infertile soils. However, it responds to fertilization and is most vigorous when adequate nutrients are available. It is extensively seeded in revegetation mixtures in the eastern United States.

Redtop grows well throughout the eastern United States. It tolerates acidic soils, clayey soils of low fertility, and poorly drained soils. Redtop is also shade-tolerant and will produce an effective cover, but it is short-lived.

Timothy is a cool-season species adapted to cooler climates of the Appalachian region. It grows on acidic soils and produces a good sod for erosion control on disturbed areas. Timothy is primarily grown for hay and grows well with seeded legumes.

Ryegrasses, both perennial and annual, are cool-season species that are commonly used in reclamation seeding mixtures throughout Appalachia. They are very competitive and are an important component for pasture mixtures. Perennial and annual ryegrasses are often used to establish a vegetation cover for soil protection during the winter. They grow on a wide variety of soil types but generally require fertilizer additions.

Kentucky bluegrass is commonly used in pastures on nonreclaimed sites and has been used successfully in mine reclamation. Bluegrass will not persist under low-fertility or low-moisture conditions. When seeded in combination with tall fescue, bluegrass will not persist unless the site is grazed or cut regularly. Therefore, bluegrass is best used in reclamation only on sites that will be actively managed as hayland or pasture.

Weeping lovegrass is a nonnative grass species that has proved adaptable to low-fertility, surface-mine sites. It is a perennial warm-season bunchgrass with an extensive but shallow fibrous root system. Weeping lovegrass' native habitat is East Africa, and it grows well in hot and dry climatic conditions. It is one of the fastest germinating grass species. Weeping lovegrass is easy to establish on disturbed land areas because it grows well on acidic soils (pH as low as 4.0) and tolerates droughty soil conditions. A common use for lovegrass in reclamation is erosion control on harsh, previously mined sites. On the more favorable sites that are generally produced by modern reclamation in Virginia, other grass species will be more productive and – in most respects – more desirable. Weeping lovegrass is considered an invasive species in Virginia.

Switchgrass is a warm-season grass species that is native to the eastern United States. It is a perennial bunchgrass that spreads through rhizome extension and seed dispersal. If it is not grazed or cut, this deep-rooted grass species grows from 3 to 7 feet tall. Major uses are pasture, hay, soil stabilization, and wildlife habitat improvement. Switchgrass can thrive on relatively dry sites.

Use of Grasses as "Nurse Crops"

Several fast-growing annual grass species are used commonly in reclamation seeding (table 2). **Wheat**, **oats**, and **rye** are cool-season annual grasses adapted to a wide range of soil conditions (figure 1). Oats and rye are more adapted to infertile soils than wheat. The **millets** are warm-season, annual grasses (figure 2). Warm-season annuals can be seeded and will establish during the hot, dry conditions of the summer months, while the cool-season annuals are seeded during spring and fall. Foxtail millet, Japanese millet, and pearl millet all establish rapidly and form a complete vegetation cover. Their seed is an excellent source of food for wildlife and birds.

Fast-growing annual species (such as oats or millet) may be included in reclamation seed mixes as companions to perennial grasses and forbs. These fast-growing annuals are often called "nurse crops" because they provide protection for the perennial species that are

Figure 1. Fast-growing annual grasses, most of which are annuals, are often seeded as "nurse crops" to protect the perennial grasses and legumes that are generally slower to establish. These fast-growing annuals also provide organic matter to the soil as they decompose after dying off.

Figure 2. Millets are commonly used as nurse crops during summer seedings. Japanese millet (shown here) is a prolific seed producer that attracts birds and other wildlife to the reclamation area.

Table 1A. Grasses available for seeding in mine revegetation, eastern United States.

Common Name (*Scientific Name*)	Principal Cultivars	Life Cycle[1]	Growth Season	Origin[2]	Seeding Rate[3] (lb/acre)	Ease of Establishment	Persistence
Kentucky bluegrass (*Poa pratensis*)	Numerous turf varieties	P	Cool	I	15-20	Fair	Fair
Smooth brome (*Bromus inermis*)	Saratoga, Lincoln, others	P	Cool	I	10-15	Fair	Fair
Deertongue (*Panicum clandestinum*)	Tioga	P	Warm	N	10-15	Fair	Good
Tall fescue (*Festuca arundinacea*)	Kentucky 31, Johnstone, Alta, Forager, Kenhy, Phyter, Athens	P	Cool	I	10-20	Good	Good
Weeping lovegrass (*Eragrostis curvula*)	Morpa	P	Warm	I	2-5	Good	Fair
Orchardgrass (*Dactylis glomerata*)	Pennlate, Hallmark, Potomac, others	P	Cool	I	10-20	Good	Good
Redtop (*Agrostis gigantea*)	Common	P	Cool	I	5-10	Fair	Good
Perennial ryegrass (*Lolium perenne*)	Numerous cultivars	P	Cool	I	10-15	Good	Fair
Switchgrass (*Panicum virgatum*)	Cave-in-Rock, Blackwell, Kanlow	P	Warm	N	2-5	Fair	Good
Timothy (*Phleum pratense*)	Bounty, Champlain, Clair, Timfor	P	Cool	I	5-10	Fair	Fair

[1]P = perennial, A = annual, B = biennial
[2]N = native, I = introduced
[3]Seeding rate when species is used alone; should be reduced when species is used in mixtures.

Table 1B. Grasses available for seeding in mine revegetation, eastern United States.

Common Name (*Scientific Name*)	Drought Resistance	Cold Tolerance	Acid Tolerance	Salt Tolerance	High Water Tolerance	Lower pH Limit	Comments
Kentucky bluegrass (*Poa pratensis*)	Poor	Good	Fair	Fair	Fair	5.5	Shallow-rooted sod former. Good palatability
Smooth brome (*Bromus inermis*)	Good	Good	Poor	Good	Fair	5.0	Forms dense sod. Good erosion control.
Deertongue (*Panicum clandestinum*)	Good	Poor	Good	Fair	Fair	4.0	Acid tolerant, drought resistant.
Tall fescue (*Festuca arundinacea)*	Good	Good	Good	Good	Fair	4.5	Most commonly seeded grass on mined areas. Drought resistant. Consider endophyte-resistant varieties for pasture and hay.
Weeping lovegrass (*Eragrostis curvula*)	Good	Fair	Good	Fair	Fair	4.0	Tolerant of acid minesoils and dry conditions. Short-lived perennial.
Orchardgrass (*Dactylis glomerata*)	Good	Good	Fair	Fair	Fair	4.5	Develops rapidly and long-lived.
Redtop (*Agrostis gigantea*)	Good	Good	Good	Good	Good	4.0	Sod former. Adapts to a wide variety of soils. Short lived if not managed.
Perennial ryegrass (*Lolium perenne*)	Poor	Good	Poor	Fair	Fair	4.5	Short-lived perennial. Dominates stands for two years.
Switchgrass (*Panicum virgatum*)	Good	Good	Good	Fair	Good	4.0	Rhizomatous, acid tolerant, tall. Slow to establish.
Timothy (*Phleum pratense*)	Fair	Poor	Good	Good	Fair	4.5	Good quality hay and pasture. Does not tolerate heavy grazing. Fertility demanding.

Table 2A. Fast-growing annual grass species used as "nurse crops" in eastern U.S. mine revegetation.

Common Name (*Scientific Name*)	Principal Cultivars	Life Cycle[1]	Growth Season	Origin[2]	Seeding Rate[3] (lb/acre)	Ease of Establishment	Persistence
Foxtail millet (*Setaria italica*)	German	A	Warm	I	20-30	Good	Poor
Japanese millet (*Echinochloa crusgalli*)		A	Warm	I	20-30	Good	Poor
Pearl millet (*Pennisetum americanum*)	Gahi-1, Starr	A	Warm	I	15-20	Good	Poor
Oats (*Avena sativa*)	Noble, Otee, Ogle, others	A	Cool	I	30-50	Good	Poor
Winter rye (*Secale cereale*)	Balbo, Abruzzi, Arostook	A	Cool	I	30-50	Good	Poor
Annual ryegrass (*Lolium multiflorum*)		A	Cool	I	5-10	Good	Poor
Winter wheat (*Triticum aestivum*)	Feland, Severn, Tyler, Wheeler, others	A	Cool	I	30-60	Good	Poor

[1]P = perennial, A = annual, B = biennial
[2]N = native, I = introduced
[3]Seeding rate when species is used alone; should be reduced when species is used in mixtures.

typically slower to establish. The nurse crop grows up rapidly, thus shading the perennials. When the nurse crop dies back, it provides protective mulch. As the nurse crop tissue decomposes, nutrients that the nurse crop has taken up from the soil become available for use by the other species present. Nurse crops are most beneficial when seeding conditions (either the time of seeding or soil conditions) are less than ideal.

Legumes

The family of plants termed legumes (*Leguminosae*) makes up a large group comprising approximately 20,000 species. A healthy and persistent legume component is important to nitrogen fertility on mine soils. Legumes remove nitrogen from the air for their own nutrition; their presence increases the amount of soil nitrogen available to companion species.

Nitrogen Fixation

Legumes "fix" (or remove) atmospheric nitrogen because they form a symbiotic association with bacteria of the genus *Rhizobium* that infects the roots to form nodules where they grow and proliferate (figure 3). Once the symbiotic bacteria become established in the nodules, they produce an enzyme called "nitrogenase," which allows the nodule to fix nitrogen gas from the atmosphere. The fixed nitrogen can be incorporated into plant proteins. Thus, legumes are able to grow in soils with little available soil nitrogen. The plant, in turn, supplies the bacteria in the nodule with energy and carbohydrates for continued proliferation and nitrogen fixation. The association is "symbiotic" because it is beneficial for both organisms.

The presence of vigorous and persistent legumes is important to success in mine-land revegetation.

Table 2B. Fast-growing annual grass species used as "nurse crops" in eastern U.S. mine revegetation.

Common Name (*Scientific Name*)	Drought Resis-tance	Cold Toler-ance	Acid Toler-ance	Salt Toler-ance	High Water Toler-ance	Lower pH Limit	Comments
Foxtail millet (*Setaria italica*)	Fair	Poor	Fair	Fair	Good	4.5	Rapid establishing, temporary crop. Seed in summer.
Japanese millet (*Echinochloa crusgalli*)	Poor	Poor	Fair	Fair	Good	4.5	Quick, temporary cover. Food for wildlife.
Pearl millet (*Pennisetum americanum*)	Poor	Poor	Good	Fair	Good	4.0	Fast-growing, tall annual. Food for wildlife.
Oats (*Avena sativa*)	Fair	Fair	Fair	Fair	Poor	4.5	Quick, temporary crop.
Winter rye (*Secale cereale*)	Fair	Fair	Fair	Fair	Poor	4.5	Suitable for cover crop. Provides quick temporary cover.
Annual ryegrass (*Lolium multiflorum*)	Poor	Good	Poor	Fair	Fair	4.5	Good winter annual. Outcompetes perennial grasses.
Winter wheat (*Triticum aestivum*)	Fair	Fair	Fair	Fair	Poor	4.5	Similar to rye.

Legumes can grow in soils that contain little or no plant-available nitrogen. Legumes aid rehabilitation of disturbed areas by adding fixed atmospheric nitrogen available for use by other plants.

Legumes are especially critical in postmining land uses such as unmanaged forest or wildlife habitat, where post-establishment fertilization is not an allowable management practice under SMCRA. Where topsoil substitutes (blasted overburden) are used to construct minesoils, unfertilized overburden is essentially devoid of plant-available nitrogen. Fertilization can remedy this problem, but only in the short term. Beyond the first few years after fertilization, the vast majority of the fertilizer nitrogen has been either taken up by plants or carried away ("leached") by the water that has moved through the soil. Therefore, during the latter stages of the five-year, reclamation-success period mandated by SMCRA, organic matter in the soil must serve as the primary source of soil nitrogen for the nonlegume species. The soil's organic matter is made up of dead plant tissue. Nitrogen removed from the soil by plant uptake can be "recycled" as the vegetation dies and decays, but legumes are the only plant component capable of supplying the "new" nitrogen that will be needed to support the continued growth and development of the plant community.

Legume Species Used in Reclamation

Several forage legumes have been grown successfully on mined lands in the eastern United States. Table 3 (pgs. 17-18) lists forage legumes generally available for use on disturbed areas and gives general characteristics for each. The table also shows the common and scientific name, principal cultivars, and other characteristics.

Table 3A. Legumes available for use in eastern U.S. mine reclamation.

Common Name (*Scientific Name*)	Principal Cultivars	Life Cycle[1]	Growth Season	Origin[2]	Seeding Rate[3] (lb/acre)	Ease of Establishment	Persistence
Alfalfa (*Medicago sativa*)	Pioneer 524, Hi-Phy, Classic[4], DeKalb 120[4], Saranac AR[4], Arc Vernal	P	Cool	I	15-20	Fair	Good
Crimson clover (*Trifolium incarnatum*)	Dixie, Auburn	A	Cool	I	10-15	Good	Fair
Red clover (*Trifolium pratense*)	Arlington[4], Mammoth, Midland, Lakeland, Kenland[4], Pennscott, Norlac, Kenstar[4]	P	Cool	I	10-12	Good	Fair
White (ladino) clover (*Trifolium repens)*	Ladino[4], Merit, Pilgrim	P	Cool	I	1-5	Good	Good
Alsike clover (*Trifolium hybridum*)	Aurora	P	Cool	I	3-5	Good	Good
Flat pea (*Lathyrus sylvestris*)	Lathco	P	Warm	I	25-30	Poor	Fair
Common lespedeza (*Lespedeza striata*)	Kobe[4], Tenn. 76	A	Warm	I	10-15	Good	Fair
White sweetclover (*Melilotus alba*)	Spanish Evergreen, Cumino, Hubam, Polara	B	Cool	I	5-10	Good	Fair
Yellow sweetclover (*Melilotus officinalis*)	Madrid, Goldtop, Yukon	B	Cool	I	5-10	Good	Fair
Birds-foot trefoil (*Lotus corniculatus*)	Fergus[4], Empire[4], Cascade, Granger, Tana, Viking[4], Douglas, Mansfield, Dawn, Norcen[4]	P	Cool	I	10-15	Good	Fair
Vetch, hairy (*Vicia villosa*)		A	Cool	I	20-30	Good	Fair

[1]P = perennial, A = annual, B = biennial
[2]N = native, I = introduced
[3]Seeding rate when used alone; can be reduced when used as a component of a seed mixture.
[4]Commonly used cultivar

Table 3B. Legumes available for use in eastern U.S. mine reclamation.

Common Name (*Scientific Name*)	Drought Resistance	Cold Tolerance	Acid Tolerance	Salt Tolerance	High Water Tolerance	Precipitation Range (in)	Lower pH Limit[1]	Comments
Alfalfa (*Medicago sativa*)	Good	Good	Poor	Fair	Fair	15-20	6.0	Minesoil pH must be maintained above 6.0. P needed in high quantities. Good drainage required.
Crimson clover (*Trifolium incarnatum*)	Poor	Good	Fair	Fair	Fair	14-50	5.0	Winter annual legume. Reseeds itself. Tolerates pH to 4.0.
Red clover (*Trifolium pratense*)	Poor	Good	Fair	Fair	Fair	20-50	5.0	Used for erosion control. Short-lived perennial, but reseeds itself. Requires high P levels. Found on minesoils at pH 4.5.
White (ladino) clover (*Trifolium repens*)	Poor	Fair	Fair	Fair	Good	18-45	5.5	Sod former. Used in pastures for erosion control, soil improvement, wildlife. P and Ca are critical.
Alsike clover (*Trifolium hybridum*)	Fair	Poor	Good	Good	Good		5.0	More tolerant of moist, acidic soils than other clovers.
Flat pea (*Lathyrus sylvestris*)	Good	Good	Good	Fair	Fair	20-50	4.5	Slow establishment but has hardy rhizomes. Drought and acid resistant.
Common lespedeza (*Lespedeza striata*)	Fair	Fair	Good	Poor	Fair	25-45	4.5	Forage legume under trees. Establishes quickly, reseeds. Tolerates acid soils.
White sweetclover (*Melilotus alba*)	Good	Good	Poor	Fair	Fair	14-40	5.5	Grows in early spring. Has a large taproot.
Yellow sweetclover (*Melilotus officinalis*)	Good	Good	Poor	Fair	Fair	14-45	5.5	More drought tolerant and competitive than white.
Birds-foot trefoil (*Lotus corniculatus*)	Fair	Fair	Good	Good	Fair	18-45	4.5	Grows well in mixtures. Nonbloating and rhizomatous. Found on minesoils with pH 3.5.
Vetch, hairy (*Vicia villosa*)	Fair	Good	Good	Good	Fair	20-50	5.5	Fall plant for good winter cover. Can be pastured. Important to inoculate.

[1]Lower pH limit for good growth; some species can persist, but will not thrive, at lower soil pH.

Figure 3. Nodules formed by *Rhizobium* bacteria on the roots of several legume species. When nodules are present, legumes can "fix" nitrogen from the air, satisfying their own nitrogen nutrition requirements and providing excess nitrogen to nonlegume plant species.

A few of the more important legumes are described in more detail below.

Alfalfa is probably the best-known and most widely used forage legume in the United States. It grows well on a wide range of soils and in a variety of climates, but alfalfa requires good soil fertility (especially phosphorus, calcium, and potassium), near-neutral pH, and excellent soil drainage. Effective use of alfalfa for mine reclamation in the Appalachians will be limited to only the most fertile and favorable minesoil conditions. Alfalfa produces high amounts of biomass by itself or in mixtures and has a deep taproot system that makes it somewhat drought-resistant. Because of its long taproot, alfalfa is not well-adapted to compacted soils. Due to its high fertility requirements, alfalfa is not likely to do well over the long term as an unmanaged land-use component.

Birds-foot trefoil is a common forage legume that is often seeded with Kentucky 31 tall fescue on surface-mined lands in Appalachia. It grows on poorly drained, droughty, infertile, acidic, and even alkaline soils. Birds-foot develops a deep taproot system with lateral roots and is useful for erosion control and forage. In some cases, birds-foot does not establish until a year after the initial seeding. When it establishes successfully, birds-foot trefoil is typically a durable legume species that provides an excellent erosion-control cover. The Fergus variety has proved to be well-adapted to Virginia coal-field conditions.

Red clover is an important legume in the northeastern United States. Red clover is used for hay, pasture, soil improvement, and erosion control. It has a deep taproot, but it also maintains a branching root system near the surface. Red clover should be seeded with long-lived grasses and more persistent legume species, because it tends to die back after two years. Like most legumes, it grows best where high amounts of phosphorus and calcium are present in the soil.

White clover is used widely throughout the eastern United States for pasture and in disturbed-land seeding mixtures. It is almost always seeded with a companion grass, and it has a deep taproot system that may or may not persist from year and year.

Ladino is a cultivar of white clover that is widely used in reclamation seeding.

Crownvetch is a perennial legume that was formerly used for seeding disturbed lands because it provides continuous, maintenance-free cover for erosion control. Traditionally, it was used on roadbanks and other highly erodible sites. Crownvetch is slow to establish, but after the first year, it will gradually increase its density and may suppress associated vegetation for three to four years after initial establishment. It has a deep, penetrating taproot with many lateral branching roots. Crownvetch is no longer used commonly in reclamation because of its tendency to invade and take over areas adjacent to plantings where soil and sunlight conditions are favorable to its proliferation. As such, it is considered to be a non-native invasive problem species by organizations such as the Southeast Exotic Pest Plant Council (SE-EPPC 2003) and the U.S. Forest Service (Miller, Chambliss, and Bargeron 2008).

Flat pea is a long-lived, viney legume that provides good groundcover. Establishment is slow, but once established, it suppresses other vegetation. It is drought-resistant and tolerant of acidic soil conditions. Flat pea is often used to control erosion on difficult-to-revegetate areas, such as steep slopes. There has been some concern that flat pea may be toxic to cattle at certain times during its life cycle, but this characteristic has not been verified scientifically.

Sericea lespedeza was formerly used for revegetation of highways and mined lands to control erosion and to improve soil properties. Most *lespedeza* species are well-adapted to infertile soils with low pH and low moisture availability. *Sericea* spreads easily because it produces small seeds that are carried by winds and birds. As a result and because it was planted on many older surface mines, *Sericea lespedeza* commonly establishes on reclaimed mine sites throughout the Virginia, southern West Virginia, and eastern Kentucky coalfields – even though it is no longer planted. *Sericea* can be an undesirable species in unmanaged land uses because it can become the dominant species and is capable of crowding out other species. Pure stands often become a fire hazard in the fall. Unlike most nitrogen-fixing legumes, *Sericea* does not provide much nitrogen to other plant species that are present. When it becomes established in pastures, it can contribute to livestock nutrition if the pastures are well-managed and the plant materials are grazed consistently throughout the growing season but – if allowed to grow from spring into the fall without being grazed or cut – it becomes unpalatable to cattle. Procedures required to replace *Sericea* with more desirable forage species on mined areas are reviewed in *Conversion of* Sericea Lespedeza-*Dominant Vegetation to Quality Forages for Livestock Use,* VCE publication 460-119.

Because of *Sericea's* ability to survive and prosper on low-fertility minesoils, it has been heavily utilized for reclamation in past years. The traditional varieties can be used effectively on extremely harsh sites, such as refuse banks. Due to the availability of numerous other species with more desirable characteristics, we recommend that reclamation of new mined areas with traditional varieties of *Sericea lespedeza* be avoided.

Some varieties of *Sericea*, however, can be used effectively as one component of a seeding mixture for a specific postmining land use on new mined areas. The Aulotan cultivar has relatively low tannin content, making it more palatable to livestock than other cultivars. Even Aulotan should not be seeded in new reclamation sites unless there is a definite intent to utilize the land for livestock or for regular hay production. Another *lespedeza* variety, Appalow, is low-growing and has proved to be compatible with other herbaceous vegetation and with the establishment of shrubs and trees.

Kobe lespedeza is a low-statured annual that co-exists with other herbaceous vegetation, establishes rapidly, fixes nitrogen, and reseeds itself. As a warm-season species, it grows best during the summer months, but is not competitive with grasses on fertile soil over the longer term. It has an upright form and a shallow rooting system. *Kobe lespedeza* can tolerate a soil pH of 5.0 or below.

Sweetclovers, yellow and white, are used extensively in western reclamation due to their drought-resistance and soil-building capabilities, and they have also been used in the eastern United States. They are generally considered to be intolerant of acidic soils. As biennials, the sweetclovers usually complete their life cycle in two years. On favorable sites, they will persist for longer periods as they reseed themselves.

Establishing Nitrogen-Fixing Legumes

Establishing soil conditions that will allow legumes to persist is a major reclamation challenge. Most of the legume species commonly used by agricultural producers (such as clovers and alfalfa) do not grow well under soil conditions of 6.0 or below pH. Even if legumes survive a low soil pH, the nitrogen-fixing capability is often reduced because *Rhizobium* bacteria generally prefer soils with a pH in the 6.0-7.5 range.

As "fresh" minesoils weather, the pH can change. Therefore, the long-term minesoil pH should be estimated based on materials that have been exposed to weather for at least one year, if possible. Proper liming and fertilization will enhance the ability of the seeded legume to become established, grow, and fix nitrogen. Legumes grow best in soils that are moderately well- to well-drained and non-acidic and that contain sufficient quantities of phosphorus and calcium. It is necessary to add lime and fertilizer when minesoil conditions are not favorable.

Several other factors are important to establishment of nitrogen-fixing legumes during reclamation. Too much nitrogen in the soil can inhibit nitrogen-fixing nodule formation and development. The amount of fertilizer nitrogen that inhibits nitrogen fixation varies among legumes, but usually ranges from 50 to 100 pounds per acre. When fertilizer is applied at higher rates, nodules may form but the effectiveness and efficiency of nitrogen fixation are decreased. During later years, as the inorganic soil nitrogen concentrations decline, the nodules can develop an increased capacity to fix nitrogen for the plant.

Legume Inoculation

Inoculation of legume seeds with the appropriate strain of *Rhizobium* is an important seeding practice, especially where native *Rhizobium* is not present in the soil. Minesoils constructed from raw overburden will have a very limited native *Rhizobium* population. If the "topsoil" that is used to construct a minesoil has been stockpiled for an extended period, most or all of the native bacteria may have died. Topsoils that have been removed from forested areas will not contain substantial populations of *Rhizobium* bacteria because plant species serving as *Rhizobium* hosts are not generally present in forests. In all of these cases, legume seeds should be inoculated with the appropriate strain of *Rhizobium* so that infection and nodule production will occur on legume roots.

Inoculation is the practice of adding effective bacteria to legume seed before planting to assure adequate nodulation and promote nitrogen fixation. In agricultural practice, a water-based slurry (a mixture of a commercial preparation of bacteria with a peat carrier) is usually used to coat the seed just before planting. The carrier is enriched with sugars, gums, and polysaccharides to provide nutrition and protection to the bacteria and to promote adhesion to the seeds. Because *Rhizobium* bacteria are very sensitive to hot and dry conditions, inoculation should occur within the hour before planting to decrease the length of time the inoculated seed is exposed to air and sunlight. There is a sharp decrease in bacteria quantity on seed as the time between inoculation and planting increases. It is also beneficial to plant into moist soil.

The *Rhizobium* genus has seven strains, based on the species of legume they infect. Table 4 shows the different strains of *Rhizobium* and the leguminous plants they infect. Because *Rhizobium* of one strain generally does not infect legumes outside of their infection group, seed inoculation with the appropriate *Rhizobium* strain is essential if nitrogen fixation is to occur. If more than one legume is being seeded, the right strain of *Rhizobium* bacteria must be present for each legume. Inoculum can be purchased from most seed suppliers (figure 4). *Rhizobium* bacteria can only survive in packages for limited time periods; peat-based inoculum has a limited shelf life and should not be used after its expiration date. Inoculum should be kept cool and dry during storage. After the sealed inoculant package has been opened, it should be kept in a cool place and should not be exposed to direct sunlight.

In mine reclamation, seed is typically applied with a hydroseeder. The seed and inoculum should be mixed together and put in the tank just prior to seeding – after the hydromulch, fertilizer, and water have been added – so as to minimize the amount of time the live bacteria must survive in the tank.

If hydroseeding is used to apply the reclamation seed mix, several precautions are in order. First of all, it is desirable to double the amount of inoculum that would be used to coat the seed in a nonhydroseeding application. Even more important, however, is the necessity of assuring that hydroseeder tank conditions and seeding practices will allow inoculum survival. Because *Rhizobium* bacteria are intolerant of acidic conditions, care should be taken to keep the pH of the hydroseeder slurry buffered above 4.0 with lime. The inoculant should be added to the hydroseeder tank immediately before seeding, because the inoculant bacteria will perish if left in the high-salt environment of the hydroseeder slurry for more than a few minutes. These precautions are especially important when acidic fertilizers, such as triple-super phosphate, are used in the hydroseeder mix.

Table 4. Strains of *Rhizobium* and the legumes they infect.

Strain	Legumes: Common Name (*Genus*)
Rhizobium mililoti	Alfalfa (*Medicago*), sweet clover (*Melilotus*)
Rhizobium trifolii	Clover (*Trifolium*)
Rhizobium leguminosarum	Field pea (*Pisum*), vetch (*Vicia*), flat pea (*Lathyrus*)
Rhizobium phaseoli	Beans (*Phaseolus*)
Rhizobium japonicum	Soybean (*Glycine*)
Rhizobium loti	Lupine (*Lupinus*), trefoil (*Lotus*)
Rhizobium "Cowpea miscellany"	Cowpea (*Vigna*), peanuts (*Arachis*), lespedeza (*Lespedeza*), crownvetch (*Coronilla*)

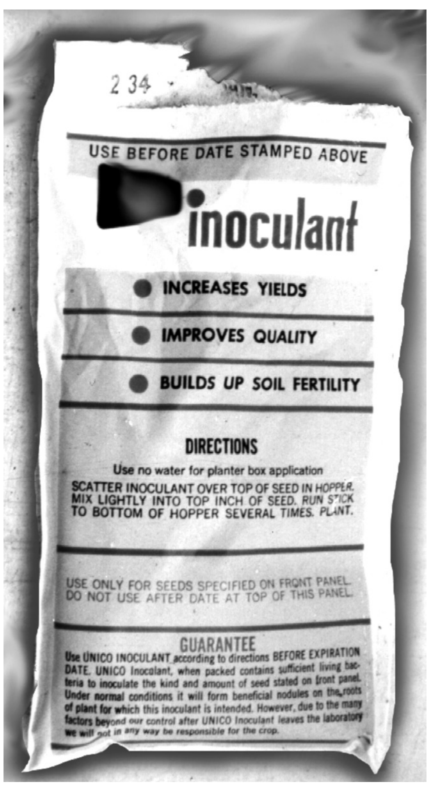

Figure 4. A package of legume inoculant purchased from a commercial seed supplier. Legumes can "fix" atmospheric nitrogen only if *Rhizobium* bacteria are present. Inoculant can be added to hydroseeder slurry, but precautions must be taken.

Revegetation Strategies

A variety of factors must be considered in a successful mined-land revegetation program. Soil properties, other site characteristics, the time of seeding, the species seeded, and soil amendment application rates will affect revegetation success. When revegetation takes place on a mine site that is regulated under SMCRA, the postmining land use declared in the mining permit and the degree of augmentation allowable within the five-year reclamation success period must also be considered.

Soil Properties

The most effective way to achieve a "match" between soil conditions, species, and postmining land use is to select and place surface-soil materials so as to create a soil that is favorable to vegetation compatible with the postmining land use declared in the mining permit (see VCE publication 460-121).

Lime, fertilizer, and organic additions can be used to remedy problems of low soil fertility and/or moderate acidity. However, no amount of fertilizer or lime can remedy soil compaction, extremely coarse texture, and/or major chemical problems, such as the presence of pyritic soil materials. Selection and placement of surface spoils will have a dominant influence over vegetation success in postmining land use. A critical factor in evaluating soil properties should be suitability for nitrogen-fixing legume species, most of which are more site-demanding than grasses.

Postmining Land Use

If the land is being prepared for reforestation, a "tree compatible" groundcover should be used (see VCE publication 460-124).

Time of Seeding

March through May and late August through October are the best times to establish vegetation in southwestern Virginia and nearby areas, but seeding can be conducted successfully during most of the year.

Regardless of the season or month in which a regraded area is prepared for seeding, grass and legume species are available that should be compatible with site conditions. Cool-season grasses are best suited for seeding from late February to April and from September to early December. Some cool-season grasses – especially the winter annuals – can be seeded in most years as early as late January, but the success of midwinter seedings will be weather-dependent.

Many reclamationists think that seeding in summer is a waste of time and material. However, experience and research provide examples of successful establishment of both temporary and permanent vegetation during the summer months. Warm-season grasses (especially the summer annuals) can germinate and establish under hot and dry conditions much better than cool-season grasses, but the summer grasses still require that some soil moisture be present. Rainfall during June, July, and August can be highly variable from year to year; moisture availability will be the primary factor affecting the success of summer seedings.

Rapid Vegetation Establishment

When establishing postmining land uses that do not require the planting of shrubs and trees, species that germinate, establish, and grow rapidly should be created to control erosion and to stabilize the site. Annual grasses (such as foxtail millet, Japanese millet, pearl millet, oats, rye, annual ryegrass, or wheat) are often seeded to provide quick, temporary cover. The millets are often selected when seeding disturbed areas during summer months (June-August), while cool-season annuals are seeded during early spring and late fall. In addition, some perennial grasses also establish quickly on disturbed sites (e.g., redtop, perennial ryegrass, weeping lovegrass, and tall fescue).

A quick, temporary cover may be established by seeding with one, two, or more of the above species. A common practice in some areas is to seed permanent species (perennial grasses and legumes) into the mulch created by the temporary annual species either in the fall or spring following dieback of the annual crop.

One or more of the above quick-germinating species may also be included in a permanent vegetation seeding mixture. The quick-germinating species will establish a vegetation cover rapidly, while the perennial species – which are typically slower to become established – develop.

Mixed-Species Stands

Most revegetation mixes will include several species of perennial grasses and nitrogen-fixing legumes. Annual grasses that act as a nurse crop may or may not be included.

There are many reasons for including multiple species in a seeding mixture. The presence of nitrogen-fixing legumes is essential to nitrogen nutrition, while grasses tend to be more effective in controlling erosion. A variety of environmental conditions are generally found on reclaimed mine sites; the presence of a variety of species – each with its own site requirements – will help to assure successful revegetation of the entire site. Stands containing several species tend to be more productive over the long term than stands containing only one or two species, because multiple-species stands are able to utilize the full range of mine site resources (moisture, light, nutrients) more effectively.

Self-Sustaining Vegetation

SMCRA requires establishment of self-sustaining vegetation. Under SMCRA, augmentation of revegetated areas with fertilizer, lime, or seed is not allowed within the five-year reclamation success period for land uses where such augmentation is not a common management practice. Establishment of a self-sustaining stand of vegetation requires that several factors be considered.

First of all, the persistence of one or more nitrogen-fixing legume components is essential to long-term success. Nitrogen is a critical and necessary plant nutrient, and most minesoils contain no native, plant-available nitrogen. The legume components of the seed mix must be adapted to soil properties, and soil amendments should be applied as needed to establish an environment suitable for maintaining the legume species.

Secondly, organic matter and nutrient cycles must be established in the minesoil. In addition to shading and otherwise protecting slower-germinating perennials for a few months after seeds are applied, a fast-growing annual nurse crop grass can help to establish organic nutrient cycles. Fertilizer nitrogen, which would otherwise be leached out of the soil, can be taken up by the rapidly growing annual grass species. When the nurse crop dies back at the end of its annual cycle, the plant remains are decomposed by soil microbes and the released nitrogen can be taken up by perennial plant species.

Similarly, the phosphorus applied as fertilizer during revegetation will become unavailable to plants after several years. "Blasted overburden" minesoils containing high levels of iron are especially prone to depletion of plant-available, inorganic phosphorus, because fertilizer phosphorus tends to form insoluble complexes with soil iron (i.e., it becomes tightly bound to soil particles, unavailable for plant uptake). A rapidly growing, annual nurse crop grass will take up fertilizer phosphorus from the soil early in the growth cycle. As the annual grass dies and decomposes, the phosphorus becomes available for uptake by companion perennials.

Developing an organic matter "pool" or supply in minesoils is essential to successful reclamation. We recommend that hayland/pasture vegetation not be harvested during the first two years after seeding so as to allow the plant remains to accumulate as organic matter in the soil. As it decays, this organic matter slowly releases nutrients that support the growth and development of a self-sustaining plant community.

Harsh Sites

The practices discussed here will be adequate for the vast majority of mined sites. On harsh sites – such as those where surface spoils are extremely coarse-textured, are low in pH, contain pyrites, and/or are dark-colored – additional measures may be called for. *Reclamation of Coal Refuse Disposal Areas,* VCE publication 460-131, contains recommendations for direct seeding of vegetation on coal refuse; these practices may be adapted to reclamation of mine sites if conventional revegetation practices prove unsuccessful due to harsh soil conditions.

Seeding Practices

Species and Application Rates

Most companies and seeding contractors use seed mixtures containing at least two or three perennial grasses, two or three legumes, and either a warm-season annual or a cool-season annual for quick cover. A wide variety of species are available for use in mined-land reclamation (tables 1, 2, and 3).

An example of plant species and seeding rates for establishing a hayland/pasture postmining land use is given in table 5. Some of the seeding rates are given as ranges. Generally speaking, poor site conditions tend to favor seeding at rates near the upper end of these ranges. On the other hand, if all of the "optional" grasses and legumes are included in the mix and site conditions are not extreme, the use of seeding rates at the lower end of each range would probably be successful. If a wide range of site conditions is present on the area to be seeded, species adapted to a wide range of conditions should be included in the mix.

Selection of species and seeding rates should be based on species characteristics and site conditions. For example, *Kobe lespedeza* is a warm-season species that would be beneficial on hot, droughty sites such as south-facing slopes. On the other hand, cool-season species such as birds-foot trefoil and redtop would be more beneficial at northern latitudes and high elevations. White clover, for example, grows best where soil pH exceeds 6.0 and adequate fertility is available. If such conditions are not present, legumes such as birds-foot trefoil and red or crimson clover, which are better adapted to low fertility conditions, should be favored.

Purchasing Seed

Several terms that appear on seed labels can be useful when purchasing and applying seed so as to reduce seeding costs.

The term "viable seed" refers to that portion of a seed lot that is capable of germination. Viable seed consists of two major components. Germination tests should have been conducted on the seed to provide a "percent germination," and these test results must be printed on the label. In addition, that portion of the seed that did not germinate during a short-term germination test, but will germinate over a longer term, is also viable. The legume-seed component known as "hard seed," and the grass-seed component known as "dormant seed," should be added to the germination test results to determine viable seed content.

The term "seed purity" refers to the percentage of the seed lot that consists of the labeled species, as opposed to weed contaminants.

The percentage of a seed lot that is viable is calculated by multiplying the percent of pure seed (percent purity) by the germination percent (percent germination plus percent dormant or hard) and dividing by 100 (table 6). Grass seed commonly has moderate purity (60 to 80 percent) and high germination (> 90 percent). Legume seed commonly has high purity (> 90 percent), low germination (< 50 percent), and a high percent of hard (dormant) seeds (20 percent). Low germination and high dormancy in legume seeds is explained by the complex seed coats that surround them. Blocking mechanisms within the seed are broken only when certain environmental conditions (temperature and moisture) or chemicals are applied to the seed coat, or when the seeds are scarified.

Preconditioning seed in cool, moist conditions to promote germination is called "stratification." Dormant seeds may germinate several years after the initial seeding due to natural stratification in the soil. Scarifying legume seeds may also help germination, but this is not a general practice in coal surface-mine reclamation.

Quality should be considered carefully when purchasing seed that is offered for a low price. Referring to table 6, the seed of supplier "A" may be priced lower than the seed of supplier "B" because it has lower purity and germination. However, because of the difference in quality, a person could pay 10 to 20 percent more per pound for seed from supplier "B" and still come out ahead.

Applying Seed With a Hydroseeder

In central Appalachia, surface mining generally requires reclamation of steep slopes. The most common technique for seeding and applying amendments is through a hydroseeder (figure 5). Fertilizer, lime, mulch, and seed are normally mixed with water in the hydroseeder tank. Commercial cellulose mulch is typically included in the mix at rates of 1,000-1,500 pounds per acre. This material improves seed germination during dry weather and aids the hydroseeding process by marking seeded areas. Procedures for adding a legume inoculant and assuring survival of that inoculant in the hydroseeded slurry are discussed above. Fertilizer rates are discussed in VCE publication 460-121.

Table 5. A typical seeding mixture for use by Appalachian mining operations on reclaimed areas that will be managed as hayland or pasture after mining, and where a variety of soil and site conditions are present.

Species	Seeding Rate (lb/acre)	Comments
Grasses		
Orchardgrass	10-30	
Tall fescue	10-30	
Timothy and/or	5	Optional
Redtop	3	Optional
Legumes		
Birds-foot trefoil and/or *Kobe lespedeza*	5-10 ea	
Clovers	5-10 ea	2 or more species
Nurse Crop		
Millet or annual rye	20-30	Millet for shading during hot months; rye for quick cover in early spring or fall.

Figure 5. A hydroseeder applying seed in a fertilizer slurry while revegetating a surface coal mine.

Conclusion

Success in establishing vegetation promptly and cost-effectively is the hallmark of successful mine reclamation and is essential to mine profitability. During the past 20 years, great strides have been made in developing effective mine-revegetation strategies.

Two keys to successful revegetation are the selection and placement of a minesoil that is suited for the intended postmining vegetation, and the selection of plant species that are suited to both the postmining land use and the properties of that minesoil.

Success in revegetation on reclaimed mine areas is indicated by plant cover that controls erosion, is sufficiently productive to support the postmining land use, and persists through time (figure 6). While each revegetation specialist has a favorite seeding technique, only a thorough knowledge of both minesoil properties and species characteristics will allow consistent and effective revegetation of surface coal-mined areas.

Figure 6. A pasture on a reclaimed mine site in northern West Virginia that was established using several grass and legume species, as described in this publication.

Table 6. Calculation of purchased-seed application rates required to achieve desired rate of viable seed application, based on characteristics of seed provided by two hypothetical suppliers.

Supplier	A	A	B	B
Species	Tall fescue	Birds-foot trefoil	Tall fescue	Birds-foot trefoil
Desired application rate:				
Viable seed (lb/acre)	20	10	20	10
Label information:				
% Purity	90	80	95	90
% Germination	80	55	85	60
% Hard seed	5	-	5	-
% Dormant seed	-	10	-	15
Calculated quantities:				
% Viable seed	76.5	52	85.5	67.5
Application rate (lb/acre)	26	19	23	15

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