SECTION 5

VEGETATION ESTABLISHMENT

Adherence to proper seeding and planting procedures and use of appropriate soil amendments and mulches will greatly increase success in establishing vegetation. This section includes information on grading; preparing seedbeds; seeding methods; planting tree and shrub seedlings; seeding and planting equipment; and using and applying fertilizer, lime, and mulch.

GRADING AND LEVELING

Grading, leveling, or smoothing of the mined site normally precedes revegetation activities. Designed grading and shaping can enhance the land for most uses. In addition, a newly graded minesoil usually provides a suitable seedbed. However, some grading practices can hinder successful revegetation and should be avoided. For example, grading minesoils when wet or muddy can alter the physical properties of soil particles and create a compacted and pavement-like surface. Grading dry materials to a fine or smooth finish also can produce surface conditions that are undesirable for vegetation establishment.

Grading of some types of spoils, especially those with a predominance of clay and silt particles, is known to be detrimental to the survival and growth of planted tree seedlings. In some of the plantings, tree growth has been adversely affected for as long as 30 years after planting. Conversely, on spoils with a predominance of coarse particles, grading was beneficial to the survival and growth of tree seedlings. Thus, the effects of grading on vegetation establishment seem to be largely related to the type of spoil materials. Because they often contain large amounts of clay-size or fine particles, the topsoils, subsoils, and parent materials used to cover mined areas may create problems--particularly where they are intensively graded and compacted by earth-moving equipment. Soil compaction should be alleviated by ripping or chiseling before attempting to establish vegetation.

The effects of earth moving and grading on revegetating abandoned mine spoils also should be carefully considered and planned before the moving of earth begins, because it is possible that redisturbance of the spoils could create additional problems relating to environmental pollution and revegetation. For example, because they are weathered and leached, minesoils at and near the surface may be less acid or toxic than spoil materials as some depth beneath the surface. Thus, grading off several feet of spoil would expose the unweathered acid-producing materials and cause revegetation problems similar to those that existed many years previously when the area was first mined.

Additional expense and effort would then be required in amending the acid material or in acquiring topsoil or other covering material.

SEEDING PRACTICES

With few exceptions, herbaceous species are established from seed; a few species of trees and shrubs also have been established successfully on mined lands by seeding. In many cases, success in establishing vegetation is more dependent on the use of a few, relatively simple seeding practices than it is on species selection.

Seedbed Preparation

A suitable seedbed is required for the successful establishment of seeded vegetation. A suitable seedbed is one that provides numerous microsites favorable for seed germination and seedling growth. An example of this is sometimes seen on mined areas where seeded vegetation is well established in depressions left by tracks of crawler tractors, but few plants are found between depressions.

Preparation of a seedbed by mechanical tillage or scarification often is essential, especially on minesoils that are crusted or compacted, and for seedings made in late spring, summer, and fall. However, broadcast seedings made on the surface in late winter and early spring sometimes are successful without mechanical preparation of a seedbed because the seed are "planted" by the alternate freezing and thawing of the soil. Also, tillage may not be necessary where seeding is done immediately after grading.

A seedbed can be prepared with a variety of implements. The physical condition of the land surface and size of the area are factors governing the size and type of implements that can be used effectively. Normally, heavy-duty implements will be more useful and suffer less breakage than lighter ones. Disc harrows of several types and chisel plows are useful for tillage in a variety of minesoil conditions (Figures 5 and 6).

Heavy-duty offset disc harrows and bog harrows can effectively break up surface compaction, incorporate lime, and prepare a seedbed on many types of minesoils. But they do not break up subsurface compaction nor satisfactorily till soils with many large rocks. When one or two discs ride over a large rock, the entire gang of discs is raised out of the ground. This interrupts tillage and may cause breakage of the one or two discs that are supporting the weight of the entire gang of discs.

Tillage with chisel plows produces narrow furrows that improve infiltration of water, especially where furrows are made on the contour. Plowing depth can be 2 to 3 times greater with chisel plows than with disc harrows; thus, with sufficient tractor power, soil compaction can be broken at greater depths with chisel plows. Chisel plows are suited for tilling rocky soils because each shank, or chisel, operates independently against the tension of heavy springs to allow the chisel points to ride over or bypass large surface and subsurface rocks. Chisel plows provide good seedbeds for broadcast

Figure 5. Offset disc harrow for preparing the seedbed or incorporating lime. (Photo courtesy of Rome Industries)

Figure 6. Chisel plow for preparing a seedbed or incorporating lime.

seeding and they effectively mix amendments with the soil. Shanks will break occasionally and rapid wear of chisel points can be expected in stony minesoils, especially sandstones. Small- to medium-size rocks that can be pulled out of the ground by the chisel plow may be unsightly and interfere with the use of other agricultural implements.

For minesoils that are extremely or deeply compacted, ripper teeth attached to a bulldozer or grader may be required as an initial step in seedbed preparation. For soils that are not compacted or firmly crusted, the use of a spring tooth harrow, spike tooth harrow, flexible harrow, or similar light-duty implement can be used to scarify the soil surface. Although it is usually an uneconomical and inefficient use of equipment, bulldozers can be used for seedbed preparation. "Front blading" offers one advantage over "back blading" in that the dozer tracks provide depressions that collect water and favor seed germination and seedling growth. "Tracking in" with a dozer is about the only method available for preparing a seedbed on steep slopes.

A commercial implement called the Klodbuster™ has limited application for scarifying short slopes that are clear of boulders, tree stumps, and other obstacles.

Some of the seedbed preparation practices that are recommended for agricultural soils are not always necessary or appropriate for preparing a suitable seedbed on minesoils. For example, a smooth, finely tilled seedbed prepared by repetitive discing can adversely alter the physical characteristics of some minesoils and actually hinder vegetation establishment. On such materials, a single pass with a disc or chisel plow is sufficient. In addition, precipitation is more effectively trapped and held in a seedbed left in a roughened condition than in a smoothly prepared one.

Methods of Seeding

Basically, there are two ways to apply seed: broadcast and drill. Seed can be mixed with water and broadcast through a hydroseeder; or broadcast dry by hand, or by ground-seeding equipment, or by aircraft. Seed can also be planted with a grain drill, grassland drill, or rangeland drill.

The hydroseeder is very popular, especially in the mountainous Appalachian Region, for seeding steep slopes and highwalls that cannot easily be seeded with other types of equipment (Figure 7). Another advantage of the hydroseeder is that seed, fertilizer, and hydromulch all can be mixed together with water to form a slurry that can be applied in the one pass over the area. Disadvantages of the hydroseeder are that a source of water must be available near the seeding job and a considerable amount of time is required to fill the tank with water. Each tank of slurry covers a relatively small area, especially when hydromulch is included in the slurry. The slurry agitation system in some types of hydroseeders may damage seeds of some grasses and large-seeded legumes. But the germination of some species, especially legumes with hard seed, may be enhanced by scarification. Extra seed to compensate for those that may be damaged can be added in the hydroseeder.

Figure 7. The hydroseeder.

Several kinds and sizes of broadcast seeders are available for dry application of seed. These seeders range in size from hand-operated cyclone seeders that hold about a bucket full of seed to those that hold several bushels and are mounted on a tractor or pickup truck. Broadcast seeding can also be done with a conventional lime spreading truck, though there may be some difficulty in accurately controlling rate of seed dispersal.

Aircraft are most efficient and useful for seeding large acreages and areas where mud or other adverse surface conditions prevent the use of ground equipment. Helicopters generally are more versatile than fixed-wing aircraft for seeding out-of-the-way or hard-to-reach areas. For greatest efficiency, a landing strip close to the work area is required. A substantial amount of ground-support equipment also is required for transporting seed and handling at the landing site.

Seeding with drills may require more time and greater expense for equipment than seeding with some of the broadcast seeders. However, with drills, fewer seed are required because most of the seed are planted at a uniform depth and covered. Because seed are placed in a microenvironment that increases their chances for germination and growth, the advantage of seeding with drills is greater in the climatically drier zones than in the more humid ones.

The use of grain drills and grassland drills is limited to areas that are free of stones and level and smooth enough for normal use of farm equipment. The rangeland drill is a rugged, heavy-duty implement designed for seeding grain, grass, and legume seeds on rough stony rangelands in the West (Fig. 8).

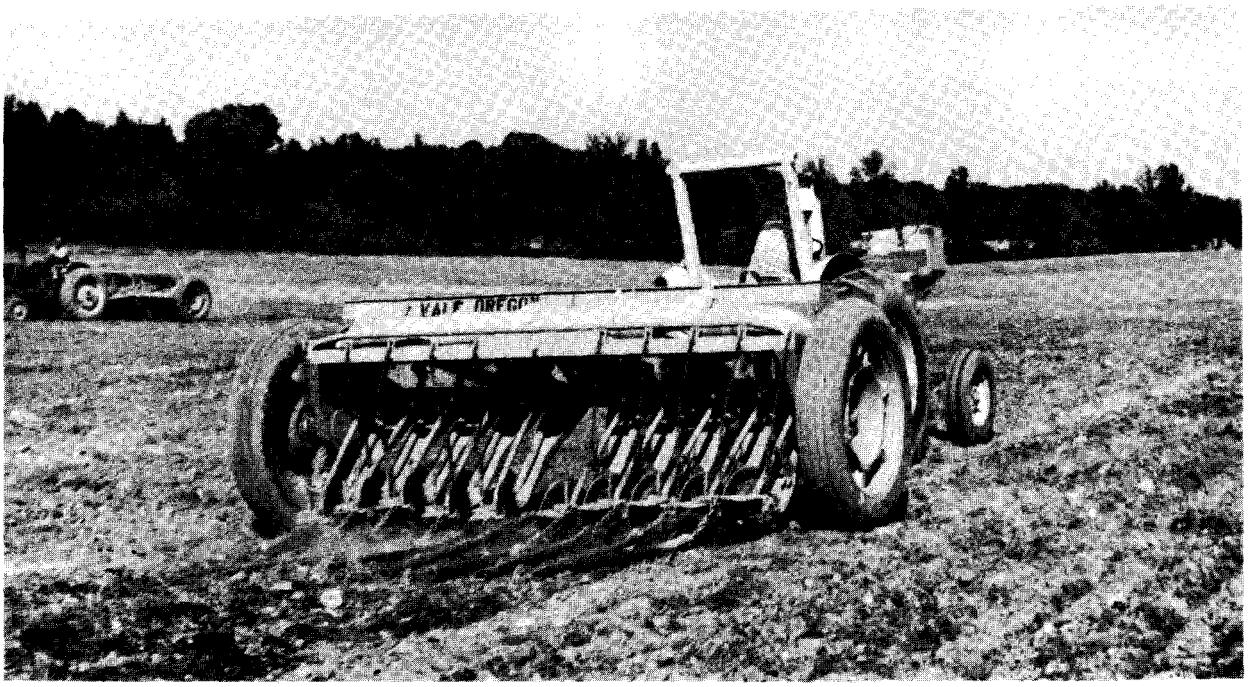

Figure 8. The rangeland drill.

This drill also has been tested on surface-mined land in western Kentucky and is capable of withstanding the rigors of operating on stony spoils with little breakage. Another advantage of the rangeland drill is that it forms furrows that catch and hold surface runoff; thus, the environment for seedlings is improved. Tillage before seeding with a drill may be necessary on minesoils that are compacted or have formed hard crusts.

Time of Seeding

The best time for seeding varies from one region to another. In most regions of the East, weather patterns favor early spring seeding for cool-season species; but fall seeding may produce the greatest success in some areas. For example, in western Kentucky, fall seedings often are more successful than spring seedings because spring-sown plants sometimes drought out during rainless periods in late spring and early summer. Early to mid spring normally is the best time to sow perennial and some annual warm-season species. Mid spring to early summer is the best time for seeding most summer annual species.

Sometimes, mining is completed and an area is ready for seeding in the summer or winter months. Seeding in late spring and summer is more risky than early-spring or fall seedings, and is not recommended in areas with hot dry summers. But in some regions of the East, such as much of Appalachia, summer rainfall usually is sufficient to establish stands of warm season annuals sown in late spring to mid summer. Occasionally, summer precipitation also is adequate for establishment of cool and warm season perennial species. Thus, in areas where summer precipitation normally is adequate, mined sites that are

graded and ready for seeding in late spring and summer should be seeded as soon as possible after grading is completed. Usually, this will shorten the period of time that the minesoils lie barren and exposed to erosion.

Mid-winter seeding is sometimes done in the southern latitudes, but it is not the usual practice in the central and northern latitudes because adverse weather and soil conditions often hinder access and travel on mined areas. Besides, seed sown in winter will not germinate until spring and much of it could be lost due to erosion and siltation.

Seeding dates obviously will not be the same in all regions. For example, the spring seeding period in Illinois may extend from about March 15 to May 1, but in Alabama it may be from February 1 to March 15. Recommended dates for late summer and fall seeding are July 15 to August 20 in Pennsylvania, whereas August 15 to October 15 is suggested for Kentucky. Recommendations for best seeding dates in a given region can be obtained from local farmers and agricultural service agencies.

Seed Quality

The use of good-quality seed that has been properly tested and tagged will help ensure the successful establishment of vegetative cover. Seed quality can be determined from information listed on the seed tag. Two of the values listed on the seed tag--pure seed and germination percentage--are used to determine pure live seed (PLS). Pure live seed is useful for figuring proper seeding rates and the real cost of seed.

To calculate PLS, multiply the percent of pure crop seed times the germination percentage and divide by 100. For example, if a batch of seed contains 95 percent pure seed and has 80 percent germination, the percent of pure live seed (PLS) is 76; (95 x 80) ÷ 100 = 76 percent. This means that in a quantity of seed weighing 100 pounds, only 76 pounds have the potential to germinate.

When purchasing seed, comparative pricing should be done on the basis of pure live seed. This is especially important when buying species that inherently differ in purity and germination between seed lots. To determine the cost per 100 pounds of pure live seed--the real or actual cost of seed--divide the cost per 100 pounds by the percent PLS and multiply by 100. For example: Lot A of fescue seed costs $35.00 per 100 pounds and has 89 percent PLS; ($35.00 ÷ 89) x 100 = $39.33, the cost per 100 pounds of pure live seed. Lot B of fescue seed costs $31.00 per 100 pounds but has only 68.4 percent PLS; ($31.00 ÷ 68.4) x 100 = $45.32 per 100 pounds of pure live seed. Although its bulk price was less, seed lot B actually costs more than lot A for an equal amount of pure live seed.

Other items that describe seed quality, such as the percentage in weight of weed seed and the name and number per pound of noxious weed seed, also are listed on the seed tag. The presence of certain noxious weed seed may be so potentially harmful that high germination would not be the most important consideration in seed quality. The date of test also should be noted to be sure that seed germination has been recently tested.

Using seed of unknown quality presents an added risk in establishing vegetation. However, such use may be necessary and justified where, for example, locally collected seed of native plants are added to the seeding mixture to increase species diversity. However, seed of unknown quality should not be depended upon to be the major contributor to a stand of vegetation.

Seeding Rates

Seeding rates recommended in this manual are expressed in pounds per acre PLS. The use of PLS seeding rates instead of bulk seeding rates will ensure that an adequate amount of viable seed is sown. This is especially important for proper seeding of species, such as some of the native grasses, that often have relatively low purity and germination. To calculate the amount of bulk seed needed to meet PLS recommendations, divide the PLS seeding rate by the percent PLS and multiply by 100. For example, if a batch of switchgrass seed has 60 percent PLS, and the recommended PLS seeding rate is 12 lb/acre, then (12 ÷ 60) x 100 = 20 lb/acre bulk seeding rate. Obviously, if only 12 pounds of switchgrass seed were sown, not nearly enough viable seed would have been sown to meet the seeding recommendations.

The PLS seeding rates suggested here usually are sufficient for vegetating minesoils that have properly prepared seedbeds and are adequately fertilized, limed, and mulched. Sowing additional seed seldom compensates for failure to prepare a seedbed or apply needed amendments. Seeding at too high a rate can cause seedling competition and result in a reduced stand, especially in drier environmental and climatic situations and in well-prepared seedbeds. In seed mixtures of herbaceous species, the temporary species especially should not be sown in excess of recommended rates because they may retard or prevent establishment of the permanent species. In some situations where temporary species are sown alone for growing mulch in place, the use of additional seed may be justified.

Inoculation of Legume Seed

Seed of herbaceous legumes should be inoculated with the appropriate strain of rhizobia. The value of inoculating seed of leguminous shrubs and trees is uncertain because some of these species have been successfully established from noninoculated seed. Inoculants are commercially available for most species of herbaceous legumes; however, for some of the woody legumes and uncommon seldom used herbaceous legumes, inoculum must be specially prepared by the manufacturer.

There are several methods of inoculating seed. For dry seeding, the inoculant can be mixed with lightly moistened seed just before sowing. The inoculant should be generously applied--using even more than that recommended by the manufacturer. Moistening seed with a "sticker" such as sugar mixed with water, molasses, or synthetic gums helps bind the inoculum to the seed and extends longevity of the rhizobia. Soil implant inoculants are available whereby the rhizobia is placed in the soil instead of on the seed. Preinoculated legume seed can be purchased from some seed dealers.

When seeding with a hydroseeder, the inoculant is added to the slurry just before it is spread. When mixed with a slurry that includes fertilizer, the inoculating bacteria may be killed by high acidity (low pH) caused by the fertilizer. To reduce loss of the bacteria the slurry pH should be kept above 5.0 and spread as soon as possible after mixing. Where slurry pH is below 5.0, hydrated lime can be added at 100 pounds for each 1,000 gallons of water to lessen the effect of the acidity. For hydroseeding, inoculants should be added at double the amount recommended for dry seeding.

Commercial inoculants are stamped with an expiration date because the viability period of the packaged rhizobia is limited. Inoculant with an expired date should not be used. The environment in which inoculant is stored also affects its viability. High temperatures will destroy it, so beware of buying and using inoculant stored or displayed in abnormally warm places such as in attics or next to stoves. Inoculant should be kept in a cool place, and partially used packages should be tightly resealed. Use inoculant only on the legume species for which it is specified.

PLANTING WOODY SPECIES

Woody vegetation often becomes established by natural seeding but adequate stands of commercially valuable forest trees seldom develop naturally on surface-mined lands. Thus, artificial forestation is the only sure way to establish fully stocked stands of desirable species. Artificial planting of woody species also hastens the initial establishment of food and cover plants beneficial for wildlife. Subsequent natural seeding adds needed diversity to the habitat.

The success of any planting is affected by the (1) quality of planting stock; (2) method of planting; (3) care of planting stock; (4) spacing; and (5) time of planting. Paying attention to proper establishment procedures is as important as selecting appropriate plant species.

Quality of Planting Stock

Planting stock often is defined in terms of age such as 1-0, 2-0, 2-1, and so on. A 1-0 seedling is produced in 1 year, lifted from the seedbed, and ready for immediate planting in the field. A 2-0 seedling is left in the seedbed for 2 years. A 2-1 seedling is grown for 2 years in the seedbed, then transplanted and grown 1 year in a transplant bed before it is lifted for field planting. The sum of the two numbers is the age of the seedlings.

Plantable stock of many of the suitable species is produced in one year. However, the size of planting stock can vary among nurseries and with different seasons in the same nursery. Thus, the quality of planting stock should be judged mainly by the size and balance of the seedlings instead of solely by age. Stem diameter, and length and weight of roots in relation to length and weight of tops, are generally considered the best criteria for judging stock quality. Root and top pruning, a practice for adapting seedling size to different methods of planting, also affects stock quality.

Generally, greater stem diameters mean better survival of seedlings. For most conifers and hardwoods, a minimum stem diameter of 0.1 to 0.15 inches (2.5 to 4 mm) is recommended. However, the maximum stem diameter that should be planted is limited or determined by the length of roots. In most planting jobs, roots are pruned to standard lengths to accommodate the methods of planting; for example, 6 inches with planting bars and 8 inches with mattocks. If the diameter and length of top are excessive in proportion to the length of pruned roots, an imbalance in the physiological processes of the seedling could greatly decrease its chances for survival. Seedlings of most hardwoods can be top pruned with no significant effect on survival. Top pruning can facilitate packing, shipping, and handling of hardwood seedlings. Top pruning is not advised for conifers.

Planting stock standards for the Central States region were developed by the USDA Forest Service for tree species commonly planted on mined lands (Tables 6 and 7). For conifers, the standards are based on stem diameters (at the ground line) and the relation of top lengths to root lengths after pruning. For shortleaf pine, for example, the recommended minimum stem diameter is 0.15 inches; if roots are pruned to 6-inch lengths, the tops should be longer than two-thirds the length of the roots (4 inches) and shorter than 8 inches. For hardwoods, the standards are based only on stem diameters; maximum stem diameters are prescribed only if roots are pruned to lengths of 8 inches or less. Planting stock standards may vary somewhat in other regions.

For the future, another factor to consider is the selection and use of planting stock inoculated with the appropriate mycorrhizal associates. The species of mycorrhizal fungi normally present in nursery beds may not be adapted to the inhospitable environment of minesoils. In addition, fumigation and fertilization practices used in most nurseries are detrimental to the existence of the fungi. Hopefully, as additional knowledge is gained about the mycorrhizal fungi and other beneficial microorganisms, nurseries will develop or adapt techniques for producing or inoculating planting stock with the mycorrhizal species that are most beneficial for the survival and growth of seedlings on mined areas.

Methods of Planting

Seedlings of trees and shrubs usually are hand planted; a planting bar (dibble) or mattock is used to make the holes (Figures 9 and 10). The planting bar is a better choice for use in minesoils that are stony or compacted. The planting hole should be large enough so that the seedling roots can be spread out and not bent or doubled under. Seedlings should be planted to the same depth at which they were growing in the nursery. The soil should be pressed firmly around the planted seedling.

Hand planting is necessary on steep slopes and small areas and is done with crews of a few to several planters (Figure 11). For large planting crews, one person should be responsible for the care of the planting stock and for distributing it to the planters. On steep slopes, where rocks could slide or roll, no planter should work directly below another.

TABLE 6. PLANTING STOCK STANDARDS FOR HARDWOODS PLANTED ON SURFACE-MINED LAND IN THE CENTRAL STATES[a]

Species	Stem Diameter at Ground Line	
	Minimum	Maximum (For roots pruned to 8 inches or less)
	Inches	
Maple, silver	0.15	0.40
Ash, green and white	0.10	0.35
Walnut, black	0.20	0.35
Sweetgum	0.15	0.40
Tulip poplar	0.25	0.35
Osage-orange	0.15	0.40
Sycamore	0.10	0.35
Cottonwood	0.15	0.40
Oak; bur, northern red, and chestnut	0.15	0.40

[a] From U.S. Department of Agriculture. 1960. Forestation of strip-mined land in the Central States. U.S. Dep. Agric., Agric. Handb. 166.

Tractor-drawn tree planting machines can be used on large, relatively level areas that are free of stones. Usually 15 to 20 percent is the safe maximum slope for machine planting on contour. For safety, steeper slopes, up to 30 percent, should be planted up and down slope; however, furrows running up and down slope can create channels for initiating gulley erosion. Care should be taken that the machine covers the furrow sufficiently and packs soil around the seedling roots. It is desirable to have someone follow the machine and tamp around loosely packed seedlings.

Hybrid poplars often are propagated from cuttings. A planting hole for cuttings can be made with the planting bar or mattock, but a pointed planting bar made from steel rod about 3/4-inch in diameter works best. The hole should be deep enough to place at least two-thirds of the poplar cutting in the ground. The cuttings usually are about 10 inches long. The buds on the cutting should point upward.

Care of Planting Stock

Planting stock should be protected from exposure to sun and drying during shipment and delivery to the planting site. Seedlings should be planted as soon as possible. If necessary to keep stock several days before planting, moisten unopened bundles and store in a cool, shaded place. For seedlings

TABLE 7. PLANTING STOCK STANDARDS FOR CONIFERS PLANTED ON SURFACE-MINED LAND IN THE CENTRAL STATES[a]

Species	Minimum Diameter of Stem at Ground Line	Allowable Range in Length of Tops	
		For roots pruned to 6 inches	For roots pruned no shorter than 8 inches
	Inches		
Eastern redcedar	0.15	4 - 6	6 - 12
Jack pine	0.10	4 - 6	6 - 12
Shortleaf pine	0.15	4 - 8	6 - 12
Red pine	0.15	4 - 6	6 - 12
Pitch pine	0.15	4 - 8	6 - 12
Eastern white pine	0.15	4 - 8	6 - 12
Loblolly pine	0.10	4 - 6	6 - 12
Virginia pine	0.10	4 - 6	6 - 12

[a]From U.S. Dep. Agric., Agric. Handb. 166, 1960.

that cannot be planted within 2 weeks after delivery, the bundles should be opened, inspected, moistened and "heeled in," or placed in cold storage at 34° to 38°F. Stock of most species can be held safely in cold storage for 3 to 4 weeks.

While planting, seedlings must be kept moist in a canvas planting bag or bucket (Figure 12). Tree roots exposed to drying can be damaged or killed very quickly. Coating seedling roots with kaolin clay is sometimes done to retard root drying while planting. To make the coating, mix 100 pounds of kaolin clay in 25 gallons of water. Dip the roots in the clay slurry. Planting trays or buckets, but not planting bags, are recommended for carrying coated seedlings.

Spacing

The spacing of planted trees and shrubs varies with locality, purpose of the planting, species, and requirements of regulatory agencies. For commercial forestry (timber production), ideal spacing is wide enough to postpone the first thinning until merchantable products can be obtained, and close enough to ensure good form and development. As a rule, conifers are planted at a slightly wider spacing than hardwoods. Planting 800 to 1,000 trees per acre usually is recommended for conservation purposes and for development of a productive forest. Spacing at 6 by 7 feet (about 1,000 trees per acre) or 7

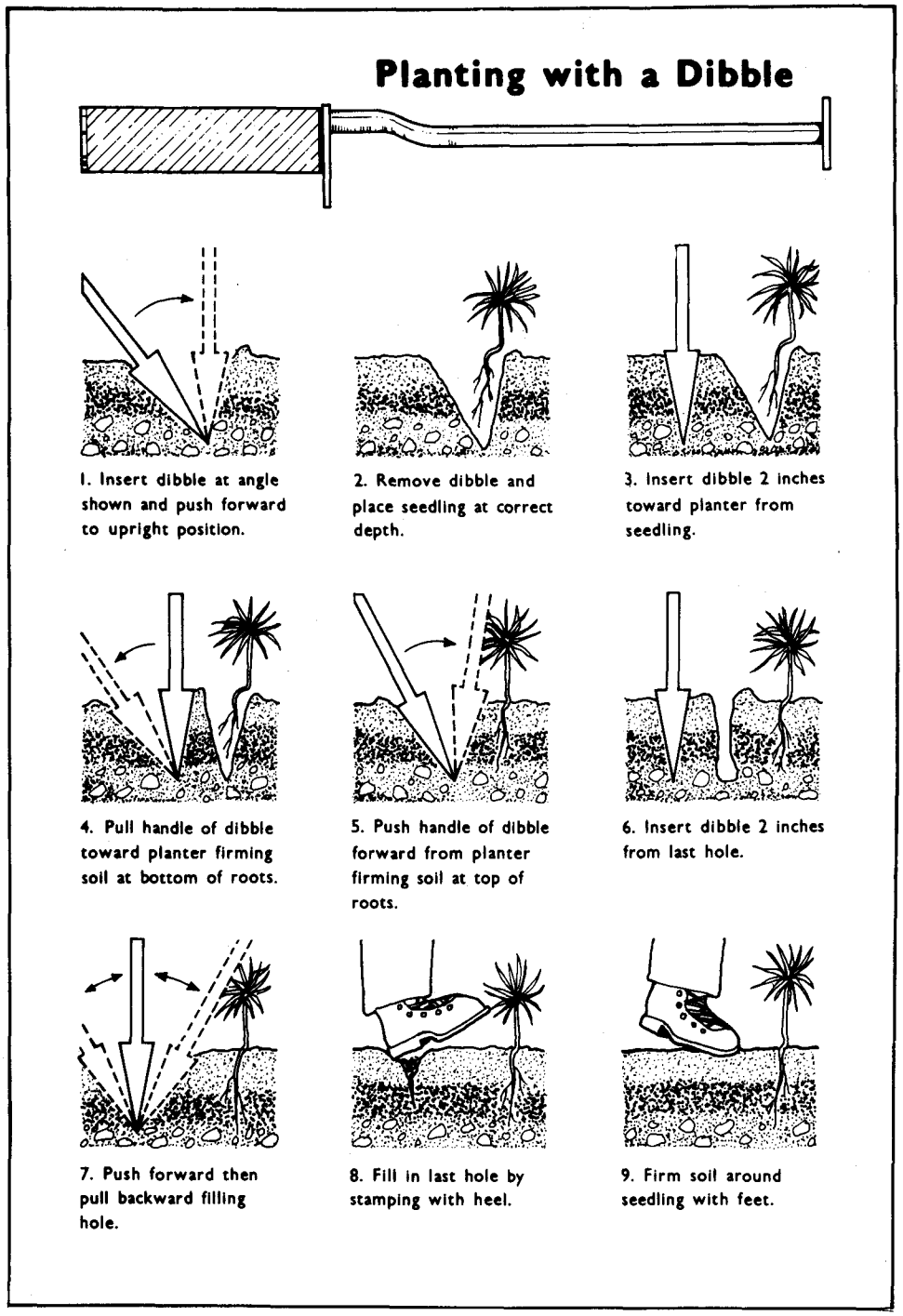

Figure 9. Planting tree and shrub seedlings with a dibble. (Redrawn with permission from John Wiley & Sons, Inc. and Alabama State Forester)

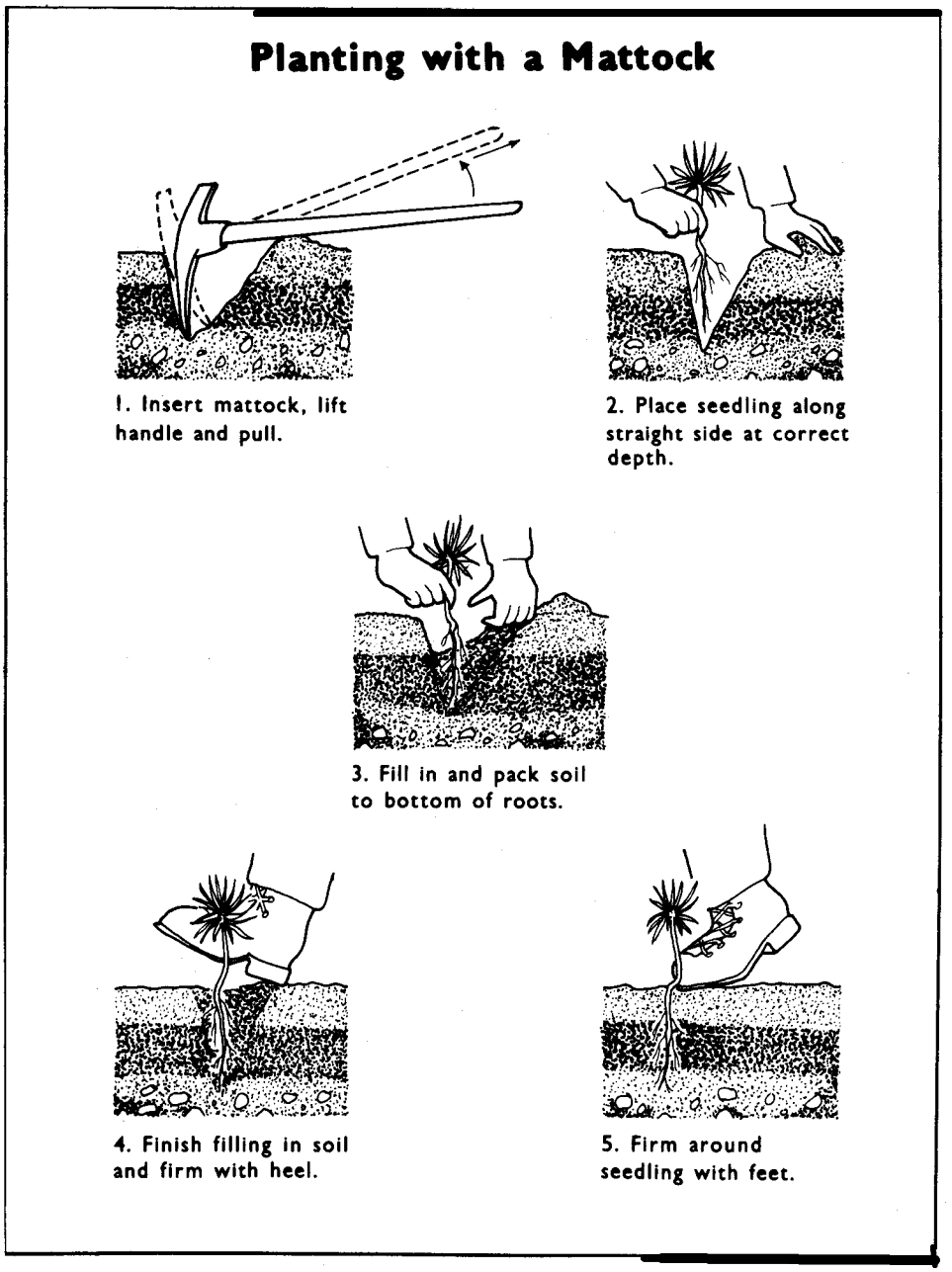

Figure 10. Planting tree and shrub seedlings with a mattock. (Redrawn with permission from John Wiley & Sons, Inc. and Alabama State Forester)

Figure 11. Planting trees with a dibble.

by 7 feet (about 900 per acre) is frequently recommended for mixed hardwood plantings. Spacing at 7 by 8 feet or 8 by 8 feet is recommended for conifers.

Christmas tree plantings usually are spaced 5 by 5 feet, sometimes 6 by 6 feet. For hybrid poplars planted alone, an 8- by 8-foot spacing is recommended, but if planted in alternate rows with a conifer, black locust, or black alder, a 7- by 7-foot spacing is advised. Closer spacings may be desired for screen plantings along roads, in block plantings of shrubs used for wildlife habitat, and on slopes where erosion control is a major concern.

The usual planting procedure is to space seedlings uniformly over an entire area. An alternate method that may improve stabilization and erosion control on slopes is to plant the seedlings close together (4 to 5 feet apart) in two to four closely spaced rows (5 to 6 feet apart) on the contour. The spacing of seedlings in one row should alternate with the spacing in the adjacent rows. The distance between groups of rows should be 20 to 40 feet. This spacing also provides a suitable planting pattern for wildlife habitat, especially when shrubs are used.

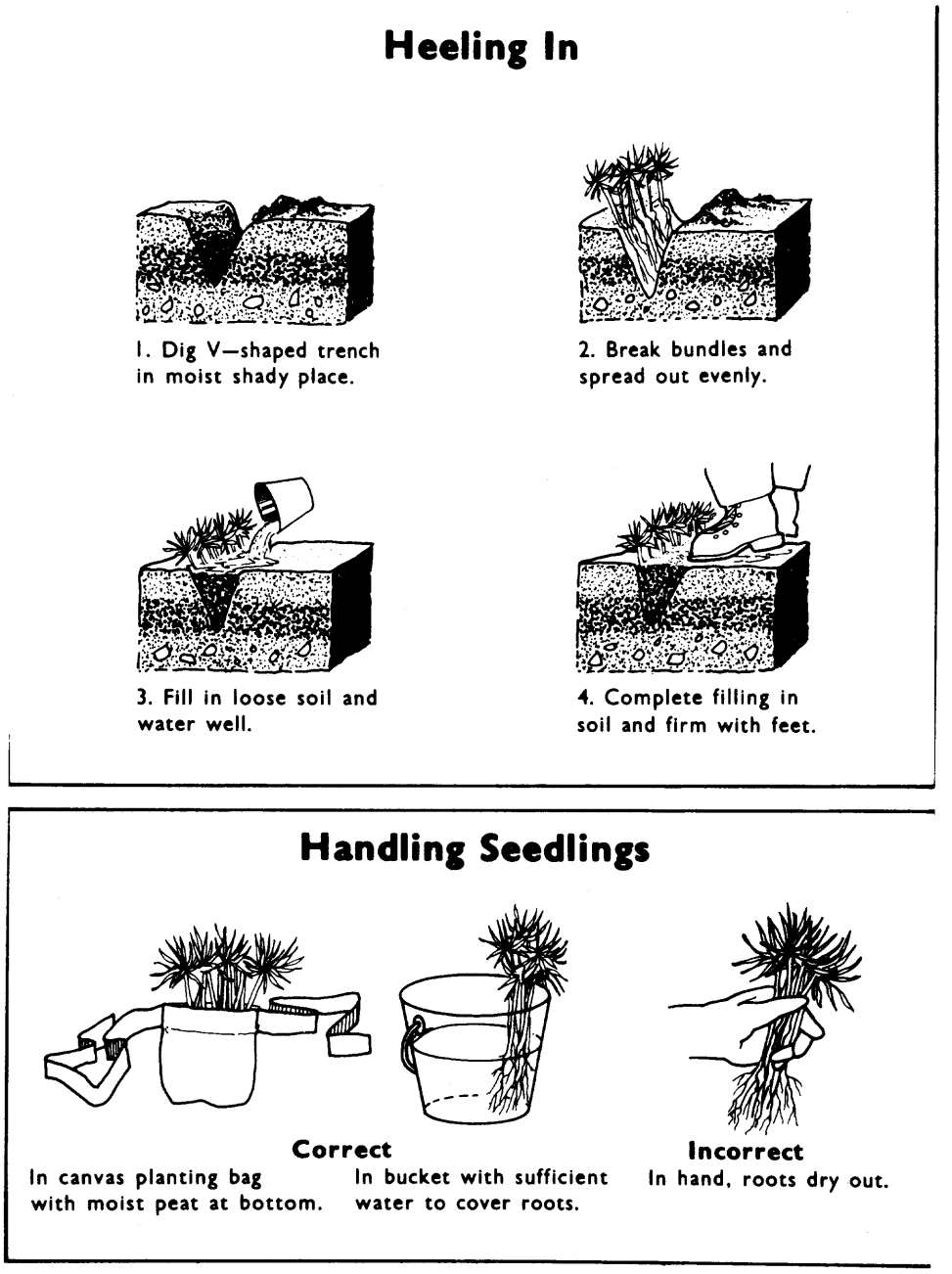

Figure 12. Methods of handling seedlings before planting. (Redrawn with permission from John Wiley & Sons, Inc. and Alabama State Forester)

Following are the approximate number of trees planted per acre at various spacings:

5' x 5' = 1,740	7' x 7' = 890
6' x 6' = 1,200	6' x 9' = 805
6' x 7' = 1,035	7' x 8' = 780
6' x 8' = 905	8' x 8' = 680
	8' x 10'= 545

Planting Patterns

Following principles discussed in Section 6 for planting woody species in mixtures, one of several patterns can be chosen. A random mixture implies that the species are intimately mixed and the seedlings planted with no designed or selected pattern for their placement. Random planting requires additional labor because it is necessary to mix the seedlings before giving them to the planting crews.

In single row mixtures, one species is planted per row. A different species is planted in an adjacent row. In multiple row mixtures, two or more adjacent rows are planted with the same species. Then, another set of two or more rows are planted with a different species. Rows usually run the full length of the area being planted.

In block or group mixtures, one species is planted in a block or group comprised of several rows that are of some predetermined length. A different species is planted in an adjacent block of similar or other predetermined size. Randomly placing small blocks or groups of single species most nearly simulates the pattern of reproduction in a natural forest.

Where included in tree mixtures, nitrogen-fixing nurse trees that are uniformly spaced throughout the planting probably provide the most benefit to adjacent crop trees. The spacing arrangement for nurse trees is related to their percentage composition in the mixture. For example, to make up 25 percent of the mixture, nurse trees should be planted in every other space in alternate rows. To make up one-third of the mixture, plant the nurse species in every third row (Table 8). A spacing pattern can also be designed where nurse trees make up 20 percent or less of the mixture, but randomly mixing them with the crop trees may be the easiest planting procedure.

Time of Planting

Late winter through early spring normally is the best time for planting woody species. Planting can begin when the ground is no longer frozen and as soon as seedlings can be obtained from the nursery. Depending on weather conditions, the beginning date for planting may vary as much as 3 weeks from one year to another. Planting of nursery stock usually should be terminated by May 15 in northern regions and by April 15 in central to southern regions. Planting can be extended later into the spring at the higher elevations in Appalachia than it can at lower elevations.

TABLE 8. EXAMPLES OF PLANTING PATTERNS FOR TREE MIXTURES

Type of Mixture	Row	Planting Pattern														
Random Mixture	1	d	c	a	b	e	d	e	b	a	c	d	a	b	c	e
of Crop	2	N	b	N	c	N	a	N	e	N	d	N	d	N	a	N
Species with	3	c	c	b	a	d	e	d	a	b	d	a	b	e	c	e
25% Nurse Trees	4	d	N	c	N	a	N	d	N	c	N	b	N	e	N	b
Single Row	1	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
Mixture of Crop	2	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Species with	3	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b
33% Nurse Trees	4	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c
	5	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	6	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
	1	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
	2	a	N	a	N	a	N	a	N	a	N	a	N	a	N	a
Multiple Row	3	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b
Mixture of Crop	4	N	b	N	b	N	b	N	b	N	b	N	b	N	b	N
Species with	5	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b
25% Nurse Trees	6	c	N	c	N	c	N	c	N	c	N	c	N	c	N	c
	7	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c
	8	N	a	N	a	N	a	N	a	N	a	N	a	N	a	N
	1	a	a	a	a	a	a	a	a	b	b	b	b	b	b	b
	2	a	a	a	a	a	a	a	a	b	b	b	b	b	b	b
	3	a	a	a	a	a	a	a	a	b	b	b	b	b	b	b
	4	a	a	a	a	a	a	a	a	b	b	b	b	b	b	b
Block or Group	5	a	a	a	a	a	a	a	a	b	b	b	b	b	b	b
Mixture of	6	a	a	a	a	a	a	a	a	b	b	b	b	b	b	b
Crop Species	7	d	d	d	d	d	d	d	d	c	c	c	c	c	c	c
	8	d	d	d	d	d	d	d	d	c	c	c	c	c	c	c
	9	d	d	d	d	d	d	d	d	c	c	c	c	c	c	c
	10	d	d	d	d	d	d	d	d	c	c	c	c	c	c	c
	11	d	d	d	d	d	d	d	d	c	c	c	c	c	c	c

a, b, c, d, e = crop trees; N = nurse trees.

Late fall or early winter planting has been only partially successful, the successes occurring mainly on the more "ideal" planting sites. Seedlings planted in the fall are susceptible to frost heaving and the resultant drying of roots. Where fall planting is necessary or desirable for distributing job loads or because of labor shortages in the spring, it should be restricted to minesoils least susceptible to frost heaving, for example, those with moderate to dense ground cover or barren sites that are sandy or loose shaly loams.

Container-Grown Seedlings

Woody plant seedlings grown in containers in a greenhouse have been used to extend the planting season into late spring and even early summer. The container-grown seedlings can be taken from the greenhouse, hardened off for a couple of weeks in a sheltered outdoor location, and directly planted on the mine site. Or, they can be hardened off, placed in refrigeration at 43°F, and planted at a later date. In a test planting in Tennessee, container-grown seedlings planted on July 1 had 87 percent survival, whereas bareroot stock that had been refrigerated had 3 percent survival. However, in Pennsylvania, survival of container-grown seedlings in most test plantings was no better than survival of bareroot seedlings when planted in the usual spring planting.

Some types of containers are unsuitable for use on minesoils because they are easily frost heaved from the ground. Tubeling type containers, especially those made of plastic, are most susceptible to frost heaving; peat pot and peat pellet type containers are least susceptible.

Direct Seeding

The direct seeding of trees and shrubs appears to be an attractive alternative to hand planting seedlings, especially on steep slopes. However, direct seeding on surface mines has been successful with only a few species; even with these, results have not been consistent. Thus, direct seeding woody species is advised only where there is a history of reasonable success.

Direct seeding is the principle method of planting southern pines on mined areas in Alabama, and is reasonably successful in southeastern Tennessee. But in Central and Northern States, success with direct seeding of any species of pine has been inconsistent and usually considered risky. Where used, pine seed should be treated with bird and rodent repellent. Cold stratification (33° to 41°F) of pine seed in a moist medium usually improves first-year germination.

Black locust and shrub lespedeza have been established successfully by direct seeding in much of the Appalachian Region, and indigobush and green ash have been established successfully in West Virginia. Direct seeding of these species is not advised at elevations above 3,000 feet or in the northern part of Appalachia.

Direct seeding of black walnut has produced variable results. In Illinois, some of the plantings that were direct seeded in the late 1940's were more successful than those established from seedlings. But, in Missouri, Kansas, and Oklahoma, establishment of seeded walnut was relatively poor in

most plantings. In eastern Ohio, direct seeded walnut were near failures. In Missouri and Kansas, seeded bur oak produced satisfactory stands in some plantings, but overall were less successful than planted seedlings.

Broadcast seeding on a mechanically prepared or frost-heaved seedbed in late winter or early spring is the most common method for direct seeding species with small seeds. A stand of more evenly spaced trees can be achieved by spot seeding. Row seeding machines can be used on minesoils that are relatively level and free of stones. Large seed, such as acorns and black walnut nuts, should be hand planted 1 to 3 inches deep at uniformly spaced spots. Two or three seed per spot are recommended to compensate for the nonviable seed, loss of seed, and mortality of young plants.

Availability of Planting Stock

Planting stock of woody species can be obtained from State-operated and private nurseries. The State-operated nurseries usually provide only those species most commonly planted in State reforestation programs. Some States provide plants only for in-state use. Others will sell surplus stock to customers outside their own State. Generally, the State nurseries provide stock that is of the quality and size suitable for planting mined lands.

Many private nurseries also advertise seedlings in quantities and size normally used in planting mined lands. Private nurseries usually are the only source of species that are not commonly used in mined-land reclamation. Those interested in planting woody species should order seedlings at least a year in advance of planting time. For some species, it may be necessary to notify nurseries even sooner because the selected species may not normally be raised in the quantities needed for reclamation planting.

To ensure the hardiness of woody plants, purchase seedlings that have been propagated from plants growing in climatic conditions similar to the area to be planted. Research has shown that variations in the characteristics of parent trees due to climatic conditions may be carried on through their seed.

SOIL AMENDMENTS

Successful establishment of vegetation usually requires the application of one or more soil amendments. Fertilizer, for example, is required on most minesoils for the establishment of herbaceous species, and lime is required on acid minesoils. By contrast, the response of newly planted tree seedlings to these amendments is less predictable. Recommendations for use of soil amendments differ among and within regions due to differences in geology, soils, and land uses. Ideally, these recommendations should be based upon research, experience, and soil-test methods that are meaningful for the minesoils in each area.

Fertilizer

Fertilizer requirements and recommendations vary with different land uses and management situations. For agricultural uses, fertilizer application should be based mainly on soil tests and follow the recommendations of local agricultural specialists for the crop being planted. Criteria for agricultural use may include split applications for crop establishment and periodic applications thereafter for crop maintenance.

For forestry and wildlife habitat land uses, fertilizer is applied primarily for the initial establishment of vegetative cover for erosion control. Generally, this requires a lower fertilizer rate than for agricultural uses, and maintenance applications usually will not be required. Ideally, without maintenance applications, the initial cover will gradually diminish in density or change in composition and thereby improve the chances for planted and natural-seeded woody species to develop.

Soil testing for fertilizer needs is less important for forestry or wildlife habitat land uses, or where herbaceous cover is established primarily for erosion control or esthetic purposes, than it is for agricultural uses. Without a soil test or with no previous knowledge of fertility requirement, a minimum rate of fertilizer recommended for establishing herbaceous seedings is about 60 pounds of nitrogen (N) and 100 pounds of phosphate (P_2O_5) per acre. On spoils that have not been "topsoiled," application of potassium fertilizer usually is not needed; but where it is used, a rate of about 30 pounds per acre of potash (K_2O) is suggested. Native soils in some regions are low in potassium; thus, a higher rate of potash may be justified on mined areas that have been topsoiled.

The benefits of fertilizing woody species are not as predictable or economically attractive as fertilizing herbaceous species. Woody species fertilized with nitrogen or phosphorus, or both, usually show a positive response in height growth, vigor, and color. But, in some plantings, the mortality of newly planted tree seedlings has been increased by the use of fertilizer--both from broadcast application and from placing fertilizer pellets in the planting hole. In other plantings, tree survival was not affected by fertilizer. For example, in an experimental planting in eastern Kentucky, phosphate and nitrogen fertilizers placed in 6-inch deep slits 8 to 10 inches from the tree seedlings increased the growth of sycamore, sweet gum, black locust, and black alder, but did not affect their survival during the first 3 years after planting. In other plantings, the early growth of black locust and European alder was increased by placing dicalcium phosphate directly in the planting hole, but tree survival was not affected. Seemingly, survival is related to tree species, soil moisture, time of planting and fertilizer application, placement of fertilizer, fertilizer formula, and rate of nutrient release. Slow-release fertilizers may have advantages for use in reforesting surface-mined lands.

The establishment and early growth of direct-seeded trees and shrubs usually are improved by fertilization with nitrogen and phosphorus. However, where trees and herbaceous species are seeded together, the rapid vigorous growth of the herbaceous vegetation in response to fertilizer may suppress or prevent establishment of seeded trees.

Maintenance Fertilization--

Requirements for maintenance fertilization of established vegetation are determined primarily by land use objectives. For agricultural uses, fertilization programs for continued crop productivity may be required similar to those in the management of any agricultural land. Because the fertility of minesoils can vary in different areas, the requirements for maintenance fertilization in agricultural uses must be determined mainly from experience and periodic soil testing.

For reforestation and wildlife habitat, little, if any, refertilization should be needed once the required vegetative cover and number of woody species are established. Thereafter, natural processes are mainly responsible for the continued maintenance and development of plant communities. For example, herbaceous and woody legumes help provide nitrogen via the associated nitrogen-fixing bacteria. Populations of other microorganisms that aid plant nutrition, especially mycorrhizal fungi that help plants obtain phosphorus from the soil, also will increase as vegetation becomes established. Application of fertilizer, especially at high rates, can impede the development and function of these beneficial organisms. Thus, refertilization is not advised where it may interfere with natural processes that benefit the development of plant communities.

Fertilizer Terminology--

Fertilizer recommendations often are confusing to those unfamiliar with fertilizer terms. Most commercial fertilizer materials include three major nutrients: nitrogen, phosphorus, and potassium. Fertilizer recommendations usually are made on the elemental basis for nitrogen (N) and on the oxide basis for phosphorus and potassium, i.e., phosphate (P_2O_5) and potash (K_2O). The "analysis" of a fertilizer material is the listing of the percent of each nutrient, always in the order: N - P_2O_5 - K_2O. For example, fertilizer labeled as 8-24-16 contains 8 percent by weight of N, 24 percent of P_2O_5, and 16 percent of K_2O. Fertilizer labeled as 10-10-10 contains 10 percent by weight of each nutrient. This applies to both dry and liquid fertilizers. Thus, if a gallon of liquid fertilizer is labeled as 10-20-10 and weighs 10 pounds, it contains only 1 pound of N, 2 pounds of P_2O_5, and 1 pound of K_2O.

Fertilizers that contain only one of the nutrients are called "straight" fertilizers. For example, 34-0-0 is ammonium nitrate and contains only nitrogen. Fertilizer labeled 0-46-0 is concentrated super-phosphate and contains only P_2O_5; muriate of potash, labeled 0-0-60, contains only K_2O. "Mixed" fertilizers contain two or all three of the nutrients; for example, 18-46-0, 0-20-20, or 8-16-8.

Fertilizers can be obtained in various formulae, but there are advantages to using or mixing "high-analysis" fertilizers--those that contain the greatest amount of the nutrient or nutrients. For example, a mix of 220 pounds of 0-46-0 fertilizer plus 180 pounds of 34-0-0 fertilizer will provide 60 pounds of N and 100 pounds of P_2O_5, the suggested per-acre rate for establishing ground cover. With this mixture, 400 pounds per acre of bulk fertilizer are needed. But if a fertilizer such as 10-10-10 were used, 1,000 pounds of bulk

fertilizer would be required to meet the 100 pounds per acre P_2O_5 requirement. This amount of fertilizer would also supply 100 pounds of N and 100 pounds of K_2O. The amount of N would be somewhat in excess of that required or needed; the K_2O may not be needed at all or be in excess of need. The advantages, then, of combining and using high-analysis fertilizers such as 0-46-0 and 34-0-0 instead of low-analysis fertilizers such as 10-10-10 are:

(1) Less bulk material is involved; thus, transportation, handling, and storage costs are reduced. For application by aircraft it is especially important to apply the most nutrients in the least amount of bulk material. (In the previous example, 1,000 pounds of 10-10-10 had to be used compared to 400 pounds of the high-analysis mix.)

(2) Cost is less because the cost of fertilizer is based on the cost per pound of nutrients. Applying unneeded nutrients increases cost of applying fertilizer.

(3) High-analysis fertilizers usually have a lower salt concentration per unit of available nutrients; this reduces the chances of salt damage to seed, especially when mixed together in a hydroseeder.

Application--

Fertilizer usually should be applied at about the same time that seeding is done, preferably when the seedbed is being prepared. However, when seeding is done in the dormant season, fertilizer, except for phosphorus, should not be applied until about the time that the seeds begin to germinate in the spring. Incorporating fertilizer, particularly phosphorus, into the minesoil is generally recommended, especially on fine-textured soils and spoils. But additional tillage for mixing fertilizer into mine soils may not be necessary where the fertilizer is applied on a roughened, freshly tilled seedbed.

Fertilizer can be applied dry with cyclone or broadcast-type spreaders, pull-type flow spreaders, regular lime-spreading trucks or those with the Estes Aerospread™ attachment, and with aircraft. It can also be spread by hand on small areas.

Fertilizer can be spread also in a hydroseeder, either by itself or mixed with the seed. Where mixed with seed, the slurry should be spread as soon as possible to prevent damage to seed by the salt solution formed from the mixture of water and fertilizer. This salt solution also can kill the bacteria in the legume inoculant as discussed previously.

Lime

Lime is used on mined areas to decrease or neutralize soil acidity. The requirement for lime depends on the degree of soil acidity, land use objective, and acid tolerance of plant species used. Obviously, minesoils and refuse materials that are extremely acid or contain high levels of sulfides will require the greatest quantities of lime. In fact, application of lime on these materials usually is essential for vegetation establishment. On soils that

are less acid, lime may not be needed to establish vegetation, but its use usually improves and hastens vegetation growth and development.

Standards for lime requirements usually are expressed in terms of liming the soil to a prescribed pH level. For agricultural uses, a pH of about 6.5 is generally recommended. For forestry and wildlife habitat land uses, a pH of at least 5.5 usually is prescribed. The reason for this is that plant species used for reforestation and wildlife habitat development generally are better adapted to acid soil than are species used primarily for agricultural purposes.

Liming Materials--

The ability of a liming material to neutralize acid is evaluated by comparing it with the neutralizing ability of pure calcium carbonate. This neutralizing ability or value is expressed in percent. For example, the neutralizing value of hydrated lime is 135 percent, but some agricultural lime may be as low as 80 percent. This and other chemical information should be available for liming materials sold commercially for agricultural uses.

Agricultural lime (ground limestone) is the material most used for amending acid soils. Limestone from different quarries and different parts of the country may vary in its neutralizing value or "calcium carbonate equivalent." Thus, adjustments to increase liming rates should be made where lime with a low neutralizing value is used. For example, if a liming recommendation calls for 2,000 pounds per acre of calcium carbonate equivalent (CCE) and lime has a neutralizing value of 85 percent, then: $(2{,}000 \div 85) \times 100 = 2{,}350$ pounds, the actual amount of agricultural lime required.

It is also important that agricultural lime be ground to meet particle-size or fineness standards recommended by the U.S. Department of Agriculture. Most dealers licensed to sell agricultural lime meet these or similar standards required by State regulation. Finely ground limestone dissolves faster than coarsely ground and thereby reacts faster with the acid in the soil. Adjustments should be made to increase liming rates where lime with a coarse grind is used. In fact, using additional lime, even as much as double the recommended rate, can benefit establishment and maintenance of vegetation on spoils high in sulfides, because a greater quantity of the finely ground limestone is available to quickly react with the active acidity. The slower dissolving coarse particles may provide a reserve for neutralizing acid produced in the future from oxidizing sulfides; but in some situations, the coarse particles of limestone become coated with iron oxides and are rendered ineffective for neutralizing acid.

Limestones from different geologic formations also vary in the content of magnesium carbonate. Those containing little or no magnesium are called calcitic, those with relatively high amounts are called dolomitic. The neutralizing value of dolomitic limestone usually is higher than calcitic limestone. Either type of limestone can be used on most minesoils, though dolomitic materials are most beneficial for soils low or deficient in magnesium. By contrast, toxicity to plants is known to occur on some acid minesoils treated with high rates of dolomite.

Hydrated lime, too, is useful for amending acid soils, but this material is more expensive than agricultural lime and more difficult to apply with conventional equipment. However, the use of hydrated lime may be desirable where it is necessary to treat small, hard-to-reach areas. The neutralizing value of hydrated lime is 135 percent; only 1,480 pounds of it are required to equal the neutralizing ability of 2,000 pounds of pure calcium carbonate. All of the hydrated lime is immediately effective for neutralizing acid; therefore, it does not have the lasting effect as does agricultural lime that contains both fine and coarse particles.

Some industrial waste products such as calcium silicate slag and alkaline fly and bottom ashes also have been used as liming materials, but they usually are less effective than agricultural and hydrated limes and sometimes cause other problems. For example, fly ash from some sources contains levels of boron that are toxic to vegetation grown on sites treated with large amounts of the fly ash.

Rock phosphate provides a long-term, slowly available source of phosphorus for plant growth and also helps to neutralize acidity. However, it has less neutralizing ability than agricultural lime at similar rates. The feasibility of using rock phosphate must be based primarily on the cost of obtaining and applying it as compared to the cost of using lime and high-analysis phosphorus fertilizer.

Determining Liming Rates--

Ideally, soil tests should be used to determine liming rates on all acid minesoils and refuse materials. However, where the appropriate soil tests cannot be obtained, general guides such as the following based on soil-water pH values usually produce acceptable results for liming minesoils that are not extremely acid (above pH 4.0).

pH (Soil-water suspension)	Rate (tons/acre CCE)*
6.1 and higher	None
6.0 to 5.5	1 to 2
5.4 to 4.6	3 to 4
4.5 to 4.0	5 to 6

*Calcium carbonate equivalent

For determining lime requirements on minesoils and refuse materials that are extremely acid (below pH 4.0) and those known or suspected to be high in sulfides, soil testing is especially important because lime requirements can vary greatly in these materials, even among those with the same pH. On materials where standard soil tests--such as the SMP Buffer pH--indicate liming rates of 20 to 25 tons per acre or more, a total sulfide analysis (potential acidity test) also is recommended and lime application should be increased accordingly. If the total sulfide analysis cannot be obtained, lime should

be applied at about 1.5 times the rate indicated in the standard soil test. An alternate strategy is to apply and incorporate at least 25 tons of lime per acre and retest with the standard soil test 4 to 6 months later. Additional lime as indicated by the test should be applied and incorporated. A temporary cover crop for reducing erosion should be sown during the periods between tests.

Liming rates indicated by soil tests normally are the amounts necessary to amend soils to a depth of about 6 inches (also referred to as the plow layer). Accordingly, lime should be incorporated about 6 inches deep. But in extremely acid material, this means that the growth of plant roots is limited to the depth to which lime has been incorporated. Thus, to increase the potential rooting depth of vegetation on extremely acid materials, lime should be incorporated 10 to 12 inches deep, or deeper if possible. However, where there is deeper incorporation of lime, the quantity of lime applied must be increased accordingly; for example, where incorporated 12 inches deep, the rate of lime indicated by soil tests should be doubled.

The need for maintenance application of lime, as with initial application, should be determined by land use requirements. Top dressing with lime to maintain a pH of about 6.5 is recommended for agricultural production. Maintenance applications for forestry and wildlife habitat may not be required unless periodic soil tests indicate a continual decline in pH below 5.5, or a visual inspection indicates that lime is needed to maintain existing vegetation.

Application--

Agricultural lime can be spread with conventional lime-spreading trucks on areas that are accessible to vehicles. Application on steep slopes as well as on accessible areas can be made with the Estes Aerospreader--a blower-impactor device that is mounted on a lime-spreading truck. Hydrated lime can be applied on relatively smooth and level land with a pull-type, gravity-flow spreader, and on steep slopes with a hydroseeder.

Before seeding or planting vegetation, lime should be incorporated into the soil, preferably to a depth of about 6 inches. A heavy duty disc or chisel plow is useful for incorporating lime on most minesoils; but on steep slopes, incorporating lime by any means is a major difficulty. Some form of tillage up and down slope may be possible with a dozer, but the furrows would collect runoff water and quickly initiate gully erosion. Lime applied on the surface and not incorporated will be of little benefit in establishing vegetation, but it is of some value for topdressing areas that are already vegetated.

Lime can be applied at any time that the spreading equipment has access to a site. Ideally, agricultural lime should be applied and incorporated several weeks or even several months before seeding. This probably can be accomplished on most older mined sites and refuse piles. However, newly mined areas should be seeded as soon as possible after the grading is completed. Thus, lime usually will have to be applied immediately after grading and given little or no reaction time in the soil before seeding. One way to compensate

for the reduced reaction time is to apply from 10 to 50 percent additional lime. Extremely acid materials that initially require large amounts of lime also will require the greater percentage of additional lime. Large quantities of agricultural lime properly incorporated usually will not inhibit establishment of seeded vegetation. For example, in eastern Kentucky, agricultural lime has been applied on extremely acidic spoils high in sulfides at 8 times the rate indicated by soil test without adverse effect on the seeded vegetation.

Organic Materials

Organic amendments can benefit plant establishment, especially on minesoils whose physical, chemical, and biological properties are unfavorable for the growth of vegetation. Addition of organic materials can decrease bulk density of the minesoil and increase water infiltration and retention. Chemically, organic amendments can reduce acidity, increase cation exchange capacity, and add plant nutrients. Irrigating extremely acid spoils with sewage effluent, for example, leaches toxic chemicals out of the rooting zone, dilutes concentration of salts, provides nutrients to plants, and lowers surface temperatures. Some organic materials also provide an energy source for beneficial soil microorganisms and soil fauna.

Organic amendments that have been tested and used on mined areas are mostly agricultural, industrial, municipal, residential, and forestry-related wastes or residues. They include products such as barnyard and poultry manures, sewage sludge and effluent, composted garbage (solid municipal wastes), leaves, and combinations of garbage or leaves with sewage sludge. Crop residues such as straw and residues such as bark and wood chips from sawmills and wood conversion plants have been used both as soil amendments and as mulches.

Factors influencing rates of application of the different organic materials include the purpose for which they are applied, physical and chemical properties of the minesoil, depth of incorporation, and cost of obtaining and applying the materials. Suggested rates of application for some of the materials are: barnyard manure and composted garbage, 15 to 30 tons per acre; leaves, 2 to 4 tons per acre (air dry); sewage sludge and effluent, volumes equivalent to 20 to 50 tons per acre of dry matter.

Several factors affect the economics of using waste and residue products, especially the costs of processing, transportation, and application. For materials such as sewage effluent, special distribution and application equipment entails high initial investment and costly maintenance. The economics of using wastes in reclaiming mined land should be evaluated in terms of costs and benefits both to the producers of the wastes and to those using it for revegetation purposes.

The incorporation of some organic materials, such as animal manure and composted sewage sludge, adds plant nutrients to the soil. However, the incorporation of materials that are not composted and are high in cellulose, such as whole-tree chips, will cause a deficiency of nitrogen to plants during the decaying process, so additional nitrogen fertilizer must be applied for the benefit of the vegetation. Where establishment of herbaceous vegetation

is concerned, a rule of thumb is to add an extra 15 to 25 pounds of nitrogen for each ton of high cellulosic or noncomposted organic material that is incorporated into the soil. This extra nitrogen usually is not required where organic materials are applied on the surface as mulch.

Microbiologic Materials

Microorganisms are essential to the establishment of permanent vegetation on mined lands. Although not an amendment in the same sense as fertilizer or lime, some types of microorganisms can be artificially added to plant materials or to the soil to aid plant establishment and growth. For example, inoculating legume seeds with *Rhizobium* bacteria ensures that the legume plants will become effective nitrogen-fixers. Similarly, under natural conditions, most plant species depend greatly on a symbiotic association with mycorrhizal fungi. For example, the survival and growth of pine on mined areas have been enhanced by inoculating the seedlings with *Pitholithus tinctorius*, an ectomycorrhizal fungus that is tolerant of high temperatures and acid conditions. Spores of this fungus, produced above ground in mushroom-like structures, are disseminated by wind and readily form an association with pine seedlings under natural conditions. Pine seedlings also can be artificially and more quickly inoculated by applying fungal spores directly to seedling roots just before planting, or by growing the seedlings in artificially inoculated nursery beds. Incorporating spores on the seed coat of conifer seed by pelletizing is another promising method of inoculation.

The endomycorrhizal fungi, another type of fungal associate, produce spores underground that are not as easily disseminated as the spores of ectomycorrhizal fungi. To inoculate plant seedlings with the appropriate endomycorrhizal fungal associate, the seedlings must be grown in nursery beds in which the fungal spores are naturally present. Because mycorrhizal fungi are naturally present in soil, spreading or mixing topsoil on the mine surface is one way to introduce these organisms into the minesoil. Where used as a mulch or soil amendment, bark that has had contact with soil is another probable source for the introduction of fungal spores into the minesoil. Spores of the endomycorrhizal fungi also can be spread through feces of soil-inhabiting rodents such as field mice and voles. Thus, a vegetative cover that provides habitat for these rodents contributes indirectly to the spread of endomycorrhizal fungal spores that subsequently aid plant growth and natural plant succession.

MULCHES

Mulches aid revegetation by reducing surface or sheet erosion, conserving soil moisture and protecting seeds and seedlings during the initial establishment of vegetative cover, and modifying extremes in the soil's surface temperature. Mulches aid vegetation establishment especially under conditions of environmental stress and on minesoils that have physical and chemical characteristics that hinder establishment and growth of plants.

The mulching materials most used in mined-land revegetation are organic products and residues from agriculture and wood-processing industries. The

choice of mulch for a specific reclamation job will depend on the availability and cost of material, transportation costs, ease and cost of application, and personal bias. Some residue materials, such as bark, often can be obtained at little or no cost, but handling, transportation, or application may require costly or specialized equipment. Sometimes an alternative mulching material is available but not accepted by the user because of lack of knowledge and uncertainty of its value. Wood chips, for example, are believed erroneously by some to be acid producing and toxic to vegetation.

Agricultural Residues

Raw residues from agriculture are some of the better and most used mulches, especially straw of cereal grains such as wheat and oats, and hay that consists mainly of grass. Straw is sometimes preferred because it does not decay as rapidly as hay. Hay mulch may be preferred where revegetation is for land uses such as wildlife habitat, because it may contain seed of its grass, legume, and weed components. However, where seeding is for agricultural uses, plants produced from these seeds may not be desired. Similarly, seed that has not been threshed from grain straw can produce vegetation that inhibits establishment of the seeded plant species.

Rates of application for straw and hay mulches should be 1-1/2 to 2 tons per acre. Resistance to wind and water movement is increased by tacking down the mulch with asphalt emulsion or other chemical tacks, or by pressing it into the soil with a disc-like implement called a Krimper™.

Other agricultural residues that may be used for mulch include peanut hulls, crushed corn cobs, shredded corn stalks or fodder, and bagassee, a residue from sugar cane mills. These and similar crop residues are used mostly in local areas and seldom are important on a regional basis.

Wood Residues

Residues such as bark, wood chips, and sawdust from sawmills and other wood-processing plants have been used as mulches. Raw or processed hardwood bark is an excellent material for erosion control and for aiding vegetation establishment. Sawdust is the least desirable material. The weight of hardwood bark and its interlocking fibers enable it to stay in place without tacking material, even on steep slopes. Pine bark, wood chips, and sawdust are less desirable than hardwood bark partly because they are lighter in weight and will more easily float in runoff water. In addition, wood chips and sawdust have a higher cellulose content than bark; thus nitrogen requirement for the microorganisms that decompose them is potentially higher than for bark. However, the concern that these wood residues contain toxic components harmful to vegetation has been overemphasized. Adverse effects on plants have been documented for only a few of the minor hardwood species.

Recommended rates of application for bark and wood chips depend partly on the revegetation job. For most seedings, 45 to 60 cubic yards per acre (3/8 to 1/2-inch deep) are adequate for reducing erosion and conserving soil moisture. Where soils are drouthy or the effective rooting zone is shallow, such as in extremely acid spoils amended less than 6 inches deep with lime, rates

of 60 to 100 yd^3/acre (1/2- to 3/4-inch deep) are recommended for greater conservation of soil moisture. Moisture conservation is even greater at rates over 100 yd^3/acre, but the emergence of some plant species with small seeds is restricted. However, where woody species alone are preferred over a herbaceous cover, bark or wood chips at rates of 400 to 500 yd^3/acre (3 to 4 inches deep) will prevent seedling emergence of most herbaceous species.

Processing whole-tree chips on the mine site from trees that will be removed ahead of mining is a potential source of wood chip mulch. The primary factors limiting such a venture are the expense of purchasing specialized equipment for hauling and chipping logs and the additional labor required. The establishment of a business venture to provide this service on several mines may be a way to circumvent the high cost to an individual mine.

Wood Fiber and Cellulose

Processed wood fibers prepared from selected woods, and reprocessed waste paper, often referred to as wood cellulose, are popular mulching materials that are applied with a hydroseeder. The fibers in these materials are short; thus, their durability as a mulch also is short lived. Most of the fiber and cellulose mulches are colored with dye so that they are plainly visible when applied on the ground; this aids the operator in obtaining uniform coverage. These materials are sold in bales that are easily handled and conveniently stored.

Rates of application that have been used for the wood fiber "hydromulches" often are insufficient to provide effective erosion control or conserve moisture. At least 1,500 pounds per acre, and preferably higher rates, are needed. However, the higher rates greatly increase the cost of application, because the hydroseeder is limited in the amount of mulch that it can handle in each load. For example, a hydroseeder with a 3,000-gallon tank can hold 1,500 pounds of fiber mulch--enough for 1 acre. On the average, up to 6 loads, or treatment for 6 acres, can be applied in an 8-hour day. In comparison, up to 40 acres can be mulched with straw in an 8-hour day using a power mulcher.

Often, these mulches are applied in a slurry mixture with seed and fertilizer. Such a mixture allows some of the seed to be perched above the soil surface in a web of mulch, thus exposing the germinating seed and tender seedlings to drying and extremes of temperature. The probability of this causing seedling mortality is greatest in areas of low rainfall, but it can occur even in humid areas during prolonged dry periods. A preferred procedure in these circumstances is to apply seed and fertilizer first, and the mulch in a separate application.

Other Mulching Materials

Mats and netting made from wood fibers and other assorted organic and synthetic materials are effective for controlling erosion in specialized uses. The cost of these materials is prohibitive for general use in surface-mine revegetation. Sites for their use generally are those considered critical for esthetic purposes or erosion control, and should be prepared under controlled or engineered standards. For example, netting may be useful in an emergency

spillway on an earthen dam that requires quick, positive protection while a complete vegetative cover is being established.

A layer of crushed rock or gravel provides an effective mulch; however, the cost of material and application may be excessive for wide-scale use.

Application Methods

Application of mulches usually requires specialized equipment, especially on large areas and steep slopes. Some of the equipment also is suitable for spreading some of the organic amendments mentioned previously.

Straw and Hay--

Several types of mechanical mulchers are available for spreading straw, hay, and similar materials. Most often these materials have been baled. They are fed into the mulchers, separated by beaters, and blown out through a discharge spout. Power mulchers that handle standard-size square bales are made by several companies and are the most commonplace. Some are equipped to spray a chemical tack on the mulch as it leaves the discharge spout. Mulch can be blown a maximum distance of 80 feet in ideal wind conditions and it can be applied both up and down slope. About 40 acres can be mulched in an 8-hour day. Four people are required to operate a power mulcher efficiently. A fifth person is needed where a Krimper is used to press the mulch into the soil.

Another type of mulcher that is commercially available from a Colorado firm was developed by modifying a rotary tub grinder. An advantage of this Roto-Grind Mulcher™ is that it handles large (1,500 pounds) round bales, as well as the small standard-size bales and loose straw and hay. It also spreads bark, wood chips, composted garbage and similar materials, and is not damaged by foreign objects. Mulch can be blown 60 to 70 feet in ideal spreading conditions. This machine is more useful for mulching flat and gently rolling land than steep slopes. It requires two persons for efficient operation and probably a third where crimping is done. From 20 to 40 acres can be mulched in an 8-hour day.

Modifications of other standard farm machinery also have been made or are being developed. One, a manure spreader for applying straw and hay mulch, was developed by the Equipment Development Center of the USDA Forest Service at Missoula, Montana. Blueprints for modifying the manure spreader are available. Another innovation is a Hesston Stak Processor™ that was modified with a flail device for distributing straw and hay mulch from large (1,500 pounds) round bales. The Stak Processor normally is used to lift and transport large bales of hay and to shred and distribute the hay in windrows for feeding cattle. Information on the flail modification is available from Western Energy Company, Colstrip, Montana. Use of these modified spreaders is limited to level and gently sloping terrain.

Straw and hay mulch can be applied by hand on small areas and slopes that are beyond reach of a mulch blower.

Bark and Wood Chips--

Shredded bark, wood chips, corn cobs, sawdust, composted municipal wastes and similar products used for mulch or as organic amendments can most easily be applied with an Estes Spreader™ , a blower/impactor, or thrower, mechanism that is attached to a conventional or modified hopper of a lime-spreading truck (Figure 13). The thrower mechanism is most advantageous for spreading mulches on steep slopes, either up or down, but it also spreads efficiently on level areas. Mulches such as bark and wood chips can be thrown about 75 feet up a 2:1 slope and as much as 125 feet horizontally. In addition to the thrower mechanism, the spinners that are standard equipment on spreader trucks can be used to apply mulch on level or gently sloping areas. The thrower and spinners can be used together or independently. To avoid damage to the thrower mechanism, materials that contain large particles, such as pieces of boards, and foreign objects must be screened or ground before loading into the spreader. The Estes Spreader is also used for applying lime and fertilizer.

Figure 13. The Estes Spreader.

The modified tub grinder mulcher described previously spreads bark, wood chips, and most any other organic material. Bark, wood chips, baled leaves, and materials of similar form can be spread on level to gently sloping areas with a standard farm manure spreader (Figure 14). Spreading these materials by hand is difficult and tedious even on small areas.

Figure 14. Leaves, bark, and wood chips--mulching materials that can be spread with a standard manure spreader.

Wood Fiber and Cellulose--

The wood fiber and wood cellulose mulches are applied with a hydraulic seeder, more commonly called a hydroseeder or hydromulcher. Two people usually are required to operate a hydroseeder. The main advantage of the hydraulic method of mulching is that mulch can be easily applied to areas, such as the far end of steep slopes, that cannot be reached by other methods. The spreading distance by the larger hydroseeders is as much as 200 feet. For treating areas beyond that distance a hose attachment is available. One drawback of hydromulching is that only a relatively small area can be treated with each load of material. For example, a hydroseeder loaded with a slurry containing seed, fertilizer, and hydromulch will treat about one-tenth as much area as a load of slurry containing only seed and fertilizer.

Mulches Grown in Place

Quick-developing annual grasses can be sown for growing mulch in place. The grass species should be compatible with the season; for example, winter annuals such as wheat and rye are sown in late summer to fall and summer annuals such as sudangrass, sorghums, pearl millet, or Japanese millet are used for late spring through early summer seedings. For growing mulch in place, the seeding rate of the annuals should be increased over that normally sown, and soil amendments should be applied as needed to promote plant growth.

Perennial species can be subsequently established by seeding or planting them directly into the annual crop residue (in-place mulch). Where mulch is produced by summer annuals, this planting can be done the following spring. But spring planting of perennials into a winter annual crop may first require

the use of a herbicide to kill the annual-plant competition. This would be most essential for establishing woody species. Seeding perennial herbs could wait until late summer, after the winter annual vegetation is mature.

SOIL STABILIZERS

Soil stabilizers are organic and inorganic chemical products that are applied in water solutions to the soil surface to temporarily stabilize the soil against wind and water erosion, and to retard the evaporation of soil moisture. In the humid East, the effectiveness of chemical stabilizers is relatively short lived compared to most mulches. The stabilizers are expected mainly to control erosion only until vegetative cover is sufficiently established to protect the site.

Soil stabilizers often are classed by their basic formulas, e.g., polyvinyl acetates, acrylic copolymers, elastometric emulsions, and natural vegetable gums. There are many of these products on the market and similar products may differ from each other only because of additives mixed with the basic formula. The additives affect curing time, crust durability, and moisture infiltration rates. The effectiveness of these products is further influenced by dilution rate with water, soil properties, weather conditions, and amendments such as fertilizer added to the solution to aid vegetation establishment.

Some of the stabilizers form a thin film on the surface that provides temporary protection against soil movement. But most of these products infiltrate as much as 1 inch into the soil and bind the soil particles together to form a crust that resists erosion. High content of soil moisture limits the depth of infiltration, so the use of stabilizers may be more effective on soils with moisture content below field capacity. Also, warm dry weather is more conducive than cool damp weather to proper curing of the stabilizers. Tough crusts may form that physically restrict seedling emergence of some plant species, especially grasses and forbs with tiny seeds.

Many of the stabilizer products can be used as chemical tacks to hold straw, hay, and other lightweight mulches in place. The stabilizers also are used in combination with wood fiber and wood cellulose mulches. In fact, the wood fiber-stabilizer combinations are used more frequently than stabilizers alone. Presumably, site protection obtained with low rates of the combined materials is comparable to that obtained with high rates of either product used alone. A combination recommended and used in some Eastern States is: 50 gallons per acre of stabilizer mixed with a minimum of 500 pounds per acre of wood fiber or wood cellulose.

Because they can be applied with a hydroseeder, soil stabilizers have an advantage over most mulches for treating long steep slopes and other hard-to-reach places. However, for general application, mulches still are more widely used and provide several advantages over soil stabilizers. One reason is that soil stabilizers cost more and require more precise preparation and procedural control than do mulches. Also, the use of soil stabilizers is a relatively

recent development and there still is insufficient knowledge about the comparative value of different products and about the most effective application rate for specific soils, sites, and weather conditions.

It is not possible here to list all of the soil stabilizer products currently available, or to make a comparative rating of their value. For those interested in using soil stabilizers, advice should be sought from research reports on their use and from reclamation companies, highway departments, and conservation agencies. Sales promotional data are not always reliable sources of information; and many products sold as soil stabilizers have come and gone from the market.

Hydroseeders most often are used for applying soil stabilizers, either alone or in combination with wood fiber or wood cellulose mulches. Conventional pump and spray equipment also can be used for applying soil stabilizers.