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Reclaiming Disturbed Lands

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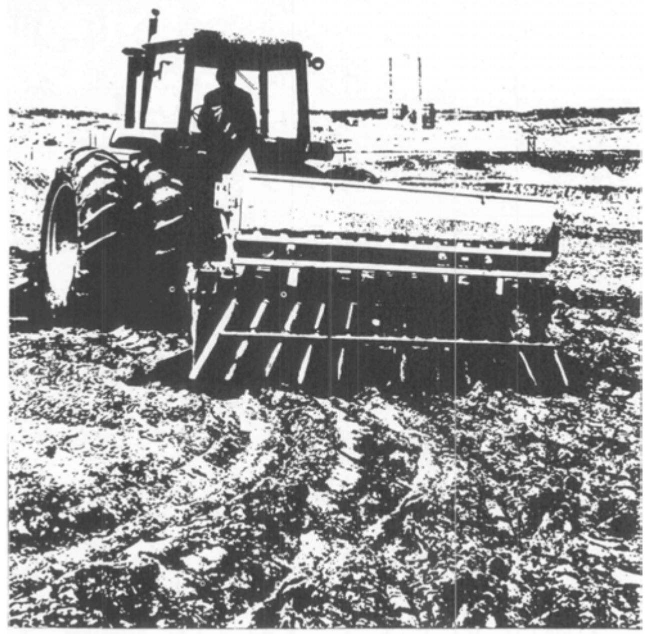
Reclaiming Disturbed Lands



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Abstract

This report describes equipment and techniques used in reclaiming surface-mined land in the West. Handling overburden, preparing the soil for planting, planting, fertilizing, and irrigating are discussed.

Contents

I. Introduction

Background

Some natural resources such as coal, gypsum, bentonite, and uranium are in such demand that they are of more economic value than the land that covers them. In the West many of these resources are surface mined because relatively small amounts of overburden cover relatively large amounts of resource, which allows these minerals to be removed cheaply and easily.

Coal, one of the more important resources being surface mined, is an excellent example. Coal beds in the West can be as thick as 200 feet; 25-foot thick beds are common. Much of this coal is beneath 10 to 150 feet of overburden. The overburden to be removed, combined with the large amounts of coal, which is 70 to 90 percent recoverable using surface mining techniques, often makes surface mining economically appealing,

Surface mining leaves disturbed lands that must be reclaimed. In 1978, all of the states in our area of interest, except Nevada, had laws affecting surface mine reclamation. In 1977, the Surface Mining Control and Reclamation Act became public law. This federal law and subsequent guidelines set down by the Department of Interior's Office of Surface Mining have a major impact on reclamation not controlled by the states. The legal requirements for reclamation vary widely by state, but virtually all surface mining operations are legally required to reclaim the land.

The social and political climate affects reclamation practices also. Our society considers reclamation an integral phase of mining; we expect surface-mined lands to be reclaimed as a normal step in the mining process. Some mining companies have responded to this attitude by going beyond minimum legal requirements for reclamation. Even some abandoned spoil piles from surface mining 40 to 50 years ago, for example, are currently being reclaimed.

Since the early 1970's the USDA Forest Service Missoula Equipment Development Center (MEDC) has been involved in the effort to develop specialized surface mine reclamation equipment. Although there have been several new or modified machines, investigations showed that much of the equipment necessary for reclamation is already available, but land managers are often not aware of it. Young professionals are particularly unfamiliar with the availability and applications of equipment. The USDI Bureau of Land Management (BLM) in recognition of this problem, requested that MEDC prepare a report to describe equipment available for reclamation work, as well as basic applicability of the equipment and techniques for using it.

Figure 1.—Area of interest

Scope of the Report

This guide deals with reclamation equipment for the arid and semi-arid West, which incorporates the Southwest deserts, the Intermountain region, and the Northern Great Plains (Fig. 1). Many of the problems and techniques discussed however, may apply to other areas.

The area of interest is generally dry; most of the land receives less than 20 inches of precipitation a year, and much of it gets 10 inches or less annually. Temperatures range from -20˚F to -30˚F in the winter to over 100˚F in the summer. Much of the area is subject to high winds. Soils are quite variable, but are usually shallow and relatively unproductive. Much of the area subject to surface mining is grass-or-shrub-dominated prairie to desert. The topsoil is thin and develops slowly. Vegetation has evolved to protect the soil from the harsh elements of the climate. When the vegetation is removed, the soil is easily destroyed. Water-bearing layers of rock, or aquifers, are responsible for much of the subsurface water distribution and retention in arid lands. Surface mining destroys aquifers above the mineral being extracted. This disruption of water flow is considered by some ecologists to be the most serious long-term impact of surface mining in some areas.

This report discusses reclamation equipment and techniques related to these environmental problems. Users of the report are assumed to have basic knowledge of range science, soil science, and plant ecology, but are assumed to be inexperienced in mining and reclamation.

Definitions

Reclamation is defined as creating a site that will support organisms in approximately the same percentage and number after the reclamation process is completed as it did before mining began. That means the same number and kinds of habitats or ecological niches will exist after mining as before mining. This definition does not imply that only organisms native to the site will be used to repopulate a reclaimed area, but it does require that any nonnative species introduced must be ecological equivalents of the displaced natives.

Restoration, on the other hand, implies that the land will be returned to precisely the state it was before mining. This is nearly impossible to achieve. It would require rebuilding the soil, precise placement of trees and rocks, and use of only native plants and animals to repopulate the site.

Rehabilitation means that the site will be returned to a stable form and productivity level, according to the predetermined land-use plan. This implies land-use alternatives were considered and an acceptable option was chosen. Premining use is not necessarily post-mining use. Conversion of rangeland to farmland, reservoirs, or wildlife habitat could all be acceptable options. A key feature of rehabilitation is that a plan for post-mining use is determined before the mining is begun. The selected option should be ecologically stable and of relatively high value to society (Box, 1978).

This report deals with techniques and equipment for reclamation. Restoration is considered nearly impossible, and rehabilitation techniques will depend on land-use goals and will vary widely.

Objectives

Reclamation is an integral part of the entire mining process. Some reclamation-oriented tasks must be completed before mining starts in order to meet some legal requirements. Other reclamation tasks are accomplished throughout the mining process to reduce site disturbance. If reclamation is considered throughout mining activity, revegetation will be of higher quality, more quickly achieved, and cheaper than if reclamation is strictly a post-mining effort.

The section on mining and overburden handling presents mining equipment common to most surface mines. The equipment is described and mining techniques and major uses for the equipment are presented along with the effects if the equipment's use on reclamation. Final spoil handling and topsoil handling are emphasized.

The second section deals extensively with seedbed preparation. Soil surface conditions, both physical and biological is vital for successful reclamation, especially in the hostile climates in the arid and semi-arid West.

Finally, the third section covers species selection, seed collection, planting techniques, fertilization, and irrigation. The quicker a successful stand of vegetation is established on mined land, the less adverse impact there will be from such things as wind and water erosion, evaporation, and heat from solar radiation.

In addition, references have been included to aid further research into reclamation.

II. Mining and Overburden Handling

Common Equipment

Although cost usually is the major criterion for choosing mining equipment and techniques, the way equipment and techniques affect the speed and ease of reclamation should be considered when designing a mining operation. Legal requirements like topsoil handling and time limits for completing reclamation must also be considered.

The most common equipment for moving overburden at surface mines in the arid and semi-arid West are draglines, power shovels, and scrapers. Bucket-wheel excavators are not currently important, but could become so. Each type of equipment has inherent advantages and disadvantages for reclamation. Specialized techniques and operator skill can also affect reclamation.

Dragline

Draglines used in the West are usually large, self-propelled machines (Fig. 2). They are the most common primary stripping machines in the West.

Draglines work from benches above the mine pit. The bucket is pulled toward the dragline into the material to be excavated. After the bucket is filled, it is hoisted and swung to dump. The swing generally ranges from 90˚ to 180˚, depending on the configuration of the mine. As successive bucket loads are dumped on previously excavated material, the original overburden profile is inverted. Overburden mixing is increased by steep, vertical-bucket loading, or decreased by horizontal loading (Fig. 3a and b). Overburden mixing is increased as the pit deepens and the bucket is pulled through increasing numbers of strata. Regardless of loading technique, however,

Figure 2.—Dragline

technique, however, precisely segregation invariably reduces dragline productivity.

Further mixing results from unloading the bucket. Two methods of unloading can be used. In *scatter spoiling,* the bucket is dumped while the dragline boom is moving, scattering the spoil over-a relatively large area of the spoil pile. In *dump spoiling,* on the other hand, the bucket is unloaded after the boom has come to a complete stop (Fig. 4a and b). Dump spoiling results in a pile of material covering a much smaller area than scatter spoiling. Dump spoiling reduces dragline productivity since the boom must be completely stopped before unloading the bucket Scatter spoiling is more efficient and mixes the overburden more than dump spoiling (Dollhopf and others, 1978)

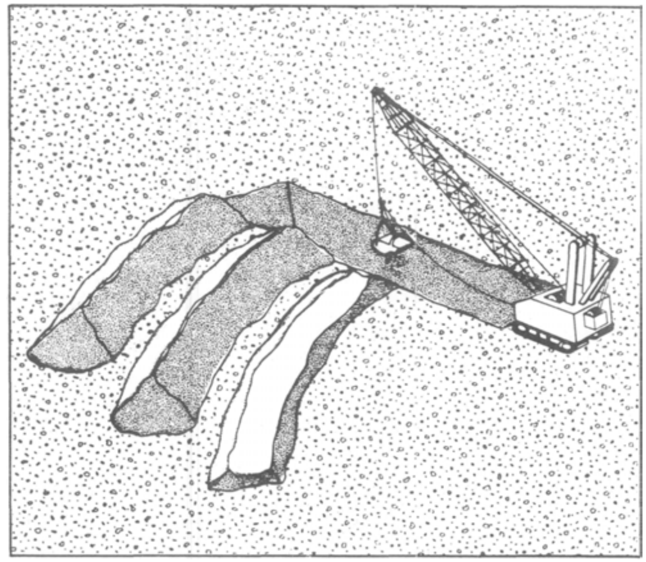


Figure 4a.—Scatter spoiling

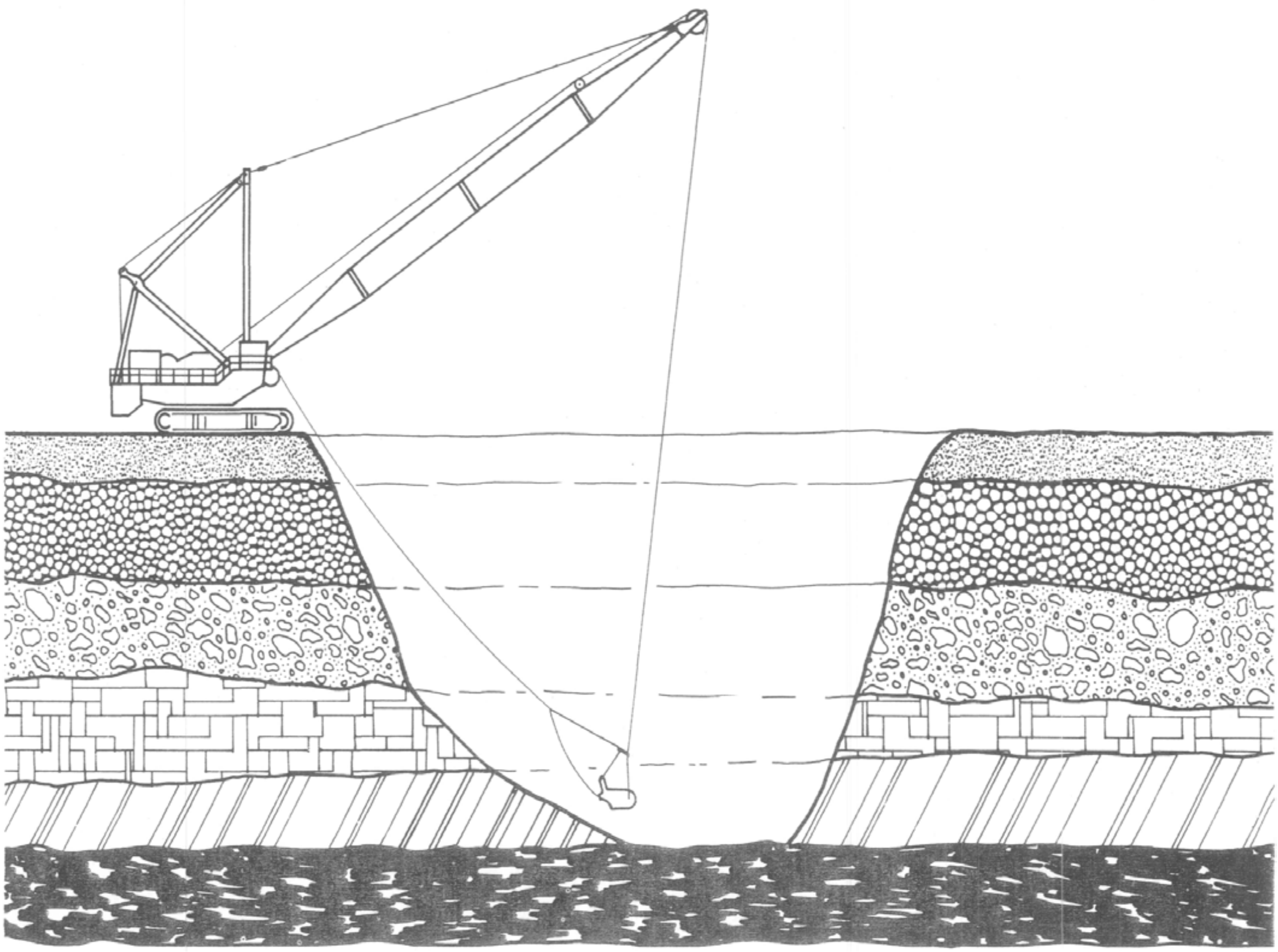


Figure 3a.—Vertical loading of overburden

technique, however, precisely segregatin

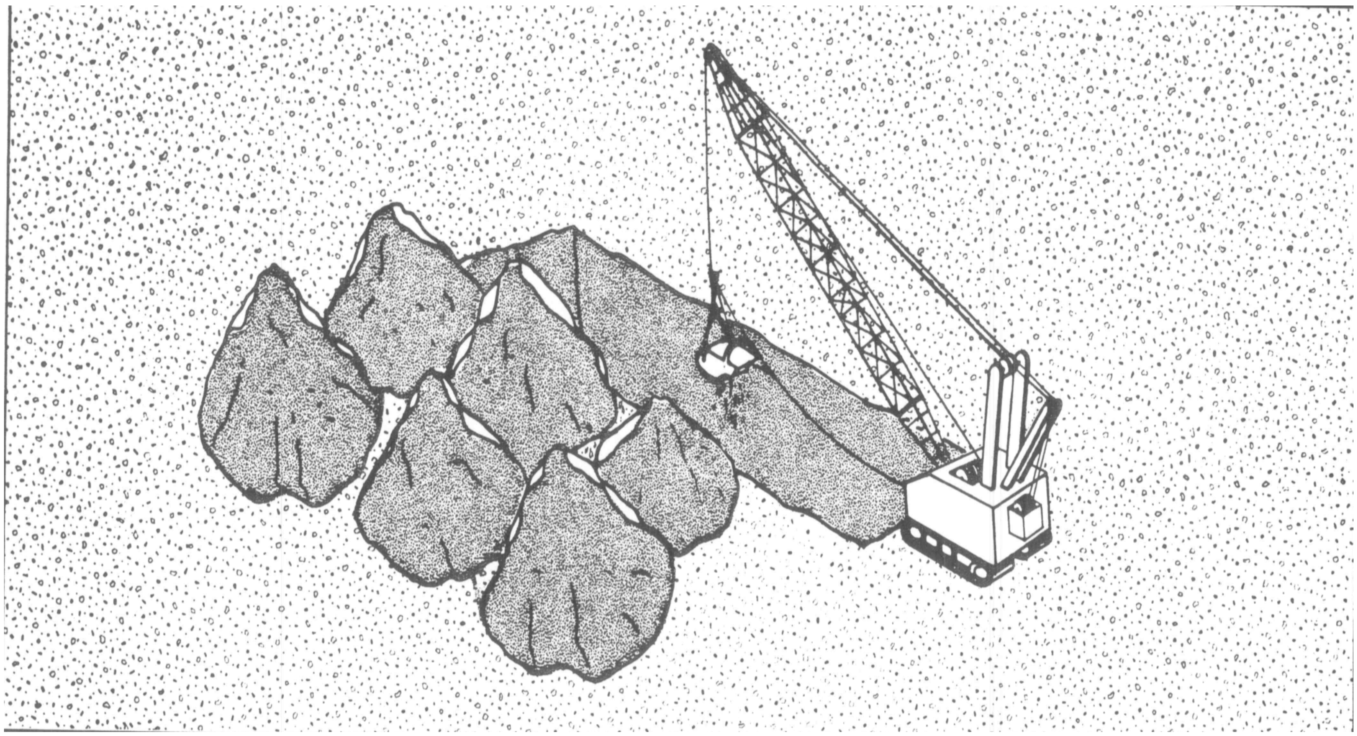


Figure 4b.—Dump spoiling

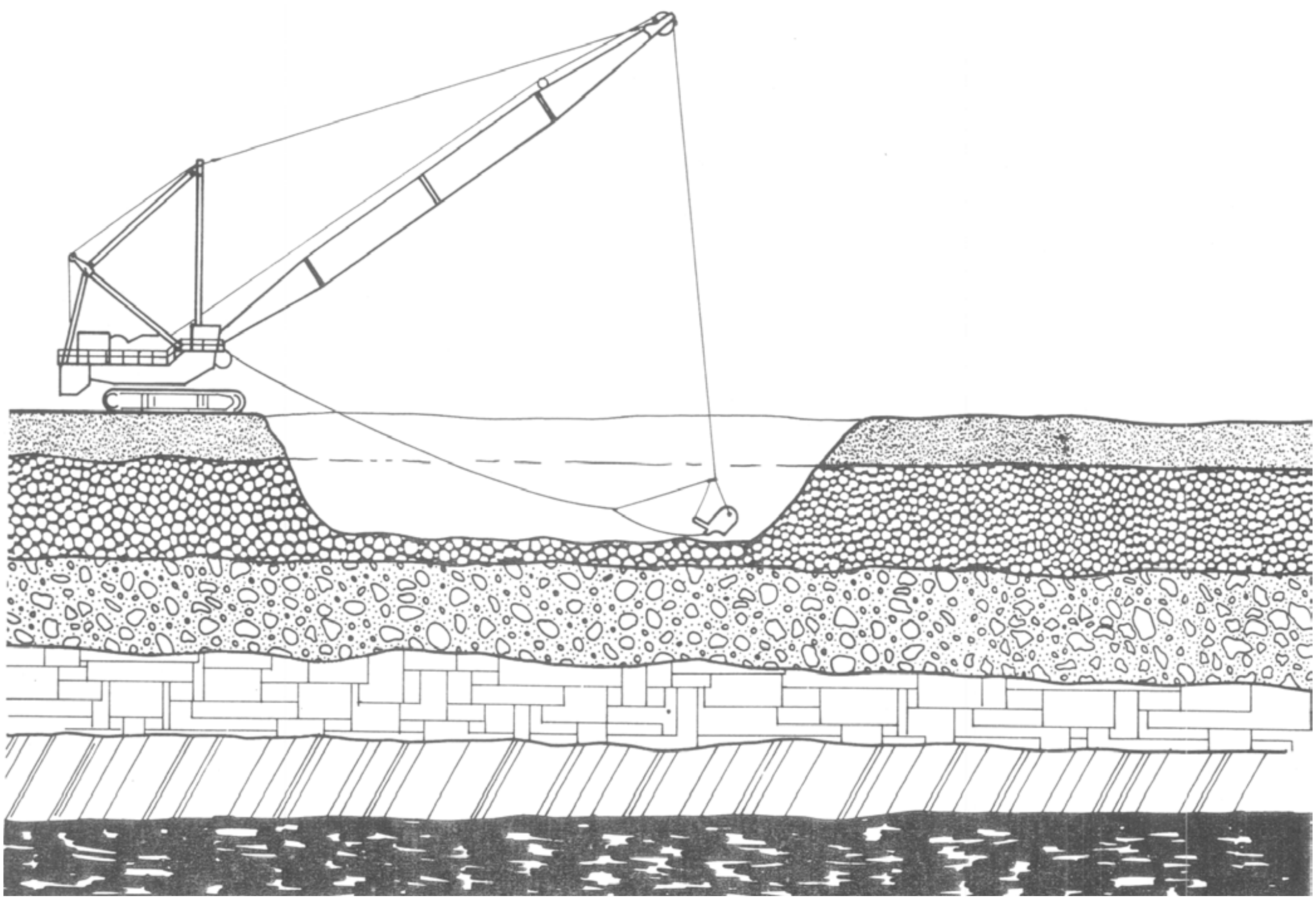


Figure 3b.–Horizontal loading of overburden

Power Shovel

Power shovels (Fig. 5) dig overburden or coal. They are crawler-mounted machines with bucket sizes from 3 to 200 cubic yards. Very large shovels, called stripping shovels, strip overburden on some mines, but are not widely used in the West. In our area of interest, most power shovels have buckets of 40 cubic yards or less. They load overburden or coal into large trucks and work in the mine pit, rather than on a bench above the pit.

Power shovels dig by pushing and pulling the dipper bucket through the face of the pit. They mix the overburden strata much the same as draglines. Since the small and medium-sized shovels require more than one lift to remove all the overburden, materials can be segregated by dumping lifts separately. Spoil materials can then be handled only once to achieve adequate selective placement of the spoils. With draglines, selective placement of spoils sometimes involves rehandling the material. Although the economics of shovel and truck operation for primary stripping are greatly influenced by the haul distance to the dumping site, draglines are usually less costly in stripping operations.

Scraper

Scrapers (Fig. 6) are almost universally used to remove and replace topsoil. They are capable of removing very thin layers of material, a decided advantage for segregating materials.

Scrapers are the primary stripping equipment in few mines in the West. They are cost-effective only when thin overburden overlays thick coal beds, in areas where large equipment is restricted, or when other equipment is not readily available. Using scrapers to remove all the overburden provides a very flexible reclamation operation. Undesirable materials can be

Figure 5.—Power shovel loading a truck

Figure 6.—Scraper

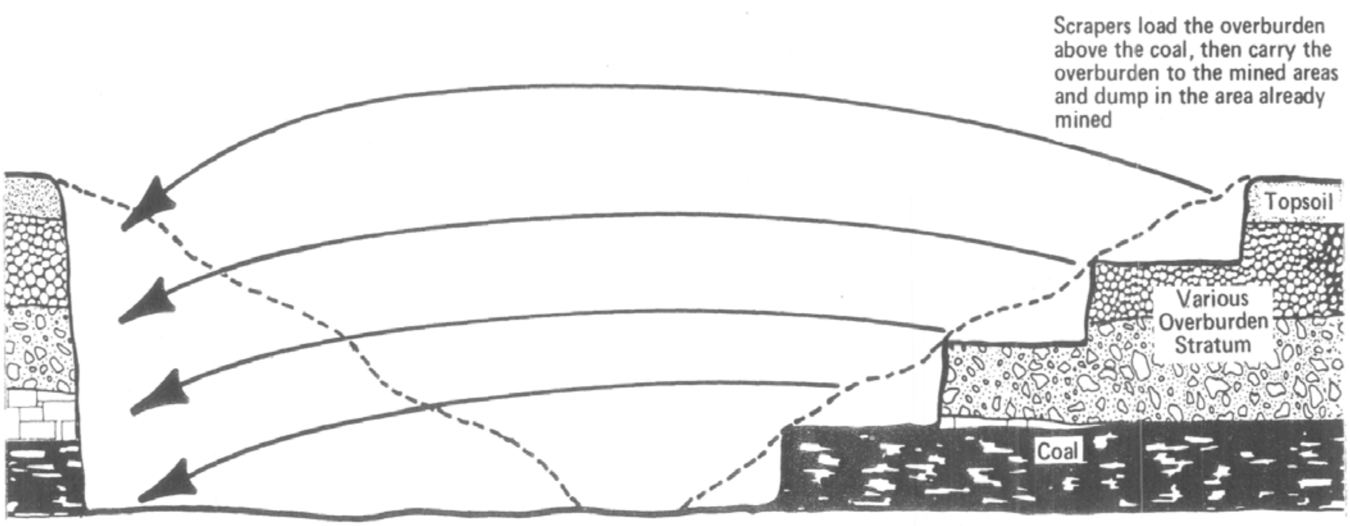


Figure 7.—Scraper mining operation

As scrapers are increasingly used to remove overburden, the mining operation gets more complex. Scrapers load from one of several stripping benches and deposit their loads on one of several reclamation benches (Fig. 7). The pit is constantly moving and reclamation in the mined-out area constantly progresses (Brown, 1977).

Bucket-Wheel Excavator

Bucket-wheel excavators (BWE's) are crawler-mounted machines that continuously dig, transport, and deposit overburden. They have a wheel with several buckets to excavate overburden and drop it onto a continuous-belt conveyor. The conveyor transports the material to a spoil bank (Fig. 8). BWE's are continuously operating machines that in favorable material are more efficient than most other equipment. They have found little application in the West because of the hard overburden encountered.

Figure 8.— Bucket wheel excavator—digging over-burden in the foreground and dumping the spoiled material in the background

Equipment Comparison

Stripping techniques affect the ease and speed for accomplishing reclamation. The original overburden profile is usually a series of layers of rock and soil (Fig. 9). The layers are usually parallel to the ore body beneath them. Each layer is more or less distinct, with certain physical and chemical characteristics prevalent thoughout the strata. Surface mining disturbs the relative homogeneity of each stratum. The kind of mining equipment and the types of mining techniques used determine the extent and significance of the disturbance.

Of the three main kinds of mining equipment used in the West, draglines are likely to cause the greatest disturbance. The overburden is usually inverted, strata are mixed, and potentially inhibiting materials are scattered throughout the spoil pile. The method of digging and dumping the overburden affects the character of the mine spoils. Selective placement techniques can reduce adverse effects of disturbing the overburden. By stockpiling some materials to be spoiled later, particularly desirable or undesirable materials can be segregated and placed in the spoil pile deliberately. This can reduce the draglines's tendency to simply invert the overburden in the spoil pile. Toxic and inhibitory materials can be buried in specially designed pockets in the spoil pile (Dollhopf and others, 1977). Growth-supporting strata can be placed above lower quality materials. Handling the overburden several times can give the spoil pile characteristics that make reclamation easier.

Selective handling technqiues, however, are more expensive than techniques that simply load and dump overburden. They require more planning, more detailed information about the overburden, more skillful equipment operation, and more time than the traditional mining techniques. These costs must be weighed against the reclamation benefits. In some cases, the overburden is either so uniform or so innocuous that selective placement is unnecessary. In other cases, selective placement of overburden is vital in the attempt to replace aquifers, prevent toxic materials from entering the hydrologic system, or provide growth-supporting material in the plant root zone.

Shovels and trucks, the second most widely used mining equipment in the West, are more easily adapted to selectively placing materials. Shovels load trucks to haul overburden to the dumpsite, where the trucks dump the loads in a specified area. In a well planned operation overburden strata can be segregated without being handled twice. The flexibility to dump the overburden at any of several sites at a

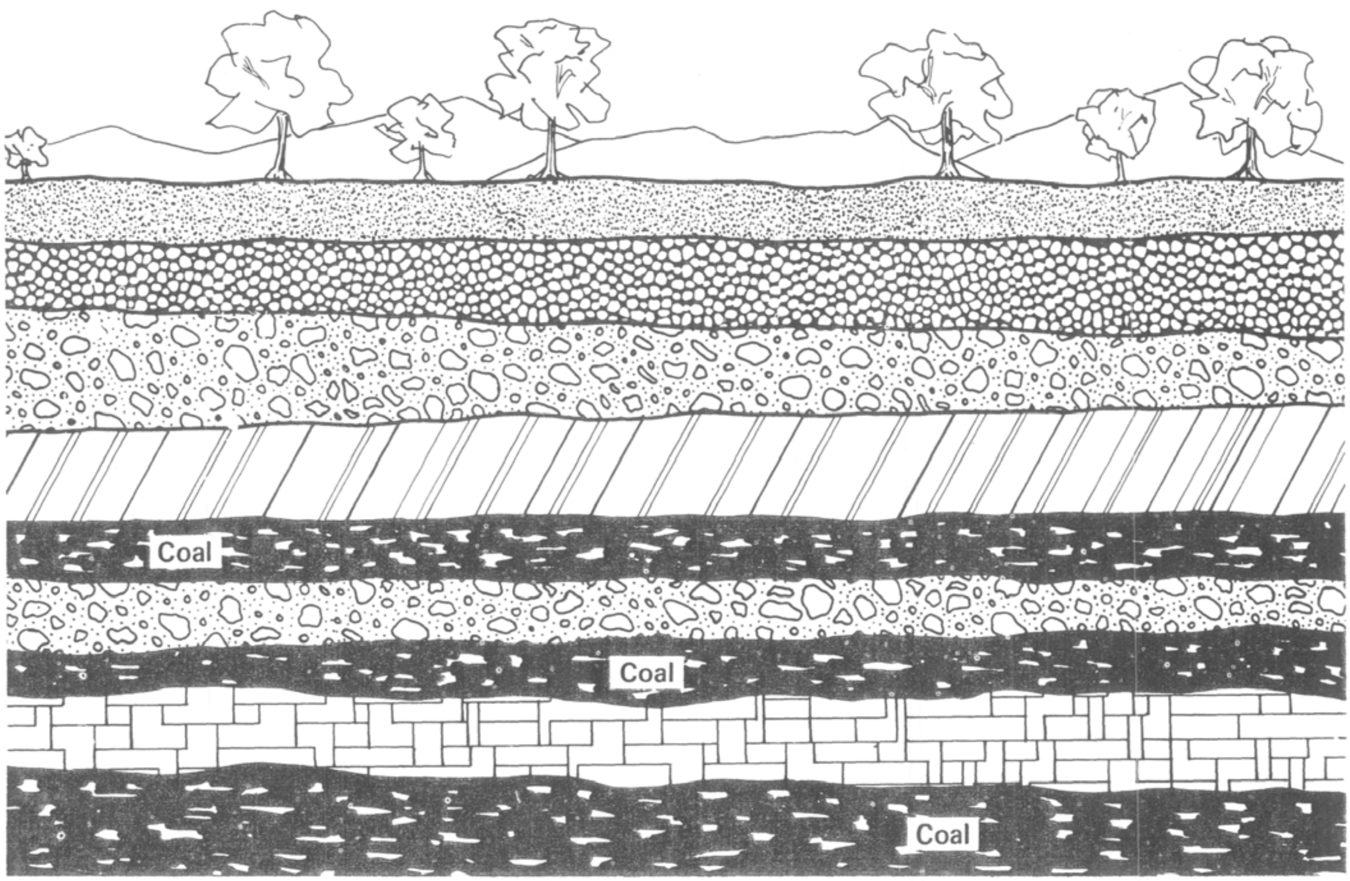


Figure 9.—Overburden and coal

given time allows the shovel-truck operation to be productive and still meet reclamation objectives. Some mixing of overburden strata is inevitable in the digging operation, but further mixing during dumping can largely be avoided.

Scrapers, the third most commonly used stripping machines in the West, can provide even more precision in loading and placing overburden materials. They can load from a single stratum; they can mix material by loading from two or more strata; and they can segregate or mix the strata by unloading at a choice of dump sites. With careful planning and competent equipment operation, desirable and undesirable materials can be accurately placed in the spoil piles.

A major problem with using scrapers or trucks for dumping overburden is the compaction that occurs with repeated passes of equipment over the spoil banks. Compaction of the replaced overburden can sometimes cause more problems than the selective placement of spoils cures

.

Final Spoil Handling

Final spoil handling has a direct and substantial effect on reclamation success. Creating special subsurface features, sealing toxic materials, and leveling spoil piles are all spoil handling techniques for improving reclamation. Final spoil handling has two steps, placing overburden and grading overburden.

Overburden Placement

Overburden placement determines the subsurface soil conditions from the rock layer originally below the mined material to where the topsoil will be laid. After replacing the overburden, only new excavations can change the subsurface conditions; relcamation must go on above what has been laid. Any problems with overburden placement discovered after this final handling will be very costly to rectify and will probably be permanent.

During mining, the physical, chemical, and topographical characteristics of the soil are altered. Careful overburden placement can mitigate potential problems.

Physical Considerations.—Physical alteration of the soil and subsoil is a result of surface mining. Texture, structure, stone content, color, and water-carrying characteristics are often affected by mining. They can all have adverse effects on reclamation.

Soil texture, the relative proportions of the soil size-classes (sand, silt, and clay) is changed by blasting, mixing, and weathering. Blasting can reduce rocks into sand or silt and can reduce large soil particles to clay. Stripping techniques that mix overburden strata can produce relatively homogeneous soil with sand, silt, and clay mixed together. This mixing can also reduce the concentrations of similar size particles found in particular strata throughout the overburden. Mixing may or may not be adequate to produce the homogeneity throughout the entire spoil pile. During the stripping process, previously buried overburden often ends up on top of the spoil pile. This overburden is then subjected to weathering, which breaks some of the overburden into soil-sized particles and increases the total amount of soil on the site. This additional weathering is often insignificant, however, due to the short periods the overburden is exposed.

Changes in soil structure are also common during surface mining. Soil structure is the aggregation of soil particles into secondary soil units. Structure often depends on soil texture. Soil structure develops over time and is reduced by disturbance Surface mining alters soil structure by compacting, breaking, and mixing the soil. Removing and dumping the overburden breaks apart the soil structure and mixes the soil particles and aggregated soil units. Since structure is strongly affected by the soil texture, changing the soil texture generally changes the structure. In addition, the physical disturbance of mining breaks down the soil units and reduces much of the soil to individual particles. Compaction of the spoiled materials is another way that soil structure is altered. The extent and seriousness of the compaction is greatly influenced by the mining methods. Scrapers and shovel-truck operations cause the most compaction, which increases significantly when the spoils are carried to the dump site by vehicles.

Stone content of soils is often changed during surface mining. Blasting, ripping, and digging all break large consolidated rock strata in the overburden into various sized rock particles. These particles are then mixed with the existing soil-sized particles. This often results in a more stoney soil than before mining. Conversely, mining can occasionally result in a relatively stone-free strata on the surface of the spoil pile.

The color of the spoil surface can be different from that of the original soil. Very dark strata on the surface of the spoils after mining can raise the surface temperature and reduce the available moisture significantly. Temperatures in excess of 150˚F have been recorded on spoil surfaces composed of very dark shale (Grim and Hill, 1974). High temperatures, especially on south and west aspects, can be detrimental to seed germination and seedling growth.

The effect of coal mining on water availability and quality is a critical issue in the arid and semi-arid West. Changes in water patterns are difficult to predict or prevent since many coal seams are important aquifers (Fig. 10). With the coal removed, water flow is often disturbed. Attempts to restore water patterns have met limited success because the material used to reconstruct aquifers seldom has the same characteristics as the original aquifer. Selective placement techniques are used to construct an aquifer that will provide the best possible subsurface water movement. Placing an impervious layer of material immediately below the desired aquifer prevents loss of water to lower strata. Compaction of material at the base of the aquifer makes it more capable of carrying water (Fig. 11). The amount of water that enters an aquifer can be controlled somewhat by the material placed over it. An aquifer designed to simply carry water from one side of the mine to the other, rather than collect water from the mine site, will be covered with impervious material. This also reduces toxic materials leaking into the aquifer from the overburden (Fig. 12).

If the hydrology of the area is such that the major problem created by mining is loss of water into the mined area, a clay or grout cutoff wall can be built to keep water from entering the mine (Fig. 13). Decisions on techniques to reduce adverse hydrologic impact of mining must be site specific. The quality, quantity, and importance of the water before mining often influence the techniques to be used (Farmer, 1980).

Chemical Considerations. — In the arid and semi-arid West, chemical problems of surface-mined lands are often related to saline or sodic spoils. Saline spoils contain soluble salts in concentrations that interfere with plant growth (Sandoval and Gould, 1978). Sodic spoils contain exchangeable sodium in concentrations that interfere with plant growth. The effect of either of these situations is to reduce water available to plants.

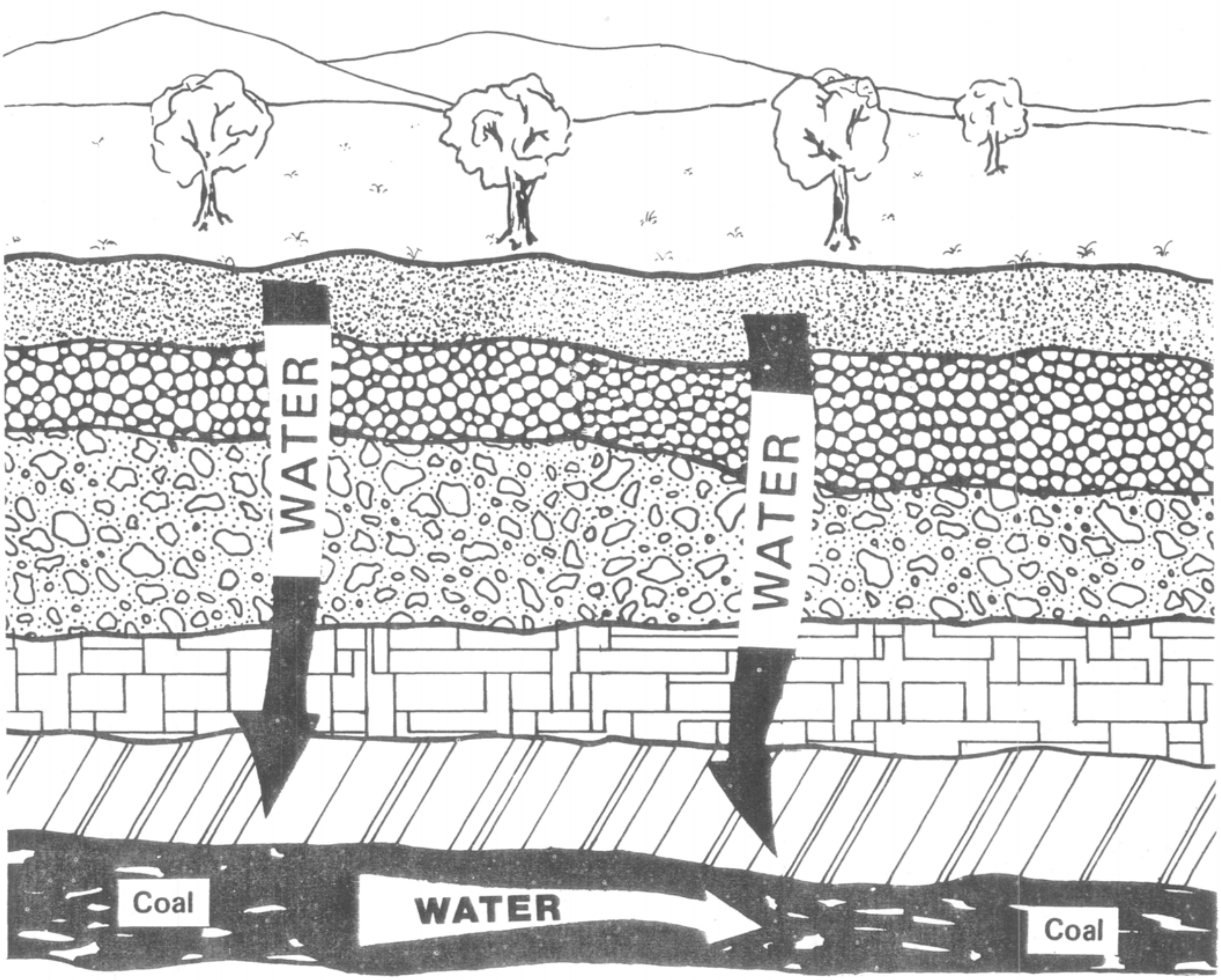


Figure 10.—Coal aquifer

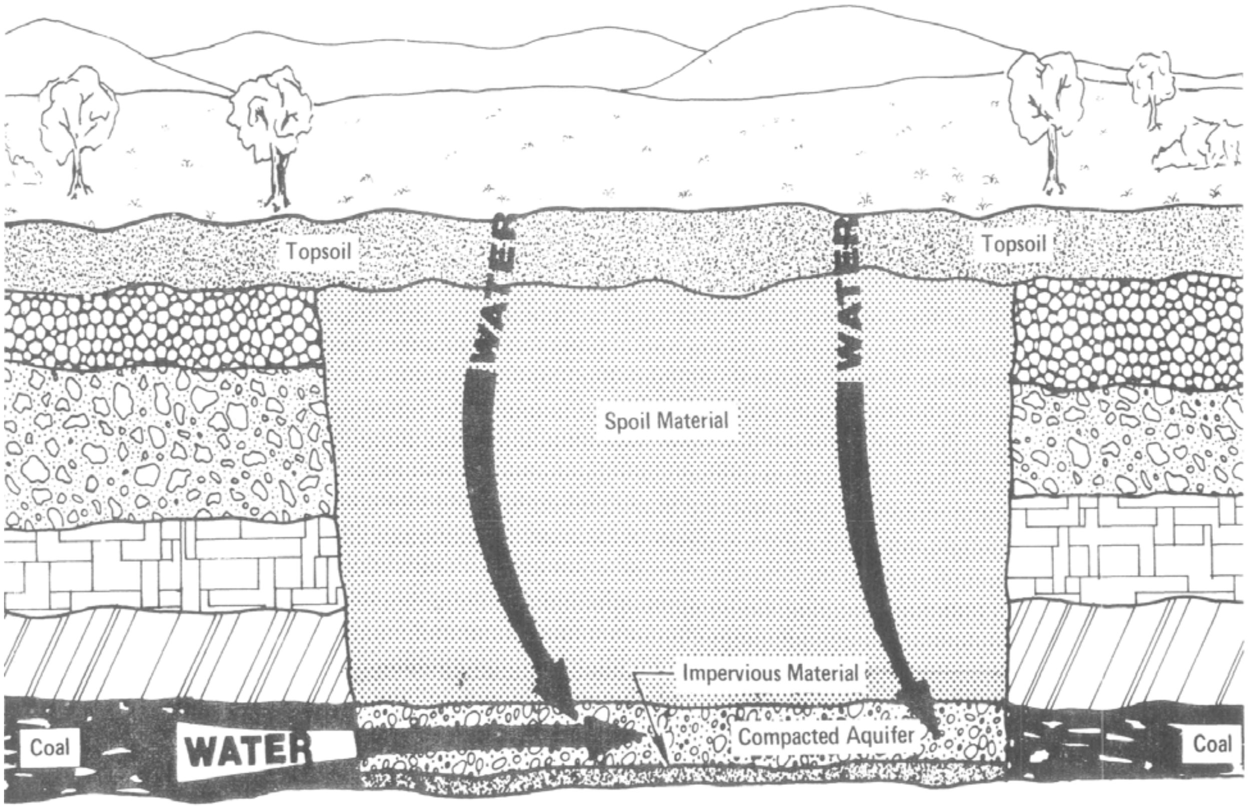


Figure 11 .—Recreated aquifer

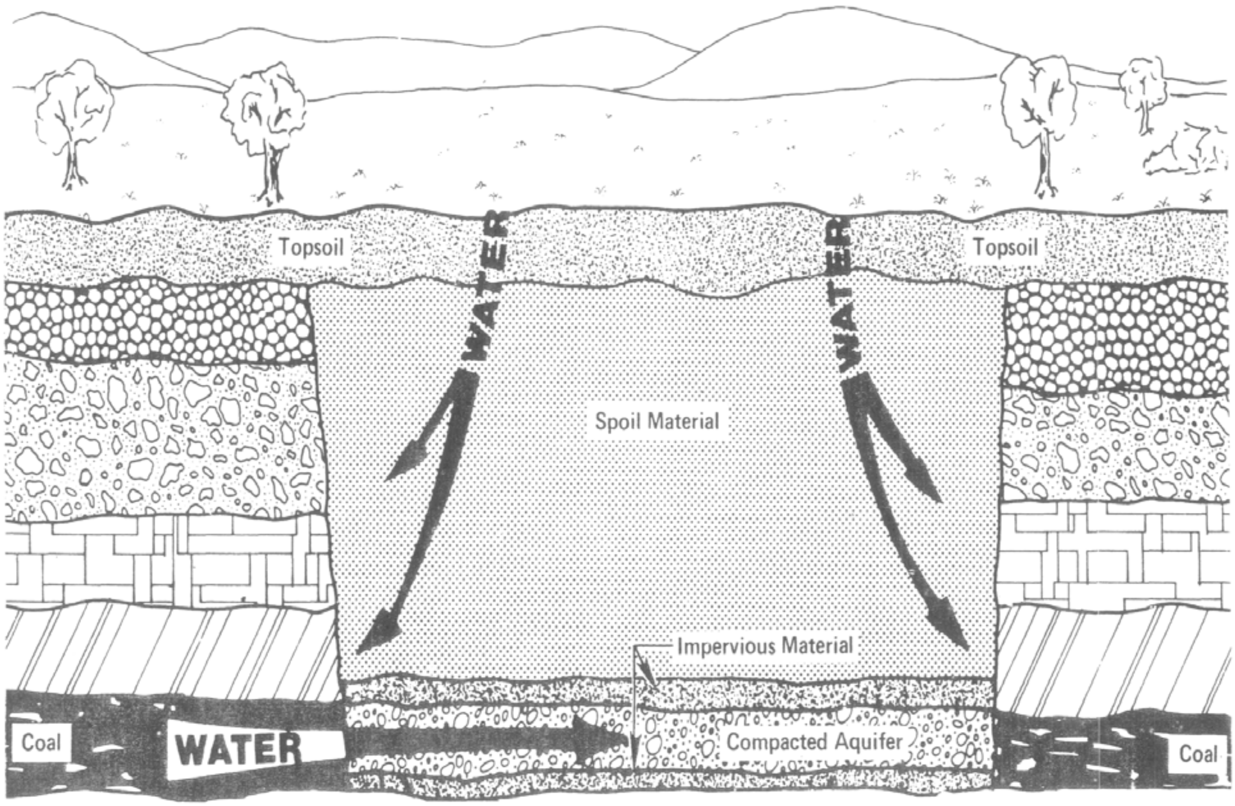


Figure 12.—Recreated aquifer with impermeable layer

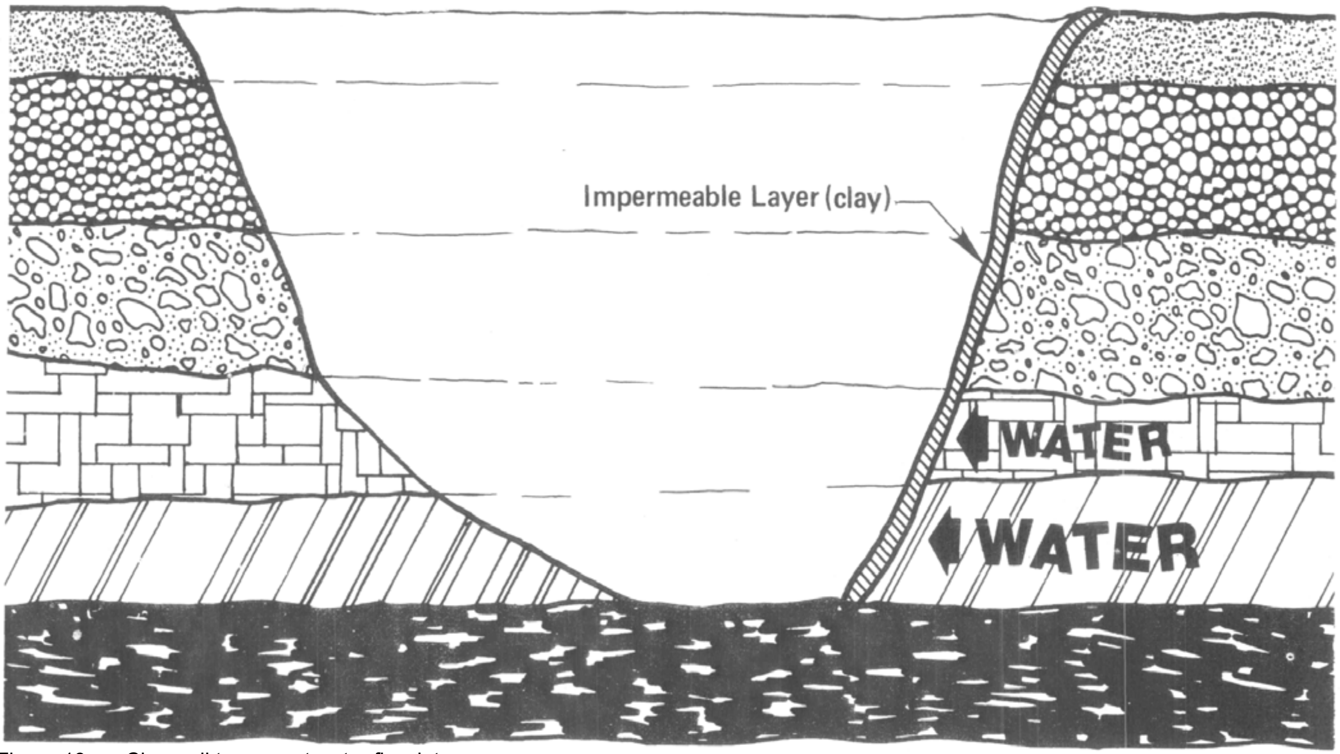


Figure 13.— Clay wall to prevent water flow into mine.

Saline soils often flocculate, where the soil particles form loosely aggregated, fluffy units that look somewhat like wool (Fig. 14). Flocculated soils are usually highly permeable to water due to their loose, open surface. However, plants have difficulties obtaining water in saline spoils because of the high osmotic pressure of the soil solution. The concentration of salts severely decreases the water available to the plants. The main force supplying water to plant roots is osmosis, which causes water to move through the root membrane to equalize the concentration of the solution on both sides of the membrane. In saline soils the concentration of salts in the soil solution is often so high that water will not pass through the root membrane into the root cells.

When wetted, sodic soils usually disperse and become virtually impermeable to moisture. As they dry, the soils form a surface crust that cracks (Richardson, 1979). As a consequence, when water falls on this soil, it will pass through most plant rooting zones. When the surface becomes moist, the soil surface closes up tightly and any additional moisture runs off. Very little moisture remains in the rooting zone.

In both saline and sodic soils, the concentration of inhibitory substances, soil pH, and the presence or absence of certain ions influence how the soils affect plant growth. Each circumstance must be analyzed individually to determine the effect of variable soil factors, factors that cannot be ignored. However, the major effect is that water is lacking in these soils (Sandoval and Gould, 1978). Such things as specific ion toxicity or deficiency are the exception, not the norm.

Sandoval and Gould (1978) note four principles for improving saline or sodic soils: (1) establishing drainage to lower the water tables; (2) leaching excess soluble salts; (3) replacing the exchangeable sodium with other cations; and (4) rearranging and aggregating soil particles to improve soil structure.

Leaching the soils by irrigating is a well-known method of reducing soil salinity. Enough moisture must be put in the soil to carry the salts below the rooting zone. In the arid Southwest this seldom happens naturally. Usually moisture falls in the hot summer months when it is quickly used by growing plants or is lost through evaporation. In more mesic climates, such as the semi-arid Great Plains or Intermountain area, moisture comes in the spring and fall when there is less evaporation and when plants will not immediately use the moisture. This sometimes allows water to accumulate and percolate below the plant rooting zone, carrying salts with it. The salts are then deposited in these lower areas, where they will not affect plant growth. Irrigation techniques are well adapted to leaching saline soils (U.S. Salinity Laboratory Staff, 1954).

Sodic soils, however, require salt-rich water for leaching. Water with low salt concentration disperses sodic soils, which makes them nearly impermeable and prevents leaching.

Figure 14.—Flocculated soil

A more preferable method for reclaiming saline or sodic soils is to bury these soils beneath higher quality soil (Doering and Willis, 1975). This can be done by burying saline or sodic materials during the mining operation or by covering surface spoils with topsoil. Even thin layers of topsoil have been found to improve grass growth and production, increase water infiltration, and decrease runoff (Sandoval and others, 1973). Sandoval and Gould (1978) observed some reductions of productivity on topsoil spread over sodic soils after 4 years of growth. They found that sodium had migrated upward into the topsoil. They recommend that the good soil material spread over the sodic soils should be deep enough to produce desired results even after some sodium has migrated into and contaminated the lower portion of the topsoil.

Although saline and sodic soils provide the bulk of soil chemistry problems, acidic soils cause important problems in some areas of the West. Acidic soils are generally associated with mining materials such as uranium, copper, platinum, and other metals. Acidity inhibits growth by causing ion toxicity or deficiencies to the plant by releasing or holding certain ions. On even highly acidic soils some plants will grow, however the productivity of the plants and the number of species are sharply reduced (Richardson, 1979). Figure 15 shows some affects of soil acidity and alkalinity.

Toxic overburden can be a problem by inhibiting plant growth or by polluting water in the spoil pile. Techniques to bury the toxic material must eliminate both potential problems. Burying material under desirable overburden will eliminate plant roots growing into the material. To prevent contamination of the underground water system, the material must be covered with an impermeable layer of clay or other overburden to keep water from permeating the material. In addition, it is advisable to put a layer of impermeable material under the toxic material to prevent any downward migration of the toxics. Toxic materials should be buried away from known aquifers whenever possible. Figure 16 shows one method of burying toxic overburden.

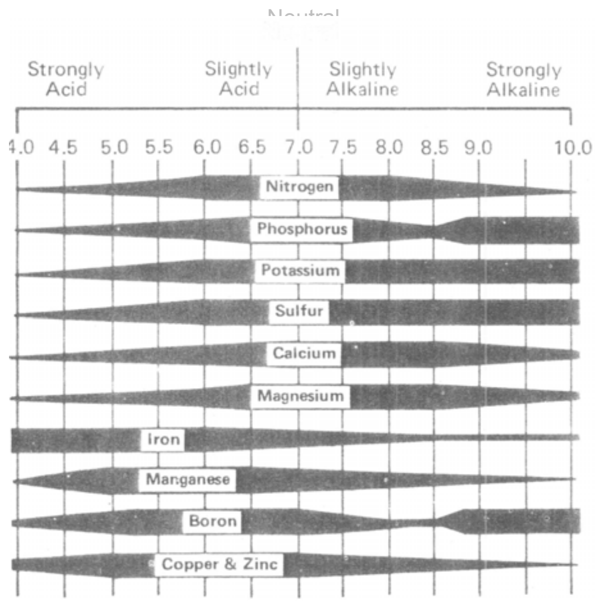
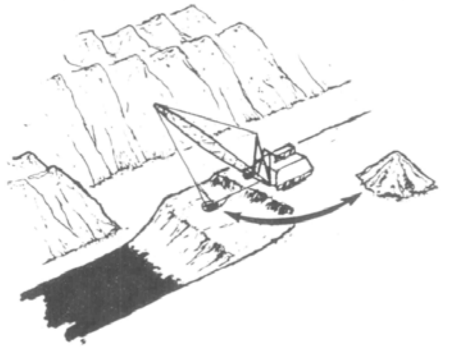


Figure 15.—Ph effect on nutrient availability

Soil chemistry problems are most efficiently handled during mining operations. Selective placement techniques for overburden can remedy most potential soil chemistry problems by insuring that the surface layer of spoil material is adequate for plant growth. These selective placement techniques should be done by the primary mining equipment. The massive amounts of material to be moved preclude performing this operation with smaller equipment.

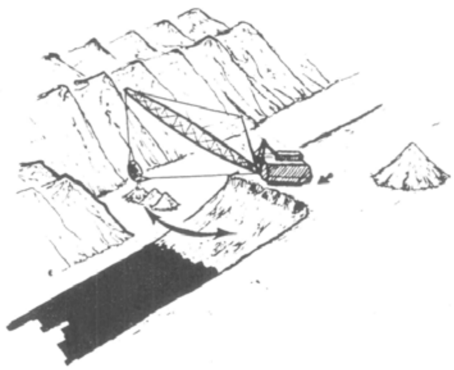
Topographic Considerations.—The third major soils problem after mining is the topography of the soil surface. Steep slopes present many revegetation problems. They are difficult to traverse with revegetation equipment; they introduce a wide variety of microsite conditions that affect the kinds and amounts of vegetation each site will support; and they are highly susceptible to erosion and slumping. These conditions all contribute to the need to reduce steep slopes on spoils to be revegetated. Additionally, most state mining reclamation laws and the federal mine reclamation regulations specify the maximum slopes allowed in spoiled material. These requirements commonly set strict standards for slopes, standards designed to make revegetation easier.

A



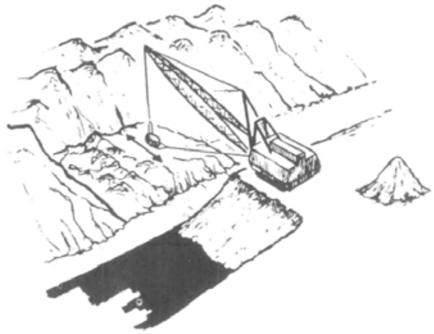
Initially, the dragline stockpiled the surface 5 yards of salt material on the highwall.

B



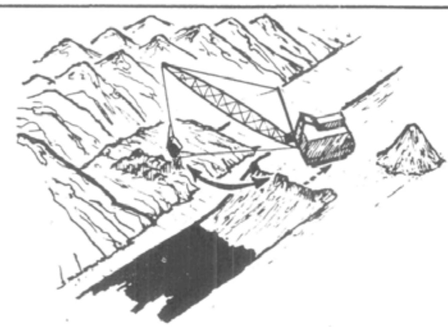
Overburden below the surface salt-affected zone was placed in the pit bottom as basement fill.

C



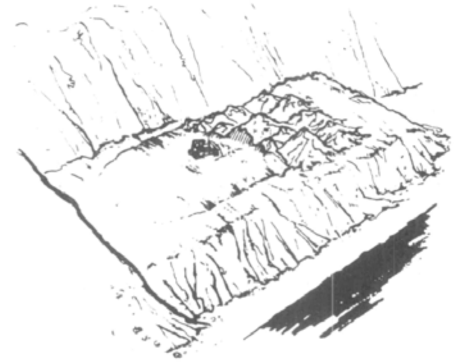
Leveling and shaping the basement material with the dragline to reduce the work required by a dozer in grading these materials.

D



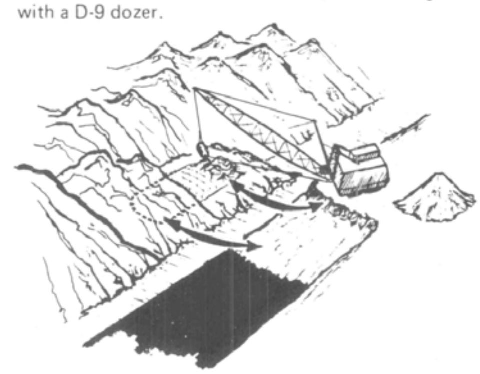
Direct deposition of saline material on the basement fill.

E



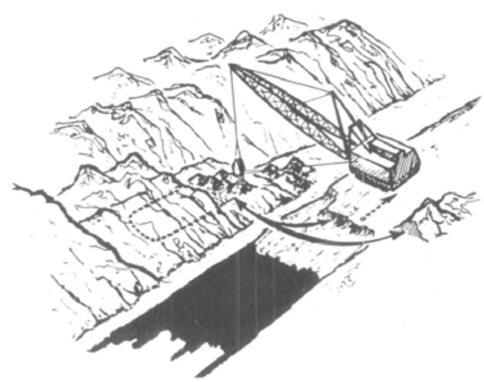
The salt-affected material was shaped to 5:1 grade with a D-9 dozer.

F



Burial of saline material (lower arrow) with nonsaline overburden.

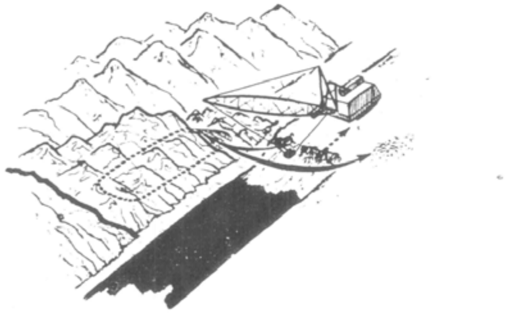
G



Deposition of saline material from both the overburden and the stockpile.

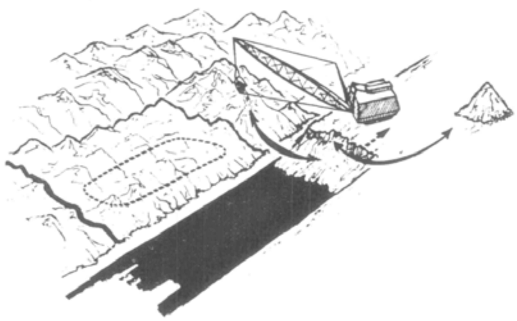
Figure 16.— Technique for selective placement of overburden 14

H



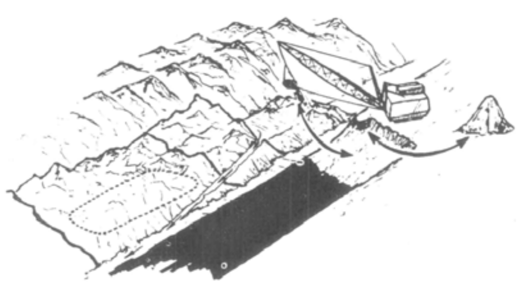
Most of the highwall stockpile was deposited on the basement fill towards the completion of the uncapped study.

I



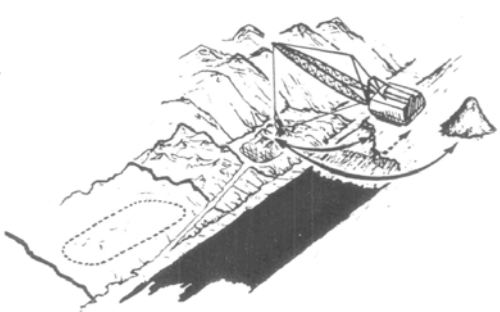
A buffer zone was constructed when the uncapped study was completed. During this phase the surface saline zone was stockpiled on the highwall.

J



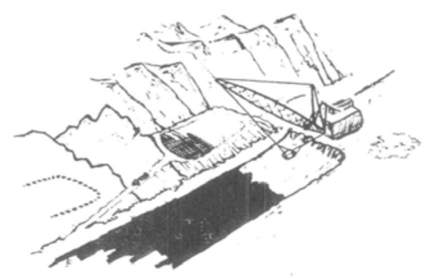
Following construction on the buffer zone, a 15-yd-thick basement fill for the capped research area was deposited in the pit bottom. During this process, the surficial saline zone was stockpiled on the highwall.

K



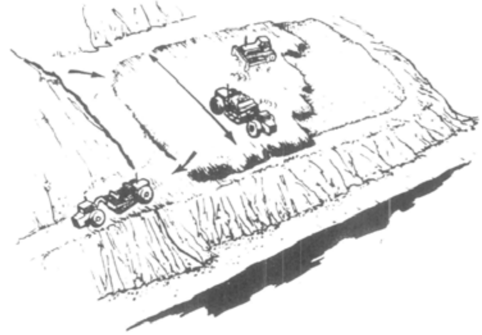
When a portion of the basement bench was completed for the capped study, the dragline deposited saline material over the basement from both the overburden and stockpile.

L



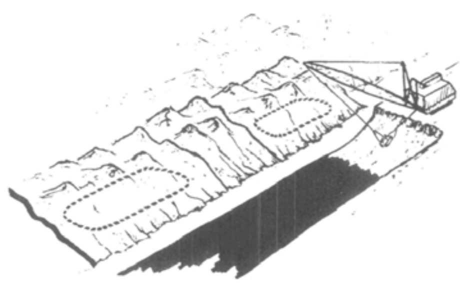
Clay located 110 yards from the demonstration site was applied to a depth of 2-½ ft by scrapers. The dragline had to shut down during this clay-capping operation.

M



Loaded scrapers were used to compact the clay cap. A D-9 dozer shaped the cap to produce an umbrella over the saline material.

N



The uncapped and capped experiments were oriented as shown above at the conclusion of the demonstration.

Conventional mining techniques can incorporate piling methods that keep the spoil piles within acceptable gradients. Smaller equipment like crawler or wheeled-tractors and scrapers are used for any additional work to reduce steep slopes. One common practice is to have a tractor work on a continuous basis right behind the mining equipment. After the spoil material is dumped, the tractor smooths the spoil surface. After the surface is acceptably worked, topsoil is spread over the surface.

Draglines can drag their buckets across the peaks of spoil piles to level them and significantly reduce the required work of the bulldozer. Trucks and scrapers can reduce the final grading and smoothing work required by controlling their dumping pattern.

Overburden Grading

Final overburden grading prepares the spoils for topsoil application. The grading is usually done by bulldozers or scrapers. It can be done continuously during the mining process or as an occasional job whenever necessary. Large mines that move and reclaim large areas of land often have equipment to follow the mining equipment and grade the spoil surface as a major portion of their job (Fig. 17). When scrapers haul overburden they continuously shape spoils with no need to go back to grade the spoils as a special job. At smaller mines, however, there is sometimes too little final grading to occupy a piece of equipment full-time. In this case, it is a part-time duty performed by one or more pieces of equipment when convenient.

Subsurface Spoil Instability.—Since final grading established desirable slopes and aspects for the future use of the site, it is imperative that the grading be

Fjgure 17.—Dozers grading spoils

permanent and stable. Subsurface spoils must be as stable as the surface. Instability in the subsurface spoil materials is exhibited in three major ways: (1) area-wide settling; (2) localized subsidence; and (3) piping.

Area-wide settling is a common and generally unavoidable consequence of surface mining. Fortunately, it seldom causes any serious problem. The post-mining spoil density is always less than the density of the overburden before mining. After the spoil is dumped, it is contoured by bulldozers or scrapers during the final grading process. The density is usually increased during this process, but it is still less than before mining. During the next year to year-and-a-half the graded spoils settle, increasing the density to near pre-mining levels. This settling is wide spread, gradual, and generally a phenomenon of the first year or two after mining (Fig. 18).

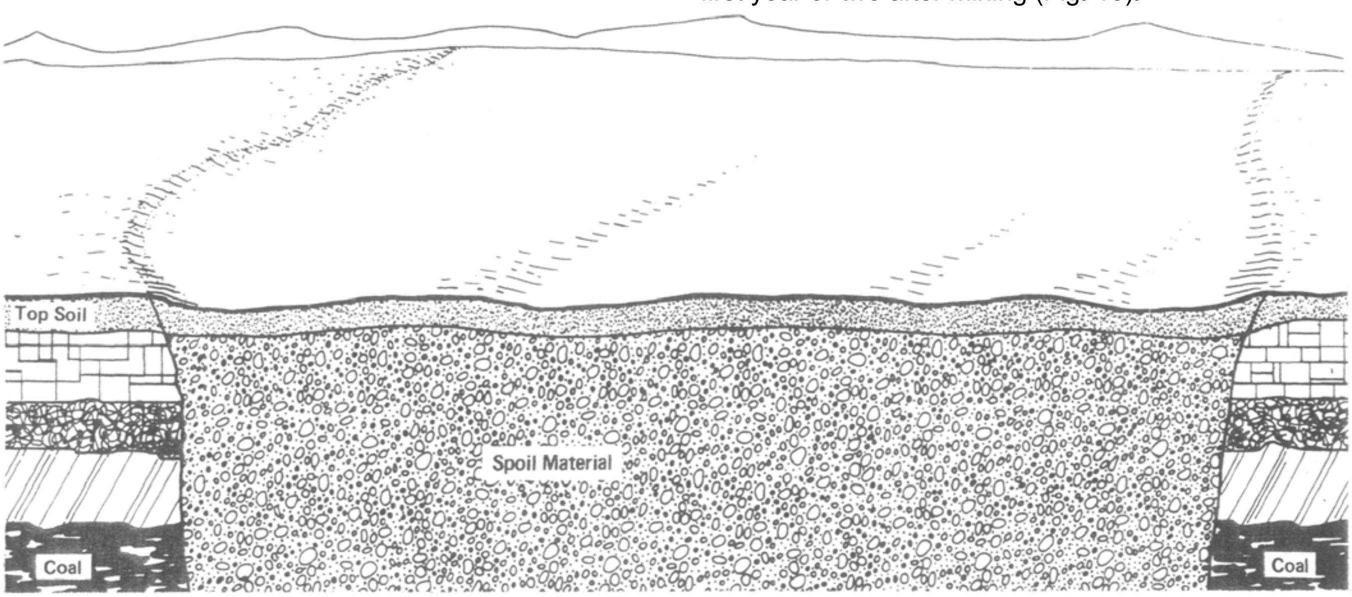


Figure 18.—Area-wide settling

Area-wide settling is influenced by the texture of the spoiled materials, by the types of equipment used to contour the spoils, and by the season the spoils are contoured. Groenewold and Rehn (1980) found that "clayey overburden commonly results in more blocky and, initially, more porous spoils than does sandy overburden." Settling will be greater in areas where fine-textured spoils are dominant than in areas where coarse-textured spoils dominate. Bulldozer-contoured spoils settle significantly more than scraper-contoured spoils. Scrapers, because of their many passes over an area and because of the thin layers of spoil they deposit each time, compact the spoils more than do bulldozers. This increases the density of the contoured spoils and reduces the settling in the spoils. This difference in settling is even more pronounced if contouring is done during winter months when the spoils are frozen. The frozen spoil materials are blocky, leaving more pore space than nonfrozen materials. Scrapers reduce this pore space by compacting and layering the spoils, but bulldozers do not counter this decrease in spoil density.

Areas mined by dragline and graded by bulldozer have inherent characteristics that often produce differential settling. Draglines dump the overburden in spoil piles and bulldozers push material from the center of the piles, using gravity to pull the material down the side slopes. Both operations pack the middle of the piles, with less packing on the pile edges. Densities of overburden vary with distance from the center of the spoil pile, causing differential settling after spoil grading (Power and others, 1978).

Localized subsidence is prevalent during the first 2 years after contouring. The subsidence areas are usually elliptical with a maximum length of 50 feet and a maximum depth of 10 feet (Fig. 19). They appear to be largely due to equipment type and seasonal conditions. Groenewold and Rehn's (1980) study found that subsidence developed only where dozers contoured frozen spoils in valley areas between heaps of spoil materials. Blocks of frozen material were concentrated in these lower areas. As these blocks settled and thawed, they caused the subsidence instability. These subsidence areas have potentially severe consequences due to the abrupt edges of the subsidence areas and the potential erosion and runoff problems inherent on steep slopes and cuts in valley bottoms.

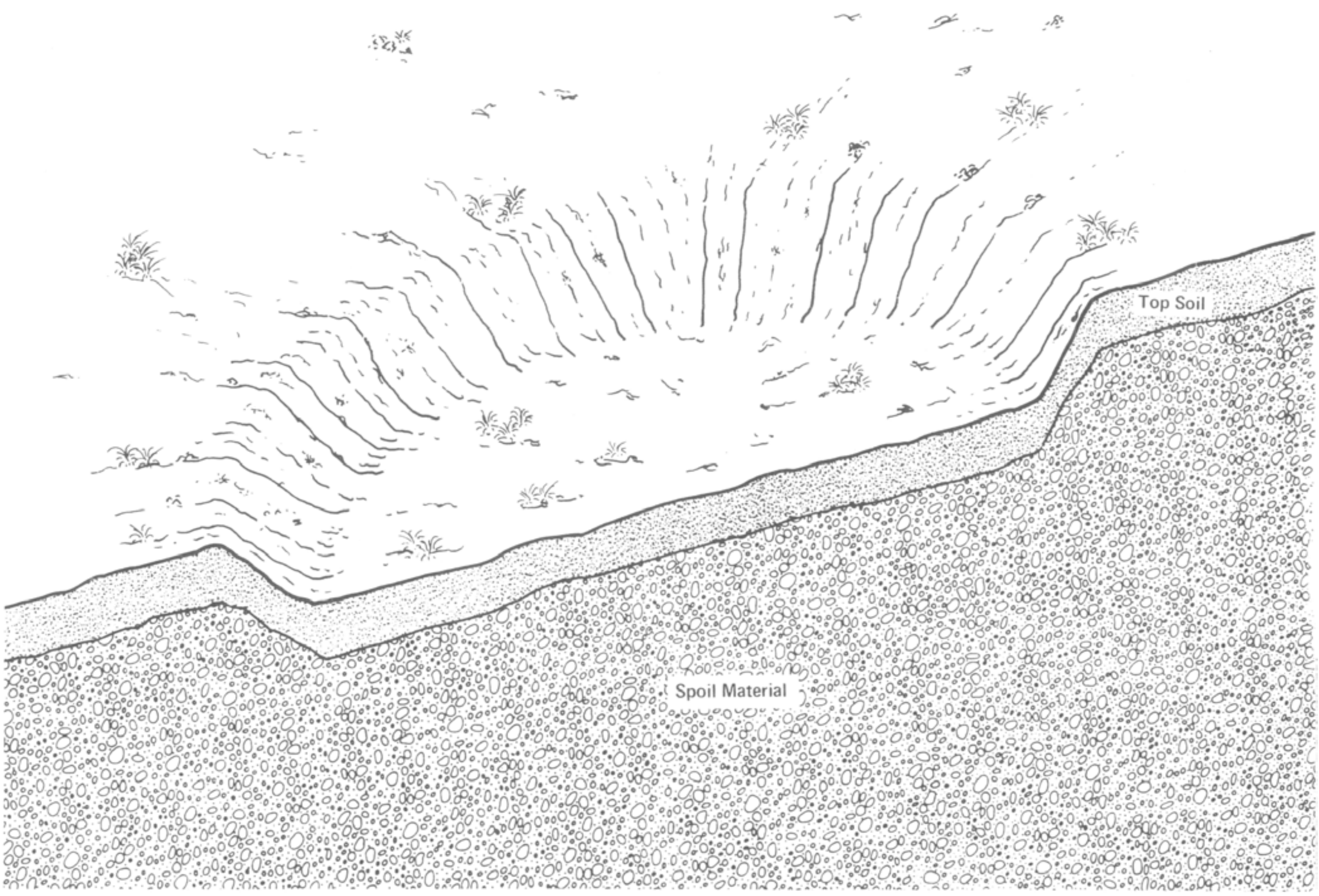


Figure 19.—Localized subsidence

Localized subsidence can be virtually eliminated by using scrapers to contour spoils or by using dozers only when the spoils are not frozen. Scraper contouring during the winter months did not result in any subsidence problems (Groenewold and Rehn, 1980).

Piping may start and show up in the first year or two after mining, or may not appear for several years after apparently successful reclamation. It is a severe and long-term problem on some sites.

Piping begins when the surface of the spoil cracks or when cracks develop on the boundary between contoured spoils and the subsequently spread topsoil. Runoff funnels into the crack, enlarging the "pipe" and carrying away topsoil and spoil materials. Piping fissures can be as large as 10 feet in diameter, but are generally 2 to 3 feet in diameter (Fig. 20).

Piping requires a crack, either in the soil surface or at the spoil/topsoil interface, and a conduit through the subsurface spoils through which water can move. The crack is almost invariably caused by highly dispersive sodic soils. The conduit for water movement is usually caused by differential settling of subsurface spoil materials. This settling difference can be between areas that have been compacted differently or can be within poorly compacted areas. Groenewold and Rehn (1980) found piping along a boundary between a scraper-contoured area that was very stable and a dozer-contoured area that was less stable. They stated that piping within a dozer-contoured area was due to relatively low compaction in parts of the area. The reduced compaction means excess pore space in the spoils, small scale settling, and fracturing. Any differential settling or fracturing can produce a conduit for piping. Most piping in Groenewold and Rehn's study was on nearly level surfaces. Piping seldom begins in areas where runoff is rapid.

Piping can be substantially reduced by keeping spoil piles steeply sloped, thoroughly compacting the spoil, or placing dispersive sodic spoil material far enough below the surface of the spoil that it will not be wetted enough to cause dispersion. Since both steep slopes and densely compacted spoil materials can cause other problems in soil stability and plant establishment and production, placing sodic materials away from the spoil surface is the best way to prevent piping. Groenewold and Rehn (1980) state that selective handling of highly sodic overburden "may prove to be the only means of controlling piping in many settings of the Nothern Great Plains."

Attempts to control piping by filling the cracks with topsoil or other spoiled materials have not been successful. The materials are generally carried away as the pipe continues to develop. The most reasonable method of controlling piping is to prevent it from starting. Sodic soils should be located in the overburden before mining and then carefully placed in the spoil pile, away from areas where they can cause harm.

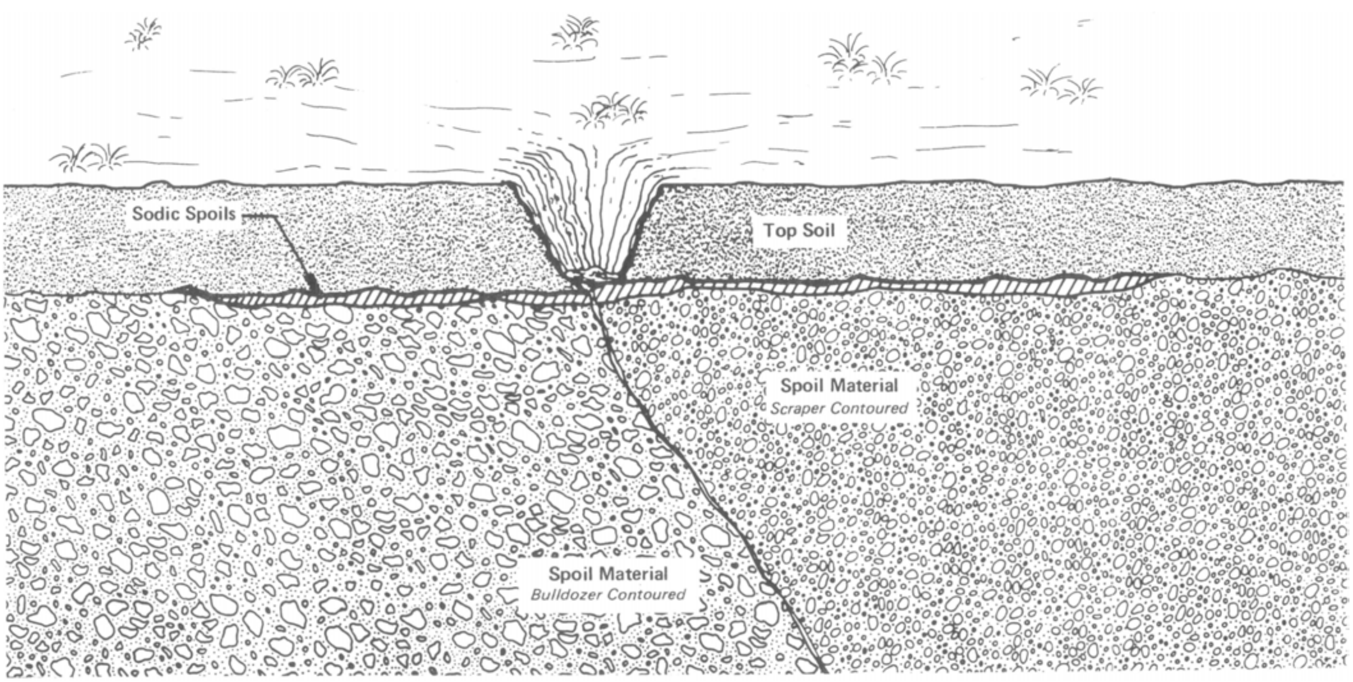


Figure 20.—Piping

Soil Compaction. — During the mining operation, spoiled overburden materials are dumped using methods that almost invariably decrease the density of the materials. This reduction of density is in large part responsible for much of the subsurface spoil instability. However, during handling and grading operations designed to smooth the spoil surface and establish the final topography of the spoils, the top several meters of the spoil material are often compacted by repeated passes over the spoils with bulldozers and scrapers. The compaction reduces water infiltration and percolation rates, reduces soil moisture holding capacity, and reduces plant root penetration rates and depths. These problems seriously inhibit successful reclamation in the West.

Applying topsoil over compacted soils is one possible remedy. However the topsoil necessary to totally mitigate the effects of compaction is seldom available. Even when adequate top-soil is available, spreading it over the graded spoils may compact the topsoil itself. To reduce this compaction or the compaction of the spoil materials, many operations use rippers or plows.

Rippers (Fig. 21) are large shanks attached to a tool bar or special hitch on a tractor, scraper, or other prime mover. The shank is pushed into the ground and then pulled along by the prime mover. It rips a furrow that breaks up compaction to improve water infiltration and root penetration. Hydraulic cylinders raise and lower the ripper shank, controlling the depth of the furrow. On some rippers the angle of the shank is manipulated by hydraulic cylinders. Rippers can penetrate 7 feet into the spoil; at least one massive ripper will rip as deep as 14 feet.

Compacted spoils materials can usually be ripped using relatively small prime movers and relatively lightweight rippers, since the materials has recently been broken and moved during the mining operation.

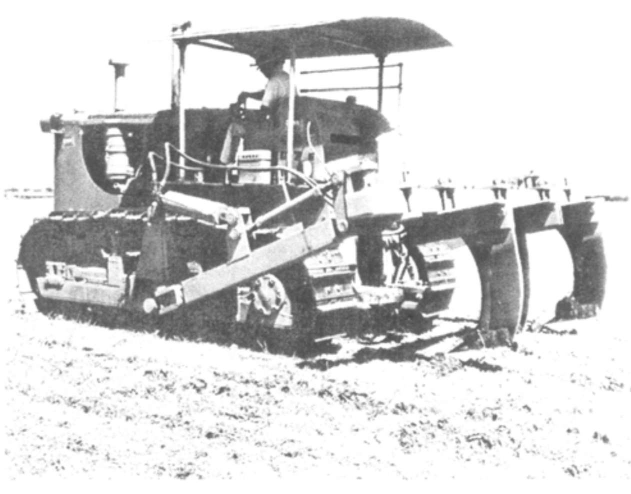


Figure 21.—Ripper

The major obstacle to breaking up compaction in large rocks. Multi-shanked rippers are sometimes used to increase production rates. Large rocks can hinder multi-shanked rippers; the rocks would be pushed around a single shank.

The condition of the soil before it is ripped, the availability of ripping equipment, and the amount of seedbed conditioning to be done after ripping will determine the size and type of ripper needed. Special circumstances like heavy, wet, clay spoils that have become severely compacted will require special ripping efforts to successfully alleviate the compaction. Successively less difficult conditions will lower the demand for heavy-duty equipment, will increase production rates, and will make the entire ripping operation easier. Ripping does not leave an adequate seedbed. Large clods or chunks of soil and rocks are pulled to the surface and must be worked with chisel plows or disk plows before seeding can begin.

Topsoil Handling

Handling topsoil is important from both a legal and ecological viewpoint. Topsoil is the original relatively dark-colored, upper soil horizon (Fig. 22) that ranges from a fraction of an inch to 2 or 3 feet thick, depending on the kind and condition of the soil. The majority of the organic matter in the soil profile is concentrated in the topsoil. Topsoil is generally considered to be the A horizon of the soil profile (USDA Forest Service, 1979a). From a reclamation sense, topsoil can be defined as soil material that can serve as a plant growth medium without continued additions of soil amendments, such as fertilizer or artificial irrigation (Cook, 1976). The Office of Surface Mining (OSM) defines topsoil as the A horizon or the upper 6 inches (15 cm) of the soil that federal law requires be salvaged. Subsoil is material from the B and C horizons, which may be required to be salvaged if it increases soil productivity. In this report, the OSM definitions will be used. Selected overburden is material from below the root zone that can be substituted for topsoil or subsoil when it is equal or superior in quality (Schaefer, 1980; Federal Register, 1979). Overburden quality is based on results of chemical and physical analysis of the overburden and the topsoil for which it is to be substituted. OSM regulators make the determination.

OSM regulations require that: (1) All topsoil be removed from the area to be mined in an operation separate from removing other overburden materials, unless a topsoil substitute has been approved; (2) if the topsoil iis less than 6 inches (15 cm) thick and no topsoil substitute has been approved, ail the soil down to 6 inches (15 cm) will be removed in a separate operation and handled as topsoil; and (3) the B horizon and portions of the C horizon, or other underlying materials, may be required to be handled as topsoil if OSM determines that the materials ensure desired soil productivity. In the West, the A horizon is usually thin, so the B and C horizons are commonly used as topsoil. If selected overburden materials are approved as substitutes for topsoil, they must be handled as topsoil.

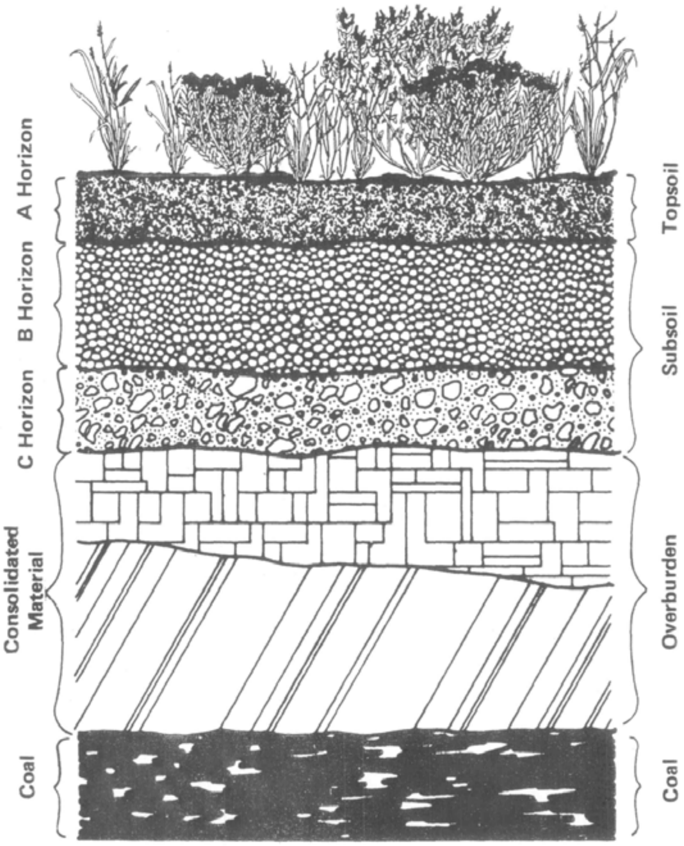


Figure 22.—Soil profile

After removing the topsoil, the mine operator must immediately place the topsoil on previously graded spoils or stockpile the topsoil for later use. The topsoil may be stockpiled only when it is impractical to immediately spread it on regraded areas. When stockpiled, topsoil must be protected from wind, water, compaction, and contaminants that reduce its productive capability. The protection must be achieved using a vegetative cover of quick-growing nonnoxious plants or by another approved method. Stockpiling topsoil decreases organic matter content, disrupts nutrient cycles, increases bulk density, upsets the carbon-nitrogen ratio, and negatively affects the mycorrhizal response in the stored materials (Schaefer, 1980; Argonne National Laboratory, 1979; LaFevers, 1977; Curry, 1975). However, freshly spread topsoil is easily eroded and must be protected. If the topsoil cannot be stabilized by vegetation or other means soon after it is spread, short-term stockpiling may be a preferable alternative.

Federal regulations require that spoils be scarified or otherwise treated to eliminate smooth surfaces between the spoils and the topsoil and to allow roots to penetrate the spoils and the topsoil and to allow roots to penetrate the spoils. The treatment must be done before spreading the topsoil unless the mine operator demonstrates that no harm will be done to the topsoil or vegetation by scarifying the area after topsoiling. The topsoil must be spread until it is of a uniform, stable thickness appropriate for the post-mining land uses, contours, and surface water drainage system. Excess compaction of the topsoil must be eliminated and topsoil must be protected from erosion before and after it is seeded and planted (Federal Register, 1979).

Topsoil Loading

Bulldozers and scrapers are the most common equipment used for handling topsoil. Scrapers are superior in both removing and replacing topsoil. Pan scrapers are used in rocky areas and either pan or elevating scrapers are used where the topsoil material is relatively smooth and rock-free. The overall mining operation, the availability of bulldozers to assist in loading, the material to be loaded, and other uses of the scrapers will all be considered when determining the type of scraper to use for reclamation.

Scrapers can load topsoil down to a precise depth, can load from several areas in a single cycle, and can unload in a stockpile or directly on graded spoils at a prescribed depth. This flexibility increases the handling possibilities, and allows the operator to vary how the topsoil is handled according to reclamation needs. Bulldozers are less adaptable, especially since their economic efficiency decreases rapidly as the distance the topsoil must be moved increases. Bulldozers are most likely to be used in piling stockpiled topsoil. Endloaders and trucks are efficient only when topsoil is very deep. Draglines and power shovels are not precise enough to segregate the thin layers of topsoil usually encountered in the West.

Topsoil Storage

When mining and reclamation conditions warrant, topsoil is collected at one time and stockpiled to be used at a later time. The topsoil must be stored for several weeks or months. At some mines, topsoil for the initial mine cut is stockpiled for the life of the mine pit, then spread on the final spoils when the pit is closed down. Years, even decades, may pass while the topsoil is stockpiled. The topsoil being collected during normal mine operation will be spread immediately or stockpiled for up to several years.

Topsoil and subsoil may be kept in separate piles, then redistributed in sequence over grade spoils. This keeps the basic horizons of the soil after mining similar to those before mining and increases the productivity of soils where the topsoil is thin. Plants have the opportunity to extend their roots into the distinct subsoil layer, which is usually more desirable than the overburden under the subsoil. The chance that sodic overburden materials will migrate into the topsoil is reduced when the subsoil layer separates the topsoil and any sodic spoils. By stockpiling the topsoil and subsoil separately, the topsoil is kept as concentrated as possible, yet the advantages of using the subsoil are not lost. Power and others (1978) found that applying topsoil and subsoil in two separate layers was superior to mixing the materials.

Topsoil stockpiles built by scrapers are usually elongated piles often several meters deep. As they are piled, the materials are compacted by the repeated passes of scrapers. Too much moisture results in too much compaction; sometimes the materials will become almost cemented. The soil texture also contributes to compaction. Clay soils will compact readily when moist. When the topsoil is very dry or sandy, compaction is less serious; however, stabilization may be more difficult.

Topsoil stockpiles must be protected from wind and water erosion. Stabilizing the piles will not only protect them from physical degradation, but will reduce their chemical and biological decline. Stockpiles topsoil degrades both chemically and biologically as a plant growth medium. By establishing vegetative cover on the piles, the surfaces are kept biologically active. Establishing quick-growing annual or perennial species will provide the stability and protection needed for the stockpiles.

Stockpiles to be kept for short periods will usually be seeded to annuals. Long-term storage will require long-term stabilization, which is best provided by perennial plants. Seeding a mixture of annuals and perennials to get both quick establishment and long-term stability is a reasonable choice for stockpiles to be kept for long periods.

When seeding stockpiles, species compatible with the ultimate use of the topsoil must be used. Using undesirable species for reclamation is counterproductive, even if the species are excellent for stabilizing stockpiles. When stockpiling topsoil for areas dominated by undesirable species, a vegetative cover must be established that will reduce the noxious or weedy species natural on the redistributed topsoil. Since most pioneer species are not desired in the final reclamation project, and since they will vigorously invade the topsoil piles, a vegetative stand that excludes or inhibits them is beneficial. A further advantage of a good vegetative stand on the stockpiled topsoil is the organic matter and seed source provided. The dead vegetative material each year increases the quality of the soil. When species to be seeded on the reclaimed spoils are used to stabilize the stockpiles, viable, ungerminated seeds produced by plants grown on the stockpile will provide an additional seed source for the reclaimed spoils.

Even though the microoganisms in stockpiled topsoil become relatively inactive when the topsoil is stored, microbial activity increases rapidly after the topsoil is spread (Hodder, 1976). Other studies have shown that long-term storage of topsoil may increase the nutrient levels in the buried topsoil (Land, 1976). A possible explanation is that the organic matter decomposes while it is buried, but is not used because it is beneath plant rooting zones. When the topsoil is spread, there is a flush of nutrients available for plant use. This is not necessarily desirable, however. Even though the increased nutrient levels will increase microbial activity and potential productivity in the topsoil, weedy and pioneer species are able to take advantage of the nutrients as much as desirable species. Many undesirable species are well adapted to invading and occupying the redistributed topsoil. The flush of nutrients can increase the density of the undesirable species and make establishing desirable species difficult. Moreover, species adapted to the extra nutrients can become established on the site. When the extra nutrients are expended, species not adapted to the normal, lower level of nutrients will lose vigor or die. At this time, weedy pioneer species will have a new opportunity to invade the site.

Spreading Topsoil

Spreading topsoil is usually done with scrapers whether the topsoil is stockpiled for a time or spread immediately after it is loaded. After the topsoil is spread, bulldozers shape and grade the topsoil to meet reclamation requirements.

Conventional bulldozers commonly smooth the spoil or top-soil surface. A grading bar attached to the dozer blade increases the efficiency of the dozer work. A grading bar (Fig. 23) can improve bulldozer efficiency by increasing the area that can be smoothed in a given time (Davis, 1978). The grading bar also reduces the compaction, cost, and time involved in final spreading. When leveled with the grading bar, the reclaimed land is easily worked with conventional farm equipment (Brown, 1977).

Office of Surface Mining regulations require scarifying the overburden surface, either before the topsoil is spread, or, if there are no adverse effects, after the topsoil is spread. Many kinds of equipment can accomplish scarification, from massive rippers to small farm equipment. This equipment works the same whether used before or after the topsoil is spread. In the process of scarifying the soil, furrows, pits, basins, or patterns of indentations can be made.

Figure 23.—Grading bar

III. Seedbed Preparation

The revegetation process begins after the overburden is replaced, the spoils are shaped and graded, and topsoil is spread and smoothed. The first revegetation task is to prepare the newly spread soil for seeding and planting. This preparation often consists of physical, biological, and chemical treatments.

Seedbed preparation is vital to reclamation success. Soil must provide moisture, nutrients, shelter, and spade for plant establishment and growth. To provide these ingredients, soils must absorb and hold moisture when it is provided, must have nutrients available in forms usable by the plants on the site, must have adequate microsites to protect seedlings from the vagaries of western weather, must allow sufficient root penetration to firmly anchor the plants and provide access to nutrients and moisture, and must free the desired species from stifling competition from weedy species. The soil must be open enough to soak up precipitation, firm enough to protect plants until the seedlings are established, and loose enough to allow root penetration.

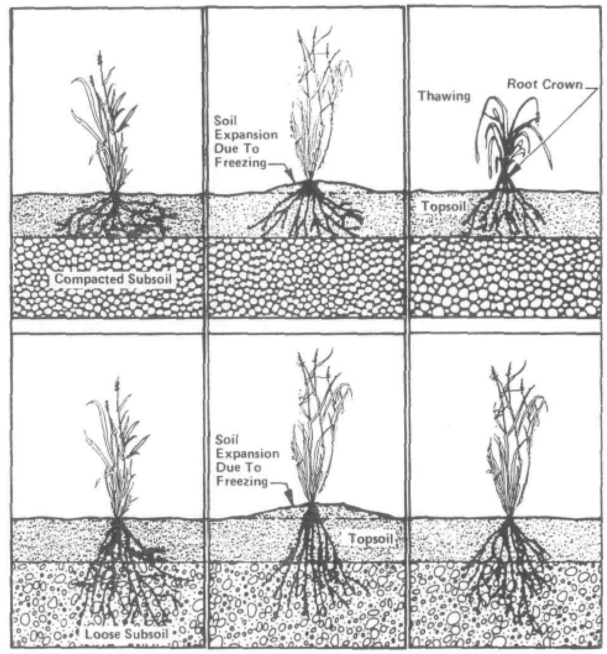


Figure 24.—Effects of frost heaving

Seedbed Conditioning

Seedbed conditioning provides important benefits for plant germination, establishment, and long-term vitality. Seedbed conditioning can loosen compacted soils, provide catchments to increase water available to plants, create microsites that shelter seeds and seedlings, and remove competing vegetation.

Compaction must be alleviated because it reduces infiltration of precipitation, inhibits the percolation of water that does infiltrate, prevents root penetration, and contributes to concentrations of salts above the compaction zone. Compaction under the topsoil can cause problems even if the topsoil is loose. Plants that root in the loose topsoil, but cannot penetrate the subsoil or overburden under the topsoil, can be subject to soil-induced moisture or physical stress. If the roots cannot penetrate to where the deep moisture is held, plants will be limited to the moisture in the topsoil. In the hot, dry, windy areas of the West, the amount of moisture held in this layer is small and short-lived. This will limit the plants that can survive in these areas to shallow-rooted opportunist species. The deeper-rooted, slower-growing plants that stabilize a site will have difficulty getting established and being competitive. The shallow-rooted species will be subjected to physical stress due to frost-heaving in many of the areas of the West. Since their root systems are not able to penetrate deeply into the soil, they will be vulnerable to ejection from the soil by freezing and thawing (Fig. 24).

The seedbed should be conditioned to collect, absorb, and hold as much moisture as possible. By reducing compaction, infiltration rates are increased and the amount of precipitation lost as runoff is reduced. Even so, the intensity of rainfall in the West, the soil conditions encountered, and the slopes of graded spoils all combine to cause some runoff. Seedbed treatments that catch some of this runoff increase overall moisture available for vegetation. Methods to catch runoff include basins and pits that hold pools of water, contour furrows that slow the runoff and allow it to infiltrate the soil, and windrows of mulch to slow and hold water.

Equipment for seedbed conditioning ranges from rippers (described on page 19) to conventional chisel plows to specialized sidehill pitters to bulldozer blades. Each has its own advantages. Methods can be combined to provide desired reclamation results.

Plows

One-Way Disk Plows. — One-way disk plows (Fig. 25), a single row of circular or serrated disk blades mounted on a common frame, are designed for deep plowing. The plowing depth can be adjusted hydraulically to a depth of 30 inches to allow the use of one-way disks to loosen and scarify the topsoil as well as the top portion of the overburden, since most western mines do not have 30 inches of topsoil to spread on their graded spoils. The effect is to improve water infiltration and percolation rates and water holding capacities in the spoils material.

Root penetration into the spoil material allows deep- and medium-rooting plants to establish themselves on the site.

This in turn increases the diversity and stability of the vegetation and meets not only legal but ecological criterion for reclamation success.

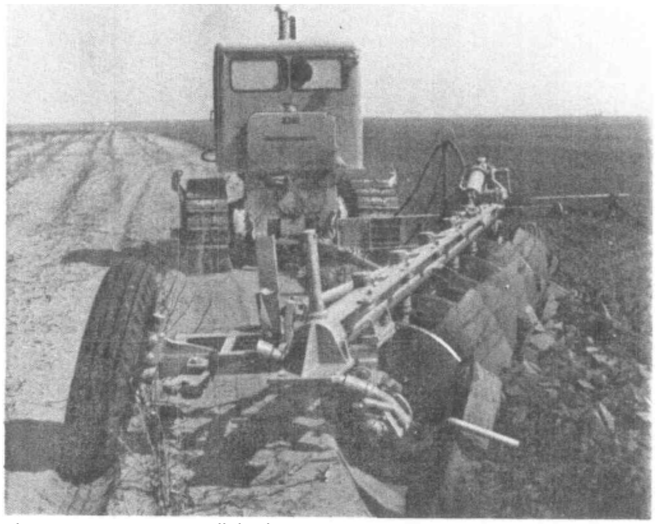


Figure 25.—One-way disk plow

Pitting Disk Plows.—These plows (Fig. 26) are essentially one-way disk plows with the standard disks replaced by cutoff disks. The disks only contact the ground during part of each revolution, leaving alternate strips of plowed and undisturbed ground. The long, narrow pits catch broadcast seed and accumulate rain and snow. The increased availability of water in and around the pits stimulates plant growth and helps establish seedlings. Furrows created this way are not long-lasting. This treatment is appropriate for broadcast seeding but not drill seeding.

Off-Set Disk Plows-Offset plows (Fig. 27) have two rows of serrated or circular disk blades. Each row is on a separate frame and axle; the frames are set at an angle to each other. When pulled through the soil, the first row of disks turns the soil one way, the second row turns it the other, which gives a double disking action. If topsoil on the spoils has been invaded by weeds, the plow is an excellent mechanical means of getting rid of the weeds. In many cases the multiple disking action is not required. Off-set disks are designed mainly to eliminate undesired vegetation, which is not often a problem on newly topsoiled spoils.

Off-set disks break up surface compaction caused by bulldozers or scrapers. They are limited to approximately 16 inches of penetration and do not break compaction in subsurface materials. They are heavy-duty equipment suitable for dry and broken surfaces. The disks leave a well-broken, easily seeded soil surface.

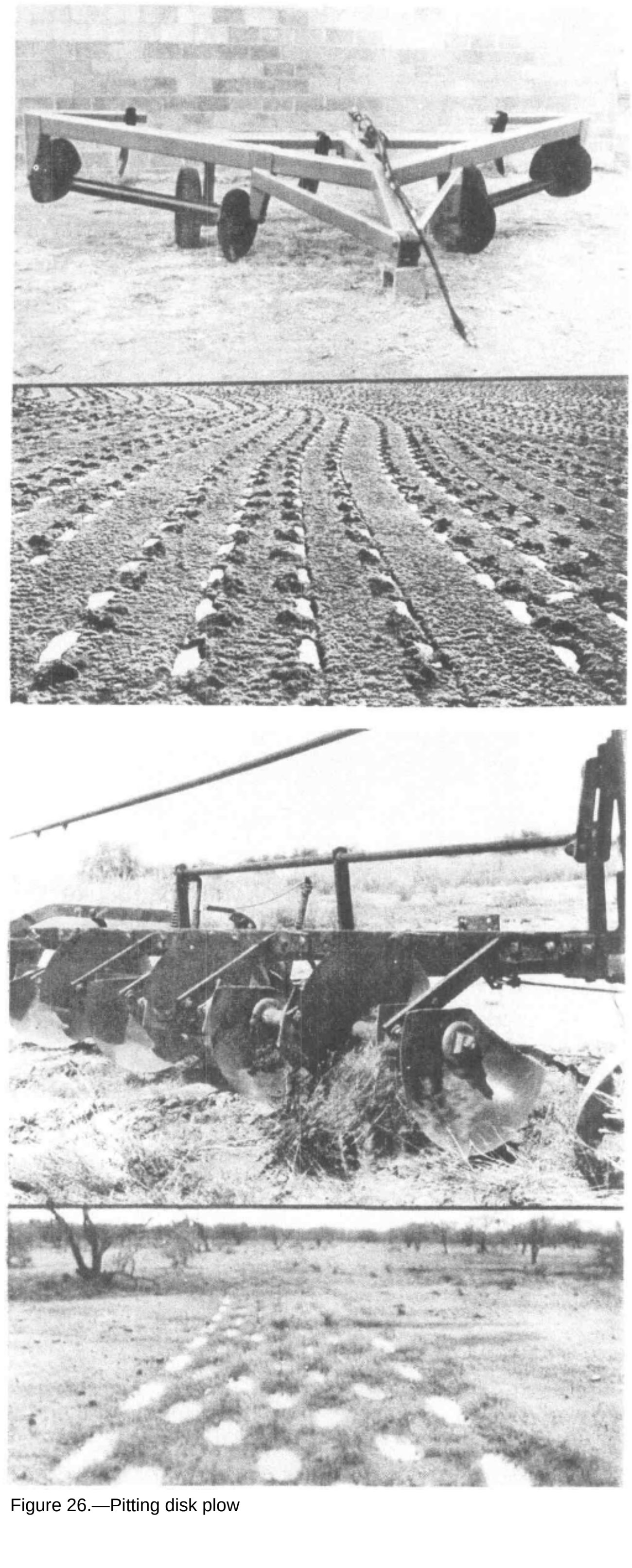


Figure 26.—Pitting disk plow

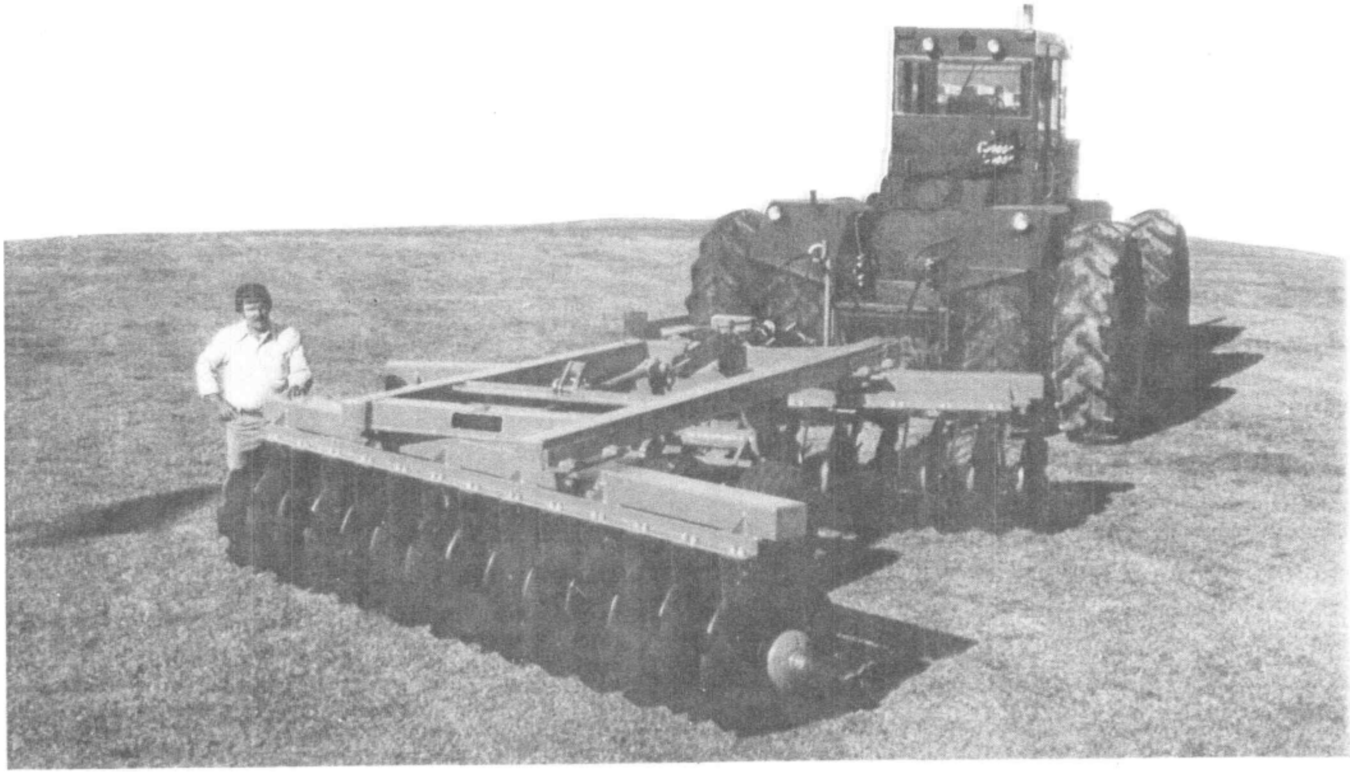


Figure 27.—Offset disk plow

Chisel Plows.— These plows (Fig. 28) have curved shanks mounted on frame members or toolbars with spring-loaded clamps. The plows are pulled through the soil, scarifying and opening the ground. The spring-loaded clamps allow individual shanks to clear obstacles independently. Shank penetration into the soil is controlled hydraulically. Chisel plows are limited to depths of 12 inches. This is not sufficient to reduce compaction in overburden at most mines. When the overburden is sufficiently loose before the topsoil is spread, however, chisel plows are often adequate to break up topsoil compaction.

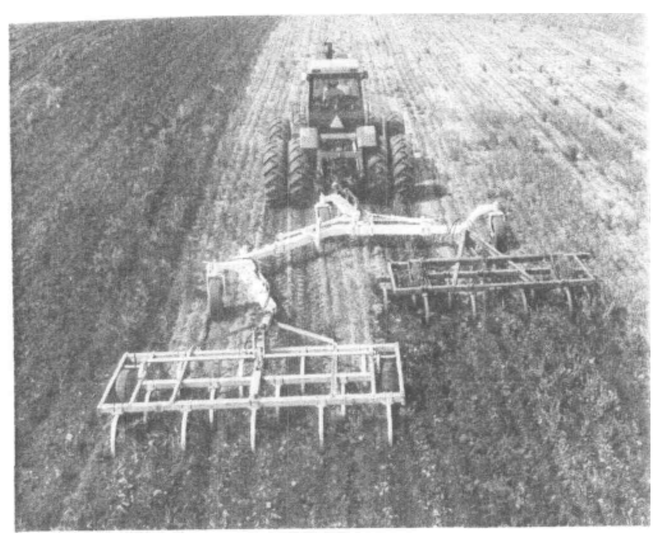


Figure 28— Chisel plow

Chisel plows leave an excellent seedbed. The bed is smooth enough to accommodate drill seeders pulled by conventional farm tractors and is irregular enough to catch and trap broadcast seeds. The small furrows formed by the chisels not only catch seed but trap moisture and reduce runoff and erosion. To maximize the water-trapping benefits, chisel plowing should be done along slope contours. The furrows are shortlived, however, and should not be relied on for long-term erosion control, nor for erosion protection from severe storms. Their benefits are most applicable to quickly establishing seedlings the same year chisel plowing is done.

All plows are limited by rocky conditions. Offset disks and one-way disks are subject to excessive breakage in rocky soils. Stony and rocky soils, especially those composed mainly of sandstone or other abrasive rocks, rapidly wear the points on chisel plows. Even though spring loaded, the chisel shanks can pull up rocks large enough to interfere with other types of reclamation and farm equipment.

Subsoilers.—Subsoilers (Fig. 29) are small ripper-type shanks mounted on a toolbar or frame. The shanks are solidly mounted rippers designed for breaking medium depth compaction rather than for final seedbed preparation. They are light enough to be pulled by conventional farm equipment, yet are strong enough to break up relatively compacted soil. They penetrate to 30 inches and can break compaction in topsoil and some overburden concurrently. Subsoilers should be pulled along the contour of the graded spoils to reduce the erosion caused by their furrow. The loosened soils and the relatively persistent furrows increase percolation and water-holding capacity in the treated soils. The seedbed is usually adequate for broadcast seeding. Subsoilers are not as susceptible to breakage as are plows.

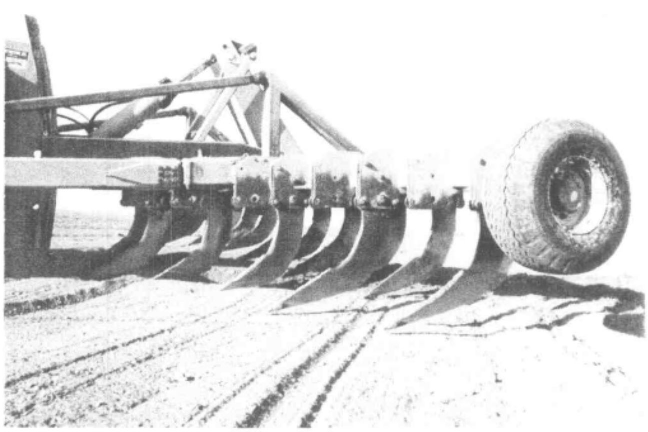


Figure 29.—Subsoiler

Land Imprinter

The land imprinter is a custom-made tool that creates a series of small pits or furrows when pulled over the soil. The imprinter (Fig. 30) is two hollow metal cylinders mounted on a single axle. A toolbar attaches the axle to a tractor that pulls the imprinter across the area to be treated. Blades, ridges, or other protrusions (Fig. 31) are welded to the outer surface of each cylinder to create a geometric pattern in the soil surface. The cylinders are interchangeable; any combination of imprint patterns can be achieved by varying the cylinders. Hollow cylinders can be filled with water to increase weight.

The land imprinter is most often used with a broadcast seeder to spread seed on the imprinted land and a drag chain behind the imprinter to cover the seed with soil.

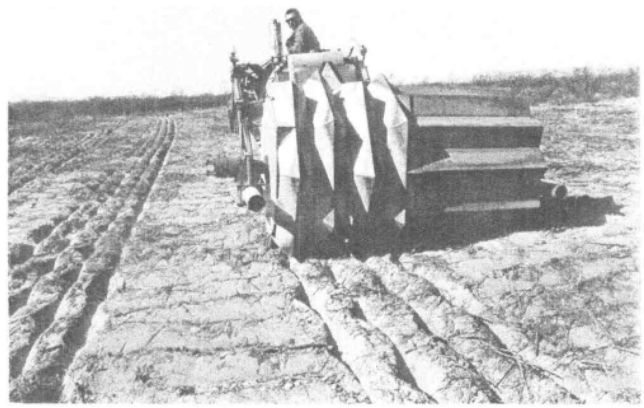


Figure 30.—Land imprinter

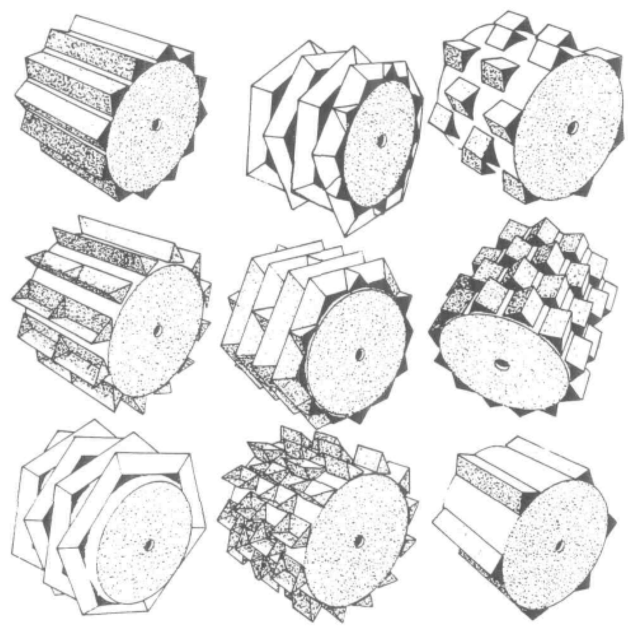


Figure 31.—Land imprinter patterns

Land imprinters produce closed furrows, small pits or depressions, or continuous furrows. The resulting patterns can penetrate as deep as 6 inches into the soil. Microsites created by the protrusions catch the seed, and then concentrate water to improve seed germination and seedling establishment. The imprinter is designed to crush brush and herbaceous vegetation as it prepares a seedbed. Because of this, it is a rugged implement, capable of working well on rocky, rough, and vegetated spoils. The imprinter will not reduce compaction; it firms the seedbed.

Contour Furrower

The contour furrower breaks up compaction to depths of 12 inches, builds furrows with intermittent dams, and broadcast seeds, all in a single pass. It has two subsoilers, two disk blades that create the furrows, two automatically tripped paddle-wheels that build the dams, and a grain box seeder (Fig. 32). The furrower is 8 feet wide and 18 feet long. It can be used on slopes up to 20 percent, but is most effective on slopes less than 10 percent. The depth that the subsoilers penetrate, the width and depth of the furrows, the spacing of the dams, and the seeding rate can all be varied.

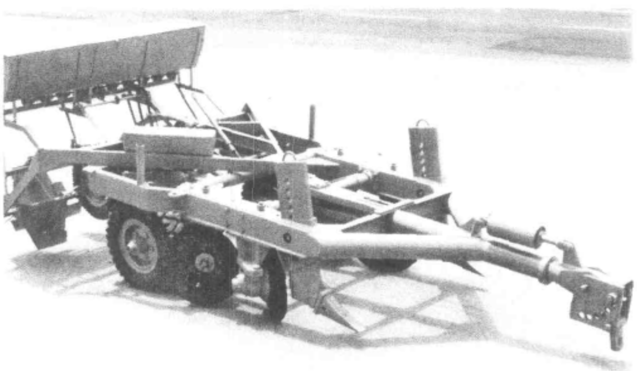


Figure 32.—Contour furrower

The contour furrower increases percolation and water-holding capacity of compacted soils, collects and holds runoff in its furrows, and seeds the treated area. All these operations are performed in a single pass over the area. The furrower is quite narrow, however, which increases the time required to work an area. It is not suitable for use on rocky soils because the disks may break. Furrows created are not long-lasting in the weather extremes found on most western sites.

Gouger

The gouger (Fig. 33) is an implement specially designed to create depressions in the surface of the seedbed. It has four or five semicircular steel blades, each with two scarifying teeth along the bottom edge. As the gouger is pulled along the surface of the spoils, a hydraulic mechanism automatically raises and lowers the frame. When the frame is lowered, the blades scoop out depressions. Automatic cycling controls the spacing of the depressions. The depressions range from 15 to 22 inches wide, from 3 to 4 feet long, and 6 to 10 inches deep. All the blades can be mounted on the rear member of the gouger frame, or to produce offset depressions, two blades are mounted on the center frame member and three are mounted on the rear member.

The gouger makes relatively long, deep depressions. The depressions catch and hold snow and runoff, protect seeds and seedlings from wind and sun, increase available moisture, and improve infiltration rates. The scarifying teeth leave the bottom of the depressions rough so there are numerous sites for broadcast seeds to be covered and protected. Seeds and seedlings in the depressions are protected from wind, often a critical factor at western mines. The depressions provide partial protection from the sun. They hold snow that would otherwise blow off. Snow melting during warm periods throughout the winter provides added moisture. Runoff from snowmelt and rainfall collects in the depressions, where it has time to infiltrate.

The gouger is limited to slopes of 20 percent or less and should be used along the contour slopes. If the water-holding capacity of the depressions is greatly exceeded, overflow sometimes erodes channels that connect the depressions (Jensen and Hodder, 1979a). This is more important as the slope gradient increases. The overflow carries sediment that erodes the areas between depressions and fills the depressions. The gouger does not reduce compaction and should be used after compaction has been broken.

Figure 33.—Gouger

Basin Blade

The basin blade (Fig. 34) is a reclamation implement specially designed for making depressions on 10- to 45-percent slopes. It is a large, crescent-shaped, heavy steel blade mounted on the rear of a crawler tractor. It is mounted on a ripper shank and is hydraulically raised, lowered, and tilted. Several teeth are mounted along the bottom of the blade to scarify the interior of the basin. Chains stabilize the soil on the edges of the basin and round off ridges formed by soil flow. A tractor carries the blade along the contour of the slope to be treated and the operator hydraulically raises and lowers the blade to create the depressions. The basins are usually 15 feet long, 7 feet wide, and $1^1/_2$ to 2 feet deep. The rows of basins are generally about 4 feet apart and should be offset (Fig. 35).

Figure 34.—Basin blade

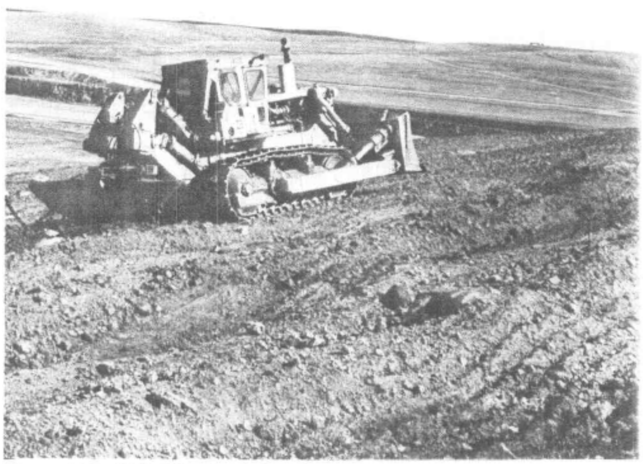


Figure 35.—Offset basins being dug by the basin blade

The depressions create a terrace-like effect on slopes. They collect runoff and snow, providing increased opportunities for the moisture to infiltrate the soil. The seedbed is adequately prepared for broadcast seeding. The scarifying teeth provide microsites to catch and protect seed until it germinates and seedlings are established. The seedbed is too rough for using conventional drill-seeding equipment.

The basin blade is not designed for level surfaces. If the basins break, the erosion can be severe due to the amount of water the basins hold and the slope on which the basins are created. Seeds on the upwind side of the basins are sometimes inundated by wind-blow soil. The moisture stored by the basins may be stored too deeply to be efficiently used by some plants. The depth of the basins requires deep topsoil or subsoil on the spoils or the bottom of the basins will be in overburden material.

Klodbuster

The Klodbuster conditions seedbeds on slopes greater than 20 percent without putting a prime-mover on the slope. The Klodbuster is a chain with 6-inch long hardened steel bars welded to the chain links at 8-inch intervals. The chain is attached to a slope wheel and a 500-pound weight on the downhill end and to a chain attached to the prime mover on the uphill end (Fig. 36).

The chain with the steel bars, called the pick chain, is 40 feet long. To work slopes longer than 40 feet, extra lengths of lead chain are used. The prime mover pulls the Klodbuster along the contour of the slope to be prepared. The slope wheel and weight keep the chain drawn out downhill. As the Klodbuster is dragged across the slope, the steel bars on the pick chain break the soil surface, level humps, and fill small rills caused by erosion. Long slopes are worked from the top down to eliminate ruts caused by the slope wheel. Two to four passes usually give the desired uniform surface texture. Water infiltration is improved, microsites to catch and protect seeds are created, and the seedbed is well prepared for broadcast seeding.

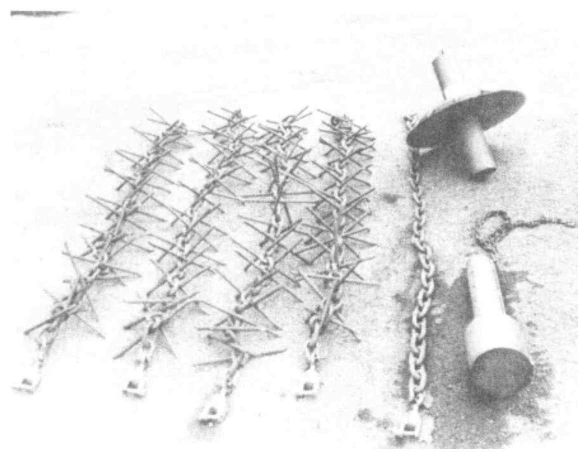


Figure 36.—Disassembled klodbuster

The Klodbuster is not effective on rocky or compacted soils. The slopes must be free of stumps, large rocks, or other obstructions to prevent undue strain on the swivels connecting the pieces of the Klodbuster. The Klodbuster exerts considerable drag on the prime mover but requires no special hookup or power-take-off to run it.

Cultipacker

Cultipackers (Fig. 37) are toothed rings or truck tires on a horizontal shaft. Standard cultipackers have rings or tires attached to each other, producing a smooth surface. Others have individually suspended rings or tires that roll independent of the other rings or tires. These cultipackers can negotiate moderately rough, rocky surfaces better than the standard models. Some cultipackers can be filled with water to increase their weight.

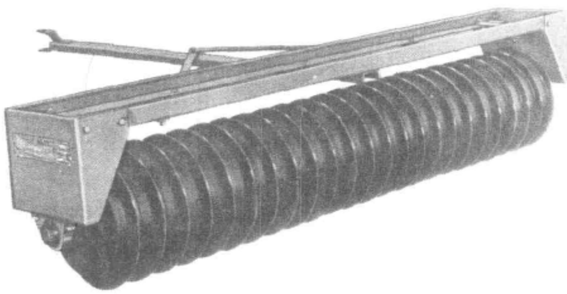


Figure 37.—Cultipacker

One cultipacker (Fig. 38) was especially designed for rough terrain. It has two sections, each with independently suspended tires and wheels. The front section has seven wheels spaced 11 inches center-to-center. The rear section has six wheels, similarly spaced but offset 5½ inches. Pulling this unit across the seedbed provides complete coverage and the design allows rough rocky ground to be treated.

Cultipackers smooth and firm the seedbed in preparation for drill seeding. They can also cover broadcast seeds. By firming the soil, water retention near the soil surface is increased.

More information on the equipment discussed in this section is available in Larson (1980) and Brown (1977).

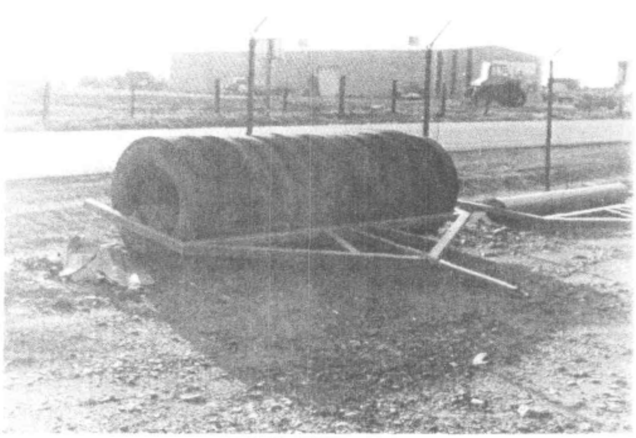


Figure 38.—Auto tire cultipacker

Seedbed conditioning treatments range from breaking up compaction to firming surface soil. The treatments required will depend on many factors, including mining method, soil types, rockiness, grading and spreading equipment, seeding and planting methods, and climate. Successful reclamation demands proper choice of equipment, proper use of equipment, and proper timing of treatment. Flexibility within a reclamation plan is vital; the ability to handle changes in any of the relevant factors is necessary. Changes in such things as soil types, slope gradients, or aspect may indicate that different equipment or techniques will provide better results, even though the change may involve the small distances or subtle shifts in the factors. Experience and knowledge of all available equipment and techniques are valuable assets for the reclamation specialist.

Mulching

Mulching places a layer of material on the soil surface to increase soil moisture, prevent erosion, moderate soil temperature, and increase seedling establishment. Materials can be organic or inorganic, natural or man-made, soil-enriching or inert.

Mulches cover the soil surface and provide a layer of insulation that lowers soil temperatures in the summer and raises them in the winter. Protection from heat is particularly important. Soil moisture on arid and semi-arid mine sites is a critical factor in seed germination and seedling establishment. By creating small air spaces above the soil surface, mulches insulate the soil from solar heat. Light-colored mulches reflect both light and heat, which is particularly valuable when the soils are dark-colored. Lowered heat reduces evaporation from the soil. This reduction of evaporation keeps a high water content near the soil surface for a longer time and promotes seed germination and seedling survival (Gardner arid Woolhiser, 1978).

Mulches protect the soil surface from wind and water erosion. They cover the soil surface and reduce wind velocity at the surface. The reduction in wind velocity reduces the particle size the wind can carry and reduces the cutting effect of particles that are carried. In addition, the mulch intercepts and holds blown soils particles. Mulches intercept raindrops, which decreases their velocity, and reduces the puddling and splashing they create when they hit the soil surface. Mulches also reduce water erosion by slowing runoff, reducing the cutting effect of the runoff, and allowing more time for the water to infiltrate the soil (Gardner and Woolhiser, 1978). In the Southwest mulches are used to prevent soil surface crusting, which can hinder seed germination and seedling emergence

Mulches, however, can be misused. Too much organic mulch can cause excessive water loss by intercepting rain i and holding it until it evaporates. In this case, the mulch is so thick that the precipitation never penetrates to mineral soil. Very thick mulches can also slow early-season plant growth by slowing the rate at which the ground warms in the spring (Packer and Aldon, 1978). Kay (1978) states that on properly mulched dry sites seeds may germinate with the first rainfall and soon die from lack of sufficient moisture for continued growth. Burying seeds in the soil is the best protection against this occurrence. Seeding as close as practical to a date when adequate moisture is expected may also help avoid this problem.

Since mulching can be done before, during, or after seeding, much of the equipment and many of the techniques are used for both seeding and mulching. Hydromulching, especially, is often done concurrently with seeding.

Organic Mulches

Organic mulches are usually an agricultural or industrial residue. They are often relatively inexpensive, with much of their cost involved in transporting them to the reclamation site. Many organic mulches require additional nitrogen to compensate for the nitrogen tied up in decomposing the mulch. When organic mulches are decomposing they can create a serious carbon/nitrogen imbalance in the soil. The addition of organic matter may cause an increase of carbon and decrease available nitrogen, which necessitates adding nitrogen to the soil. The increased organic matter causes a flush of growth in numbers of nitrogen-fixing microbes. The microbes compete vigorously for nitrogen in the soil and until the organic matter decreases and the microbes begin to die, they deplete the nitrogen available for plant growth.

Hay and Straw. — Hay and straw are the two most often used mulches on mine sites in the West. They are common, relatively inexpensive, readily available materials. Hay is usually more expensive than straw, but may have added benefits. Mulching with native or tame hay comprised of desirable reclamation plant species introduces desired seeds in the hay onto the site. Of course, using hay with undesirable plant species can be counterproductive, since the undesirable species will be brought to the site at a time of maximum disturbance. Any hay being used as a mulch should be from a clean, desirable source.

Straw is less expensive, but generally introduces only grains and weedy species to the mine site. The species can be so competitive that they inhibit growth of the desired plant species. Rice straw has been used because neither the rice nor associated weeds will grow on unirrigated Western mine sites. Unfortunately, rice straw is much less available than wheat, barley, or oat straw.

Hay and straw can be spread by special blowers, mechanical spreaders, or by hand. The blowers (Fig. 39) use motor-driven fans to blow the dry hay or straw as far as 70 feet. Bales of mulch are placed on a conveyor or chute that feeds into the blower. The blower mechanism breaks the bale apart to separate mulch fibers, and then blows the mulch out the discharge chute to provide a well-spread layer of mulch. The quantity of mulch used determines the coverage depth. The operator directs the stream of mulch to the desired areas. Power blowers minimize the number of passes equipment must make over the soil. They also mulch on slopes too steep for equipment.

Figure 39.—Mulch blower

Manure spreaders can spread hay or straw mulch (Fig. 40). They are not designed to handle loose, fibrous materials and must be adapted to efficiently spread this mulch. After modifications, the spreaders can produce well-distributed mulching on relatively level slopes (Summerfield, 1979). Equipment designed to feed livestock hay from round bales has been adapted to

Figure 40.—Manure spreader for hay and straw

Anchoring hay or straw mulches is a major problem. The winds and high intensity storms in the West blow and wash away mulch unless it is firmly attached to the ground. One method of anchoring the mulch to the ground is to apply a tackifier to the mulch, either as it is being blown out or after it is on the ground. Asphalt emulsion, wood fiber, wood fiber mixed with a plant-based gum, and wood fiber mixed with adhesive, paint, or other similar substance, are all used as tackifiers (Kay, 1977). All except wood fiber, which is only effective for a few weeks, provide good protection from wind (Kay, 1978). Straw blowers spray the tackifier on the straw or hay as it is blown out the discharge chute. Spraying the tackifier after the mulch has been spread will also anchor mulch to the soil surface.

A variety of nets can hold mulch in place. Plastic fabric, wire, woven paper, and jute nets are used. The nets are fastened to the ground with rocks, wire staples, or other items. The nets must be firmly over the mulch, providing good contact between net and mulch and between mulch and ground. Gaps in the contact can allow wind or water to move the mulch around under the net which results in irregular distribution of the mulch.

On most western mines where hay or straw mulch is used, the mulch is anchored by pushing ends of the hay or straw fibers into the soil. Rollers with studs, disk harrows, or specially designed crimpers can be used. Rollers (Fig. 41) are dragged along the mulched spoil or are lowered down mulched slopes. The studs push the fibers into the soil, which results in a staggered arrangement of tufts of mulch. Disk harrows (Fig. 42) and krimpers (Fig. 43) are pulled along the contour of mulched spoils to produce rows of mulch that are pushed vertically into the soil (Fig. 44). The rows are more effective than the tufts of mulch at reducing erosion and runoff on slopes. Rows, however, are susceptible to inundation from water-carried soil. In any method where the fibers are pushed into the soil, there are areas between the punched mulch where the mulch is not attached and is therefore subject to movement by wind and water.

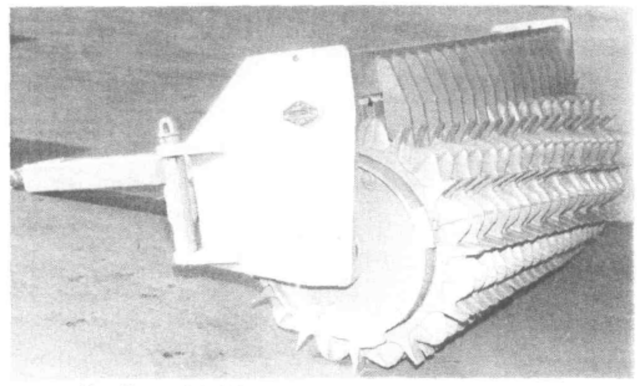


Figure 42.—Disk harrows

Figure 41.—Sheeps foot roller

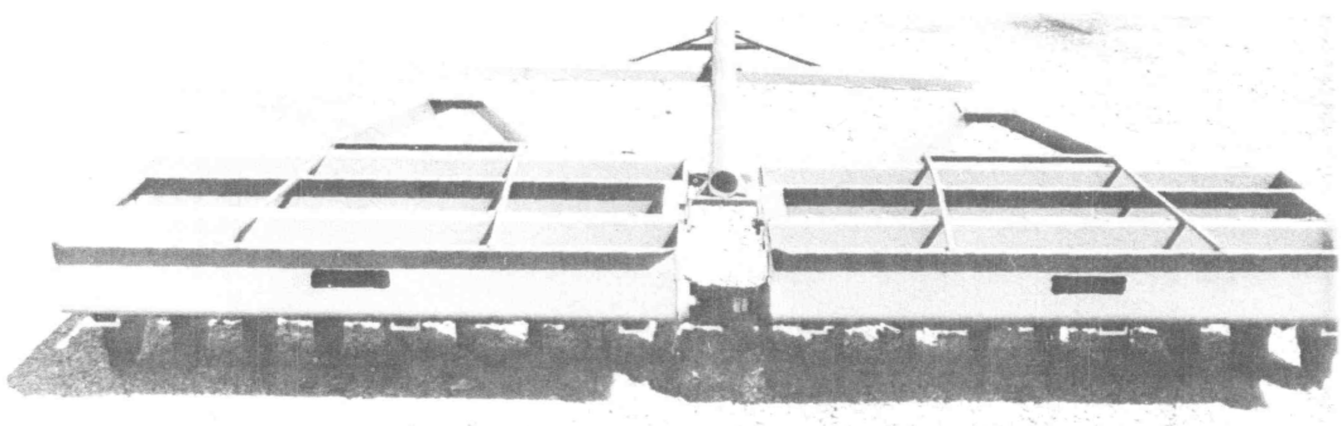


Figure 43.—Krimper31

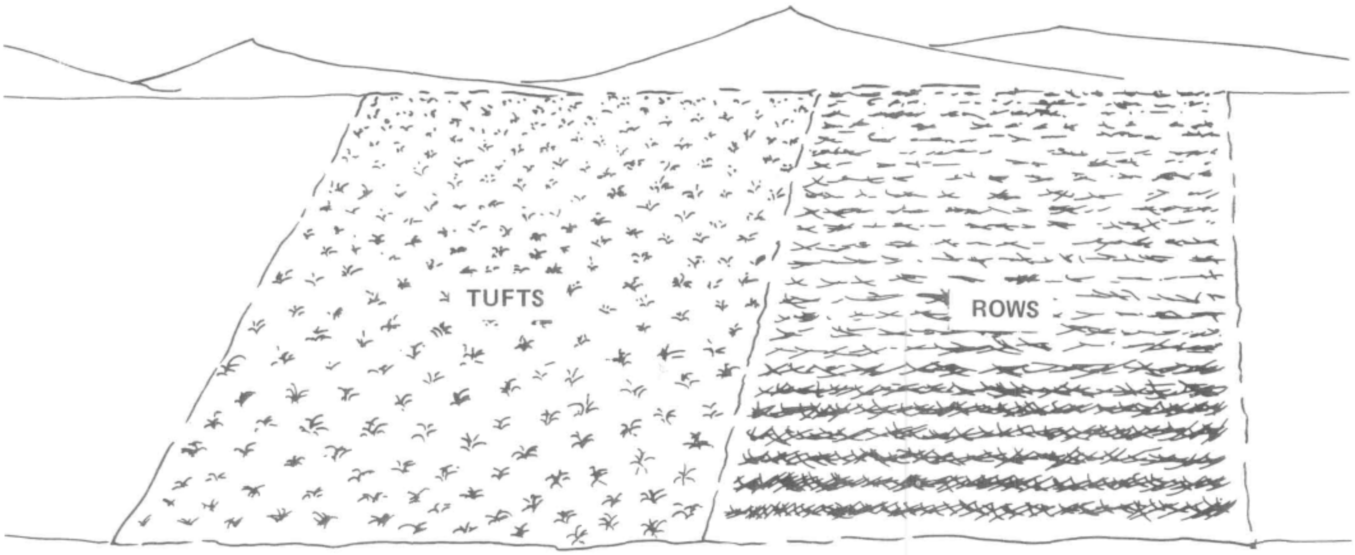


Figure 44.—Tufts and rows

To avoid areas where the mulch is not incorporated into the soil, rotary tillers anchor the mulch over the entire surface. The tillers (Fig. *45)* use vertical blades mounted on a horizontal shaft to chop and mix. The tiller is pulled along the mulched spoil to thoroughly mix the mulch into the soil (Fig. 46). This provides excellent protection from water erosion and good protection from wind erosion. The tilling action increases infiltration and percolation (Summerfield, 1979).

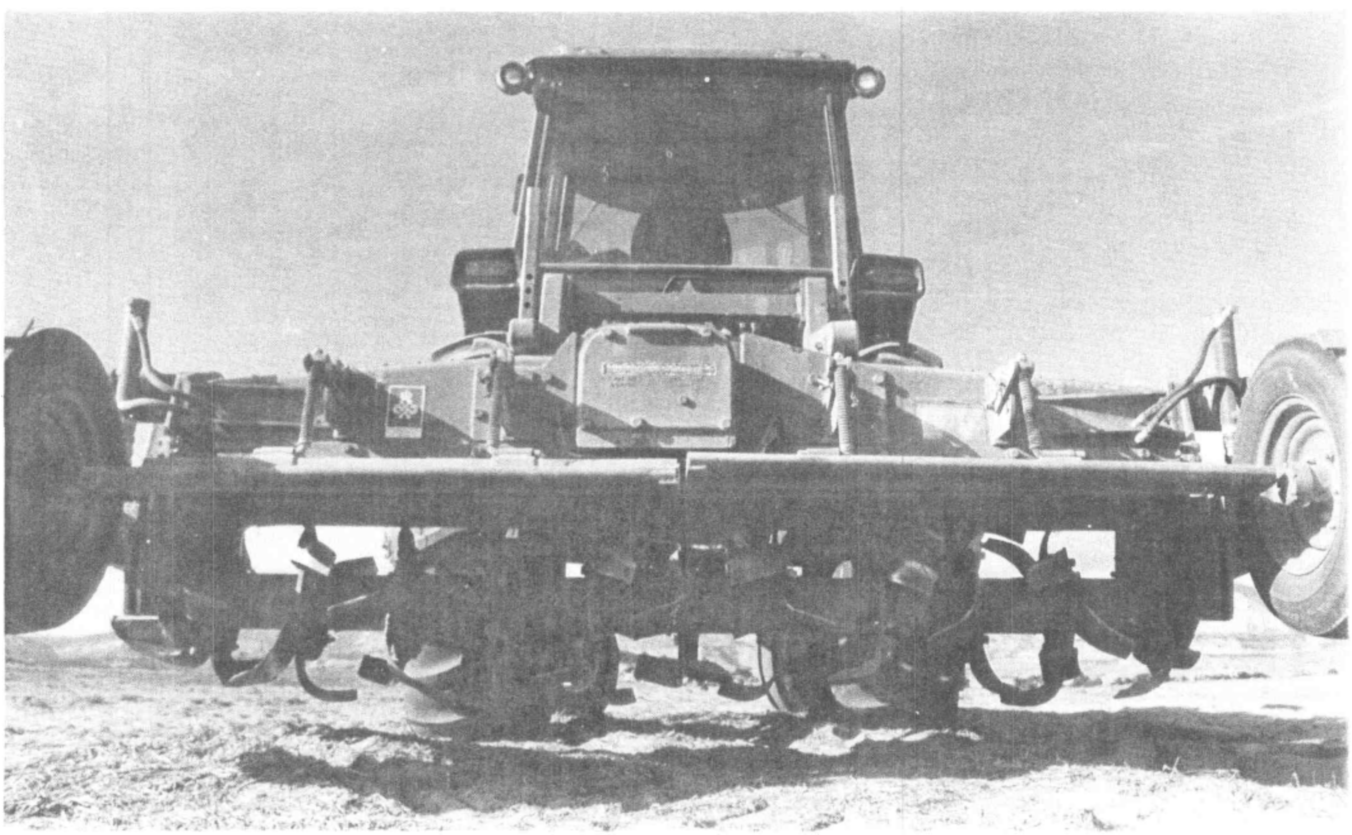


Figure 45.—Rotovator32

Figure 46.—Rotovator tilling mulch into spoil surface

Wood Residues.—Wood residues are used as mulch in areas where they are economically feasible. Woodchips and bark provide the best protection; sawdust or wood shavings are less effective, because they are easily blown or washed away. The residues can be spread with the same equipment used for hay or straw, but airblown residues are heavier than fibers and do not carry as far. Wood residues must be spread at rates of two to six times the amount of straw to achieve the same soil protection (Kay, 1978).

Hydromulch.—A slurry of water and mulch is spread on the soil with a pressurized sprayer. The slurry can contain seed, fertilizer, growth regulators, soil microbes, or other soil amendments. The mulch materials must be small enough to be readily pumped through $1^1/_2$-inch nozzles and must remain in suspension with moderate agitation. Wood fiber, recycled paper, and agricultural products are all used as hydromulch materials.

Hydromulch is applied with specialized equipment (Fig. 47). A large water tank with a pressurized sprayer sprays the slurry on the area to be mulched (Fig. 48). The mulch is kept in suspension with paddle agitators or by passing the slurry continuously through a centrifical pump. An operator directs the spray to ensure complete coverage and uniform distribution. Many mulches have an inert green dye added so that the operator can easily see areas treated.

The mulch protects the soil from wind and water erosion. It holds water, although different types of mulch have different water-holding capacities. The longest fiber length has the highest moisture holding capacities. Wood fiber has shown the greatest success in protecting steep slopes, the most common hydromulched area (Kay, 1977). Kay (1978) states that longer fibers provided the best results, remarking that recycled material could probably provide satisfactory results if more attention were paid to fiber length when the material is processed.

A major problem with hydromulching on some Western mine sites is lack of sufficient water. Hydromulching is generally used only for problem areas or on slopes too steep to mulch with conventional equipment.

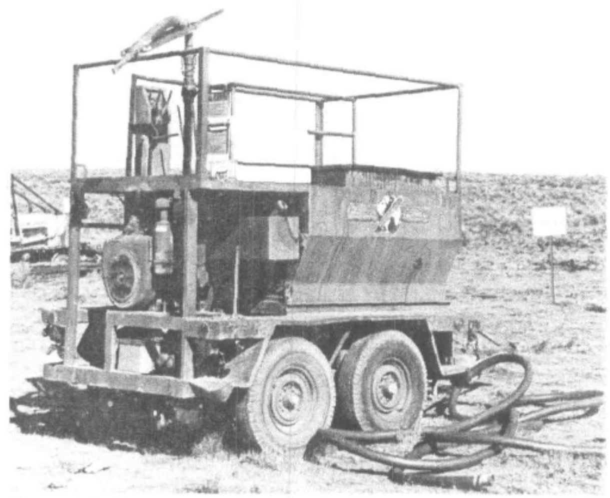


Figure 47.—Hydromulcher

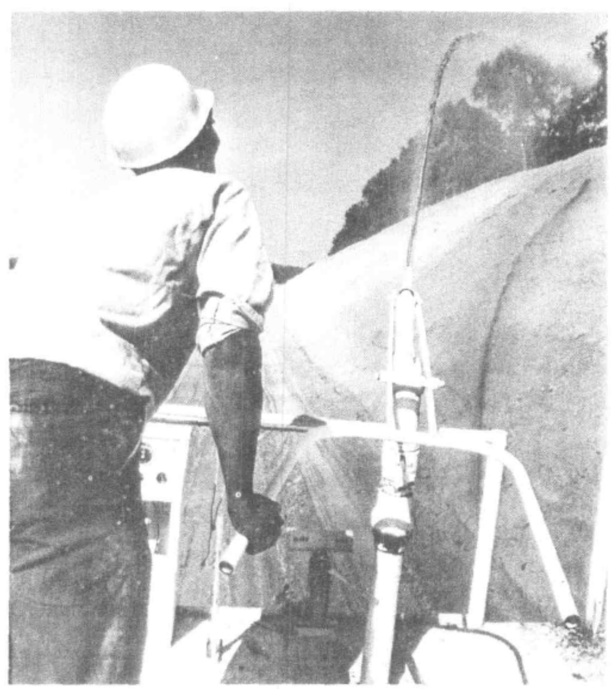


Figure 48.—Hydromulcher spraying a slope

Fabrics and Mats. — Fabrics and mats can be used as organic mulches. Rolls of excelsior, or woven paper are spread and then fastened to the soil with wire staples. The nets made of these materials must be heavy enough or anchored securely enough to prevent erosion under them. Whipping allows wind erosion and lack of close contact with the ground leads to water erosion. The fabrics and mats are more expensive than most other mulches and are used for especially difficult areas and for spot treatment. Even though they are biodegradable, some of these materials do not decompose readily in the arid conditions found in the West (Tuma, 1976).

Standing Stubble. — This is a term given to a cover crop grown to stabilize topsoiled spoils before the final plant species are seeded. This practice is increasing in the West. After the seedbed is prepared, conventional farm equipment is used to seed an annual species or a cereal grain such as wheat, barley, or oats into the spoil. The crop is either a sterile variety or is cut before it produces seed. In either case, there is little viable seed on the site when the reclamation species are seeded directly into the standing stubble. This is a particularly appropriate technique for mulching in the Great Basin, Intermountain, and Northern Great Plains areas, where the preferred seeding time is the fall. By establishing a cover crop in the spring and early summer, the spoils are stabilized until they can be seeded in the fall.

Standing stubble is very effective at catching snow and preventing wind erosion. Mason and others (1980) found standing stubble to be more effective than crimped straw. The stubble lasted longer because much of the straw was blown off the site, even though it was crimped. The stubble showed less soil temperature fluctuation, higher total water infiltration, and slightly higher percent soil moisture in the top 24 inches of the soil profile. The cost of the standing stubble was only 5 to 25 percent as high as crimped straw. The chance of a weed infestation is higher with crimped straw or hay because of weed seed in the mulch.

The major disadvantages of standing stubble are the possibility that the cover crop will compete with the desired species and that the cover crop will not prevent invasion of the site by weedy species. If weedy species are allowed to establish themselves before the desired species are seeded, they may out-compete the seeded species.

Leonardite and Slack Coal. — Leonardite and slack coal are lignite coal that has oxidized. This organic material is softer, higher in oxygen, and higher in humic acids than is lignite from which it originated. It is broken into small lumps and spread onto the surface of the mine spoils. The lumps provide protection from wind and water erosion. As the mulch breaks down, the humic material enters the soil and increases the infiltration rate and water-holding capacity of the soil. Freeman and Fowkes (1968) state that humic acids found in soil and those in leonardite are virtually identical chemically and physically.

The effects of leonardite and slack coal depend on the qualities of the source materials and the qualities of the spoils on which it is spread. Kollman (1979) states that the effects of leonardite on the physical and chemical characteristics of a topsoil may be predicted based on the properties of the mulch and the soil. Leonardite appears to decrease the upward movement of salts from sodic spoils to topsoil.

This mulch is found only in lignite coal areas, particularly in North Dakota. It is expensive for use in areas far from where it is found. Some studies have found that leonardite benefits legumes but is detrimental to grasses (Kollman, 1979). Leonardite can disrupt the sodium/potassium balance in grasses but not in legumes.

Leonardite can be spread using any spreader capable of throwing small rocks or bark. It is abrasive and can damage delicate blowers designed for light materials.

Inorganic Mulches

Inorganic mulches cover the soil and protect it from wind and water erosion. They promote seed germination and seedling establishment but are not biologically degradable, and do not release nutrients or microbes to the soil. Mulches such as gravel or stones are inexpensive, readily available, and effective protection from wind and water. They do not introduce undesirable plant species, nor do they present problems of unbalanced nutrient ratios. Some rock is not acceptable because it has inhibitor characteristics or because it weathers to produce excess clay. The excess clay can reduce the site productivity by making a nearly impermeable layer on the surface of the topsoil.

Inorganic nets, mats or meshes are sometimes used to stabilize harsh steep sites. They are durable mulches that, when properly placed to maintain good ground contact, will provide protection from both wind and water erosion. These materials have high purchase and labor costs. They tend to attract rodents, apparently because of the protection offered them from their natural predators. Nets and mats are quite expensive compared to other mulches and are often limited to critical areas or steep slopes.

Chemical Soil Stabilizers

Chemical soil stabilizers are natural or synthetic-based substances that are sprayed on the area to be treated. They are developed to prevent erosion, improve soil nutrients, or retain moisture. Most often, they are used in conjunction with other mulch materials, either mixed in a hydromulch slurry or sprayed as a tackifier on previously mulched areas. When applied alone, they are usually used as soil binders.

Natural Chemical Stabilizers.—These are generally derived from plant gums or extracts and are used with wood fiber or other long fibers as tackifiers. These products are developed for use with other mulch materials and should not be used alone. Some of the chemicals are not compatible with commercial fertilizers.

Kay (1978, 1979) found that some of these products by themselves did not improve erosion protection as much as wood fiber used alone; one actually gave poorer results than the wood fiber alone, as well as when used with wood fiber. Several products did improve erosion control, although increasing wood fiber application rates produced the same protection. The cost of the additional wood fiber application may make use of the better chemicals economical.

Synthetic Chemical Soil Stabilizers. — Synthetics are manufactured chemicals sprayed on the soil surface to form a crust that is effective in controlling erosion and dust. The crust sheds water, whereas most mulches hold water.

Synthetic soil stabilizers must be precisely handled to provide desired results. They are sold as liquid concentrates that must be diluted with water before application. The dilution rates must be strictly adhered to for maximum soil protection. Soil moisture affects dilution rates, so application to dry soil is preferable, since the chance of excess soil moisture further diluting the emulsion is minimized. Dilutions that produce runoff on the site are to be avoided. Problems often develop when the stabilizers are applied as part of a slurry containing other soil amendments. Some synthetic soil stabilizers that are easier to apply are being developed; these would make stabilizers more compatible with other slurry materials (Kay, 1978).

Synthetic soil stabilizers must cure completely before they provide effective soil protection. Minimum curing temperatures range from 13˚C to 4˚C, depending on the product. Humidity must be moderately low; fog will prolong the curing time by days. Freezing will destroy all uncured emulsions. After the crusts have cured, they must be protected to ensure continued performance. Any cuts or breaks, which can be caused by animals, vehicles, or even frost-heaving, must be repaired to keep the soil protected (Kay, 1978).

The synthetic emulsions reduce seed germination and seedling establishment. When synthetic emulsions are used, seeding rates should be increased to compensate for the emulsions' negative effects. If fertilizer is applied with the emulsion, grass tips are often burned. The emulsion keeps the fertilizer from leaching by preventing water penetration, which causes tip burn from the fertilizer. Since the crust prevents water infiltration, the soil may become too dry for plant establishment and growth. Wood fiber is necessary if seeding is done in a synthetic soil stabilizer slurry. Soil stabilizers alone will not hold seed or fertilizer on a slope. If the seed and fiber is applied after the emulsion, they will wash off.

Synthetic chemical soil stabilizers are most applicable to steep slopes where quick erosion control is of paramount importance. They are particularly effective when trees or shrubs are hand planted and the open areas between the plants must be protected.

Fertilization

Fertilization is the addition of a natural or man-made substance to the soil to supply plant nutrients. Materials used as fertilizer range from fly-ash, a waste product in the combustion of coal, to sewage sludge, to limestone. Fertilizers are spread from bulk material spreaders like manure spreaders, sprayed through irrigation systems, drilled into the soil when the seeds are planted, or broadcast from specially designed fertilizer spreaders. The methods of fertilization and the type of fertilizers used depend on the plants to be grown, the soils in which they must grow, and the economic availability of the fertilizer.

Fertilization of reclamation sites is a hotly debated issue. Since the use of fertilizers to establish and maintain a plant community does not provide an accurate reflection of how the community will fare unaided by man over the long-term, some people argue that the use of fertilizers at all is unwise. Their contention is that reclamation efforts are better served by using the soil as it is rather than by making short-term changes in the soil. Plants that respond well to the short-term changes in the soil may fail when the fertilizer is depleted. This failure would lead to a reduction in the desirable species and an invasion by weedy pioneer species. In this view, the site should be reclaimed with species that do not need fertilization for establishment and growth. This way, any plants that did establish would be expected to continue on the site, without assistance from man.

Fertilization is supported by those who believe that by assisting in the establishment of the plants, some of the negative effects of mining are mitigated. The plants are then vigorous enough to cope with the environmental stresses that will come when the effects of fertilization are gone. Often, fertilizer is applied on time and the plants are expected to alter the environment sufficiently to reduce the need for further fertilization. Fertilization is justified because mining severely disrupts the soil balances that effect nutrient availability. To quickly establish a diverse plant community as productive as the premining community, addition of nutrients may be necessary. After the initial fertilization and subsequent establishment of desired plants, the natural processes of weathering and nutrient cycling are expected to maintain the nutrient level at adequate levels to maintain the plant community.

Nutrients in the soil in forms the plant cannot use or those held too tightly to be obtained by the plants are useless for plant establishment and growth. Only available, usable nutrients are important.

Maco-nutrient (nitrogen, phosphorous, potassium, calcium, magnesium and sulfer) deficiencies are determined by soil sampling. Micro-nutrient deficiencies are more difficult to ascertain and have not been fully evaluated. The deficiencies are further complicated by the fact the soil pH affects the availability of many nutrients (Aldon, 1979). Similarly, nutrient ratios may affect the ways in which plants use the nutrients. For example, calcium:magnesium ratios can cause nutritional problems in plants even when both are supplied in adequate amounts (Bauer and others, 1978). Determination of fertilization needs is a site specific/species specific process. Bauer and others (1978) state that nitrogen (N) and phosphorous (P) are the most important nutrients in terms of size of areas where they are deficient. Most micro-nutrients are deficient in only very isolated conditions.

Fertilization can be done before, during, or after seeding. We concentrate on fertilization before seeding, although most methods and materials can be used at any time.

Chemical Fertilizers

Chemical fertilizers are either ground minerals or liquid or gaseous chemicals that have been processed from naturally occurring mineral deposits or from petrochemicals. They are common agricultural fertilizers commercially available throughout the West. The equipment used to apply the fertilizer is readily available, conventional equipment.

Fertilizer Spreaders. — Fertilizer spreaders (Fig. 49) broadcast dry fertilizer while being pulled or driven over the area to be fertilized. The fertilizer is carried in a hopper and is moved with a mesh or belt conveyor to a spinner at the back of the hopper. The spinner throws the fertilizer in a broad swath behind the spreader. The conveyor and spinner are hydraulically or power-take-off driven. The fertilizer application can be varied by adjusting the conveyor speed or the size of the rear hopper opening. Many spreaders are high flotation implements designed to minimize compaction and surface disruption.

Fertilizer spreaders can apply most to dry fertilizers. They are usually used with small, sand-sized pellets processed from minerals. Lime, gypsum, and other ground minerals are handled easily. Large areas can be covered rapidly, but the spreaders are not adapted to brushy, rough, or steep land. This equipment is generally rented, since it works land quickly and has few other uses.

Granular Applicators.—Granular applicators (Fig. 50) broadcast fertilizer in rows. They have a hopper mounted above tubes that carry the fertilizer to the ground. As the applicator

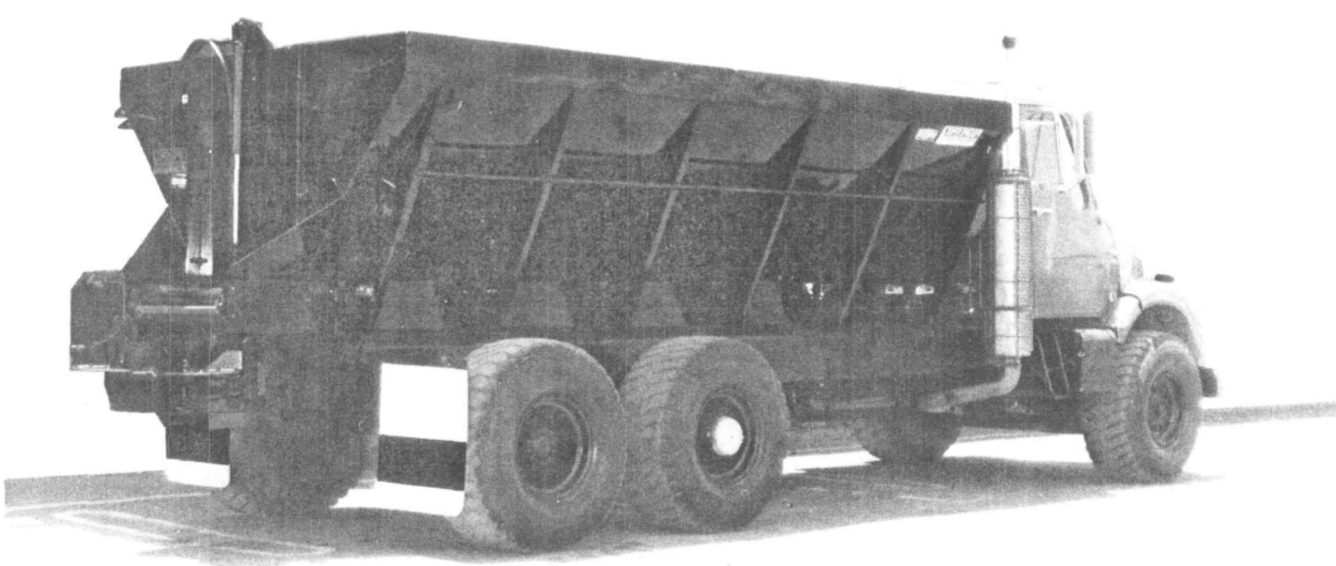


Figure 49.—Fertilizer spreader

is pulled across the site, the fertilizer is dropped on the ground. When used with seed hoppers, seeding and fertilizing can be done at one time. They can apply the same types of materials as fertilizer spreaders.

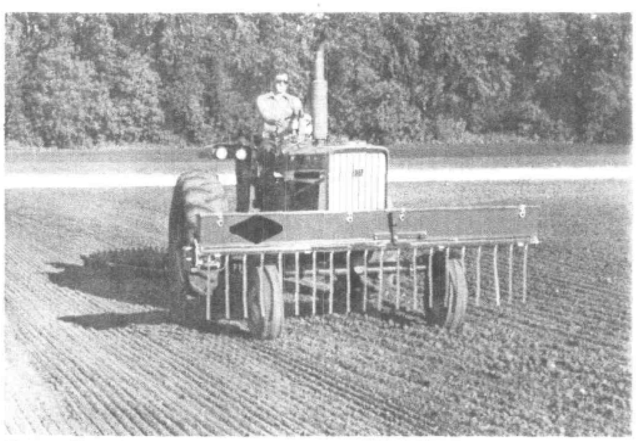


Figure 50.—Granular applicator

The applicators can be mounted on a tractor or supported by wheels. The wheeled models are limited to relatively smooth terrain while the tractor-mounted models can be used on rocky, rough areas.

By mounting a granular applicator behind a tillage implement like a disk harrow or chisel plow, fertilizer can be broadcast on a rough, cloddy seedbed. This allows the fertilizer to be covered by and incorporated into the soil.

Drill Seeders.—These seeders (Fig. 51) place granular fertilizer in the ground as seeds are planted. Seeders can bury dry fertilizer at a relatively precise depth so the fertilizer is in place when the plant roots reach it. Drill seeders are limited to relatively smooth, level areas and are usually used while seeding, not before seeding.

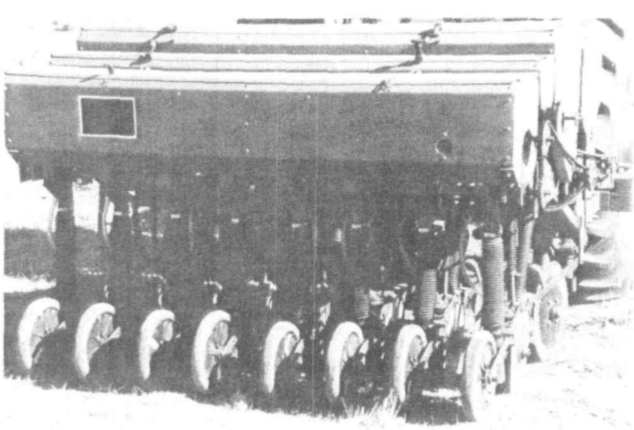


Figure 51.—Drill seeder

Fertilizer Blasting Guns —Blasting guns (Fig. 52) blow dry fertilizer granules onto treatment areas. These hand-held guns use portable air compressors to blow the chemicals as far as 75 feet onto steep or inaccessible slopes. They also treat small areas and trouble spots, but are inefficient for treating large, accessible areas.

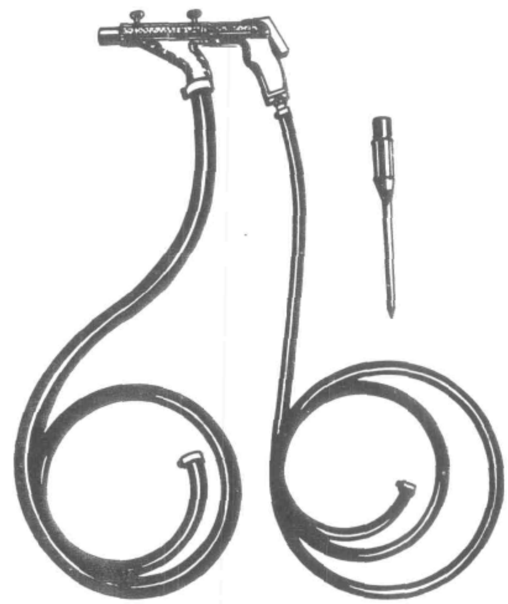


Figure 52.—Fertilizer blasting gun

Blower Spreaders.—Blow spreaders (Fig. 53) use a blower/ impactor attached to a fertilizer hopper to spread materials as far as 125 feet on one side of the implement. The truck-mounted spreader was designed for stabilizing roadsides and steep reclamation slopes. The spreader can only traverse relatively level areas, but can adequately spread dry fertilizer 75 feet horizontally on a 60-degree slope. The spreader can also apply dry mulch material, like wood chips and bark.

Figure 53.—Blower spreader

Hydroseeders.— Hydroseeders (Fig. 54) can apply a slurry of fertilizer and water. Because of the relative scarcity of water at most Western mines, hydroseeders are used mainly for treating trouble spots and inaccessible areas like steep slopes. Applying fertilizer in a slurry before seeding can leach the fertilizer from the site. Volunteer plants, especially weedy pioneer species, may quickly use the nutrients. Usually, fertilizer applied with a hydroseeder will be done in conjunction with seeding. Fertilizer slurries are sometimes incompatible with organic hydromulches and must be applied in separate operations (Kay, 1978).

Figure 54.—Hydro seeder

Subsoil Injectors. — Injectors (Fig. 55) place liquid or gaseous fertilizer directly in the soil. They consist of a tank holding the fertilizer, a pump, and injector arms that penetrate the soil. The arms open a furrow, the pump pushes the fertilizer through a hose into the ground, and the furrow closes immediately behind the injector to lock the fertilizer in the ground where it attaches to soil particles until the plant roots reach it. The subsoil injectors are truck-mounted or are on a toolbar pulled by a tractor. Many of the trucks have high-flotation tires to minimize disturbance.

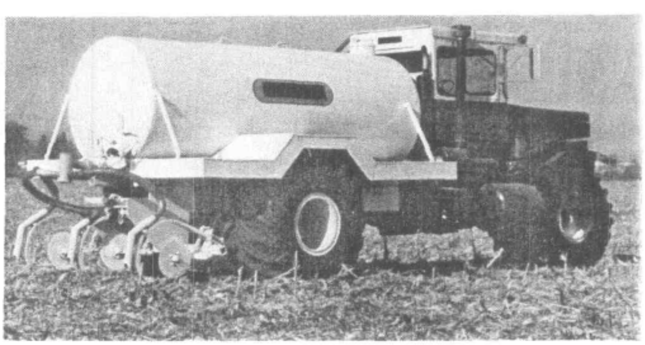


Figure 55.—Subsoil injector

By injecting the fertilizer into the soil, it is trapped until needed. The fertilizer is at the site where it will be used; wind or runoff will not remove the fertilizer. Soil injectors can only be used in soft, well-tilled soil; they are not designed for rough or rocky soils.

Biologic Fertilizers

Biologic fertilizers are animal or plant residues used to provide essential nutrients to plants. Application of these fertilizers requires equipment adapted to their physical characteristics.

Manure, compost, sewage sludge, cottonseed meal, and many other products are used as fertilizers. These materials sometimes have rather low percentages of the three main macro-nutrients (nitrogen, phosphorus, and potassium) when compared with commercially available chemical fertilizers. However, they are sometimes readily available and inexpensive sources of fertilizer. Additionally, they add organic matter and sometimes soil microbes to the fertilized area. This provides longer-lasting effects than does fertilizing with chemicals that are biologically inert. Biologic fertilizers, in addition to adding nutrients to the soil, help build the soil so that it is more capable of providing the necessary nutrients without additional fertilization. Biologic fertilizers can provide some of the benefits of mulching as well as fertilizing.

Biologic fertilizers are often called soil amendments rather than soil fertilizers. Much of their value is not in their immediate addition of nutrients to the soil, but in their overall improvement of the soil quality. They provide organic matter in various stages of decomposition. Their nutrient contents vary by source of the fertilizer; most provide not only the three major macronutrients, but also valuable amounts of micronutrients, which are usually lacking in chemical fertilizers. The organic matter works into the soil to provide better soil structure, better aeration, and improved water-holding capacity. Microbes are often included in biologic fertilizers. The microbes feed on the animal and plant residues, releasing the nutrients in these residues and making them available for plant use. The introduction of the microbes into mined soils is an important step in guaranteeing that the reclaimed site will maintain a stable supply of plant nutrients. The effects of biologic fertilizers are seldom felt as quickly as those of chemical fertilizers, but are more permanent.

Compost.—Compost is plant and/or animal residues that have begun decomposing. Most composts have a source of nitrogen and phosphorous added to them to accelerate the microbial action involved in the decomposition of the residues. Some compost is allowed to ferment for a year or more. These composts convert the original materials to a humus that has high levels of microbial populations.

Composts are relatively expensive, but are valuable for the microbes they introduce into the soil. They introduce a high degree of biological stability to the soil by providing organisms that recycle nutrients on the site. Composts are, in most cases, solid materials.

Composting in the presence of moisture and oxygen generates sufficient heat to kill weed seeds in the compost materials. Aeration is required to keep the temperature low enough to avoid killing the microbes.

Manure.—Manure is animal excreta, often mixed with plant materials such as straw. Manure can be liquid, semi-solid, or solid, depending on the type and the age of the manure. Manures are high in nitrogenous materials and are sometimes used in compost as a source of nitrogen. Fresh manure provides as much nitrogen as ammonia, a highly volatile substance. By covering the manure with soil, much of the ammonia is trapped (Stefferud, 1957). However, it is often impractical to spread fresh manure and cover it immediately. The nitrogen losses must be balanced against the timing needs of reclamation.

Sewage Sludge.— Sludge is human waste processed to destroy pathological organisms. Use of sludge as fertilizer is not common, basically because of the low percentage of nutrients. Other problems include the possibility of toxic amounts of some macronutrients, depending on the source of the sludge and the sludge treatments.

Composting sewage sludge is done by several municipalities and commercial suppliers. Often organic matter and some inorganic materials are combined to produce a compound with several benefits for the soil.

Green Manure. — This manure is a crop of legumes or grasses that is grown and plowed under for the purpose of improving the soil (Stefferud, 1957). The plants enrich the soil by providing organic matter and, in the case of legumes, by adding nitrogen to the soil. Their use in the West may be limited by the amount of moisture they use.

Biological Fertilizer Equipment

Biological fertilizers can be classed as liquid (1 to 10 solids), semi-solids (8 to 30 solids), and solids (25 to 80 solids). Handling biological fertilizer is based more on these characteristics than on the material from which the fertilizer is derived. Equipment used for applying biological fertilizer is determined by the percent of moisture in the fertilizer and the slope and accessibility of the site.

Virtually all biological fertilizers have relatively high moisture percentages; handling them in freezing weather can be a problem. If they are to be applied during freezing weather, the spreading equipment must be able to break apart the materials so they are adequately spread. Liquids and semi-solids are very difficult to spread in cold conditions; manure spreaders or blower spreaders that can break apart and throw solid particles are most applicable for fertilizing in very cold weather.

Liquid fertilizers can be handled by hydroseeders or by irrigation systems. Usually the equipment is used during or after seeding.

Manure Spreaders. —Manure spreaders spread solid and semi-solid fertilizers. The spreaders (Fig. 56) are large, open trailers or trucks with large boxes. A conveyor in the bed of the box moves the fertilizer to where paddles or flails on a horizontal axle fling the material onto the soil. Auxiliary beaters are often located above the spreading mechanisms to aid the flow of the material through the beaters.

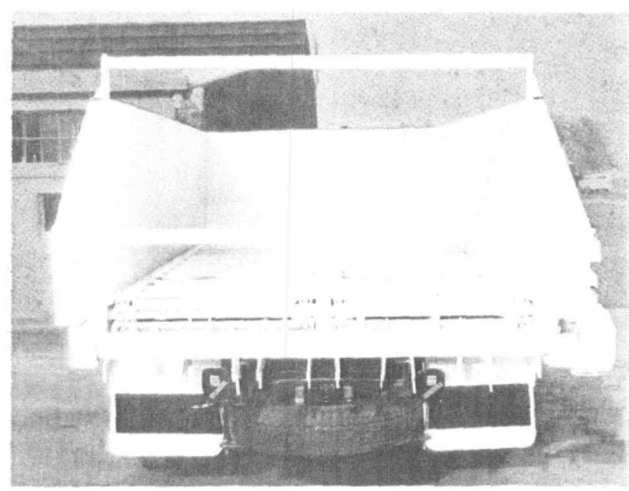


Figure 56.—Manure spreader

Spreaders are either rear- or side-discharge. Side-discharge models use flails (Fig. 57) that break up and fling the material to one side of the spreader. The spreaders must drive or be pulled along the site to be fertilized; this requires a relatively level slope. High-flotation tires are available to minimize soil compaction. Most spreaders are run by power-take-off attachments to the prime mover. Application rates for manure can be varied by changing the speed of the conveyor and paddles or by varying the driving speed. Increasing conveyor speed or decreasing travel speed increases the amount of manure applied per unit area. Solids or semi-solids can be used as a top dressing for the spoil or can be applied heavily enough to require mixing in the soil.

Spreader equipment is relatively simple and can be adapted to handle a variety of fertilizers and mulches. It is efficient and well-adapted to reclamation work on moderately sloping to level areas. The truck-mounted spreaders can haul manure over highways to reduce transport time between sources of supply and the mine site. Although use of trailers requires more trips to haul the same amount of material, if pulled by trucks or pickups rather than off-highway equipment they can also have reasonable haul times. When the source of the material is close to the mine site, trailers pulled by tractors or other such prime movers have acceptable haul times.

Figure 57.—Chain flail

Blower Spreaders.— Blower spreaders (Fig. 58) are truck-mounted fertilizer spreaders designed to blow and throw dry materials. They are not equipped to break apart materials, so the fertilizer should be dry enough to remain in relatively small particles. Semi-solids will not be efficiently spread by the blower/impactor fan mechanism.

These spreaders can throw fertilizer on slopes inaccessible to other spreaders or they can spread on level areas without traveling on the treatment site. This allows spreading natural fertilizers without compacting the soil.

Figure 58.—Blower spreader

Sludge Blowers.—These (Fig. 59 a and b) are off-road vehicles designed to spread a slurry of waste products. They use a pressure pump to blow the fertilizer to the side or behind the equipment. They can blow materials onto slopes inaccessible to some other spreaders. Sludge blowers do not spread dry materials.

Subsoil Injectors.-(See page 38.)

Further information on fertilizer equipment can be obtained from Larson (1980).

Figure 59.—Sludge blower

IV. Seeding and Planting

Seeding and planting are vital parts of the reclamation process. Most seeding and planting implements and techniques are well-known, conventional farming equipment and methods. However, seeding and planting on mine sites are more difficult than on most agricultural lands. Ecological, legal, and economical problems far different from those found in most agricultural settings prevail on mine reclamation sites.

After the proper plant species are selected, seeds or plants must be obtained. Collection areas and techniques must be identified or a commercial seed and plant supplier found. Seeds and plants must be stored until they can be planted on the reclamation site, as dictated by mining activity and climatic factors. Some seeds must be prepared for seeding by cleaning or dewinging.

Seeding and planting techniques are dictated by the plant species to be grown, the soil type and condition, and the climate. Seeding depth, water catchments, and seeding rates are dependent on the plant species. The use of inappropriate techniques or equipment usually results in reclamation failure.

Species Selection

Selection of reclamation species is an important and difficult task. In the West much of the lands being mined for coal are rangeland. The social, economic, and climatic factors found in these sparsely populated areas ensure that ranching will be the post-mining use of the land. There will be little demand for homesites, intensive recreation facilities, or farmland in the near future, therefore most sites will be restored to range or pasturelands. Many factors must be considered when choosing species to revegetate these sites (Cook and others, 1974; Stoddard and others, 1975).

Legal Requirements

Federal regulations state that mine operators "shall establish on all affected lands a diverse, effective, and permanent vegetative cover of the same seasonal variety native to the area of disturbed land or species that supports the approved post-mining land use" (Federal Register, 1979).

Additionally, all mine operators must submit a reclamation plan when applying for a mining permit. The plan details the post-mining use of the land, how the use is to be accomplished, support activities necessary to achieve the proposed use, and, where grazing is the proposed use, management plans that will be implemented (Federal Register, 1979). Since the ultimate use of the land is determined prior to mining, it is important that plant species meet the predetermined use. A poor choice may doom the revegetation effort and may prevent release from legal responsibility to reclaim the land.

Site Adaptation

The species selected for reclamation must be well adapted for the specific site. They must be able to withstand edaphic, climatic, and topographic conditions of the site.

Soils. — Soil conditions in the West range from clay to sandy soil, deep topsoil to no topsoil, toxic to harmless, stoney to stone-free, alkaline to acidic, sterile to fertile. Some plant species can survive on a wide range of soils, others are restricted to specific soils. Planning must take soil characteristics into account when reclamation species are chosen.

Tolerance for saline or alkaline soils is important in much of the West. Species adapted to clay soils are necessary in some areas. The ability of selected species must be known. In areas where soil changes are rapid and unpredictable, a seed mixture of compatible species, some of which are adapted for each of the soil conditions, will assure that each soil type will be seeded with appropriate species. Soil conditions affect plant survival through amounts of nutrients or toxic materials available to the plants and by the amount of soil moisture available to the plants. Sodic, saline and clay soils often hold moisture so tightly or prevent moisture penetration so completely that many species are unable to survive. Halophytes (salt-tolerant plants) and xerophytes (plants adapted to arid conditions) must be selected to vegetate some sites, even if the species are not productive. Soil protection is the first and most important object of revegetation. Once the site has been stabilized by the halophytes or xerophytes, micro-climatic or edaphic conditions may change enough to introduce ultimately desired species onto the site. Initial species selection, however, must be done with the soil limitations in mind.

Climate. — Climatic conditions are often the determining factor when choosing the plant species to be seeded on mined sites. Many coal mining areas are subject to bitter cold winters; dry, hot summers; intense, short storms; and year-round winds. The growing seasons are short, with moisture availability a critical problem during most of the year. Other western mines are extremely arid, with average rainfall of less than 7 inches per year (Wiener, 1980). Areas that have adequate rainfall in most years are vulnerable to occasional droughts that may last for 3 or more years. Plants that can be established on a site must be able to survive drought to provide a permanent plant community. Plants must be adapted to use soil moisture when the moisture is provided. Mines in the Great Plains, the Intermountain area, and the Great Basin receive most of their moisture during the spring; in the Southwest deserts, precipitation is greatest in summer. Plant species that most efficiently use precipitation will be different in each of these areas. In the northern Great Plains the winters are cold, windy, and long and the summers are hot, windy, and dry. Plants adapted to these conditions will not necessarily be adapted to areas in the Southwest deserts. Selection must provide species and varieties adapted to the specific climatic conditions on each site.

Moisture availability is the prime limiting factor for most species in the West. Precipitation amounts, as well as precipitation patterns, must be matched by species that can survive and prosper on the amount of moisture provided at the time it is available. The amount, form, and seasonal distribution of precipitation are all important factors in determining moisture availability for plant use (VanEpps and McKell, 1978). Total precipitation amount can be misleading if it comes in a form that is unusable by plants, for example, snow that blows off before it can melt or intense summer storms that run off before the moisture can infiltrate. Precipitation that comes at a time when plant species on the site cannot use it is also misleading unless the moisture is stored in the soil. Cool season plants that efficiently use fall, winter, and spring precipitation dominate the Intermountain area and much of the northern Great Plains. Warm season plants that use late spring and summer moisture dominate the Southwest deserts and parts of the Great Plains.

Wind causes both direct and indirect losses of moisture. Wind reduces the amount of moisture available from snow melt by blowing snow off the reclaimed site. This is most important in the first few years of revegetation, before the plant community is capable of holding the snow. Wind increases evapotranspiration on sites. It dries soils or increases the moisture requirements of plants by drying them and accelerating their transpiration rate. These effects, too, are most important in the early years of revegetation. Moisture stress will usually be alleviated somewhat as the stand grows and matures. Wind can physically damage plants, especially seedlings. Windblown sand particles may injure or destory seedlings (VanEpps and McKell, 1978). Wind can also bury seedlings on the lee side of obstructions (Fig. 60). Occasionally, cultural treatments must be used to moderate the environmental extremes of the site until the plants are well established.

Temperature is very important in choosing reclamation species. High temperatures dry out plants and can cause physiological damage. High surface temperatures are common on mine spoils. In areas where summer temperatures reach over 100˚F, soil surface temperatures on exposed south-facing slopes could reasonably be expected to exceed 130˚F at times. Plants must be capable of withstanding the heat stresses placed on them, either through their natural adaptations or by cultural techniques to protect the plant. Levitt (1972) states that heat injury is most likely to affect plants grown in regions other than where they are normally found. Injury is likely to occur on relatively rare "test summers." This would suggest that unadapted species may survive for a number of years until the critical summer arrives, at which time the unadapted species will be injured or killed.

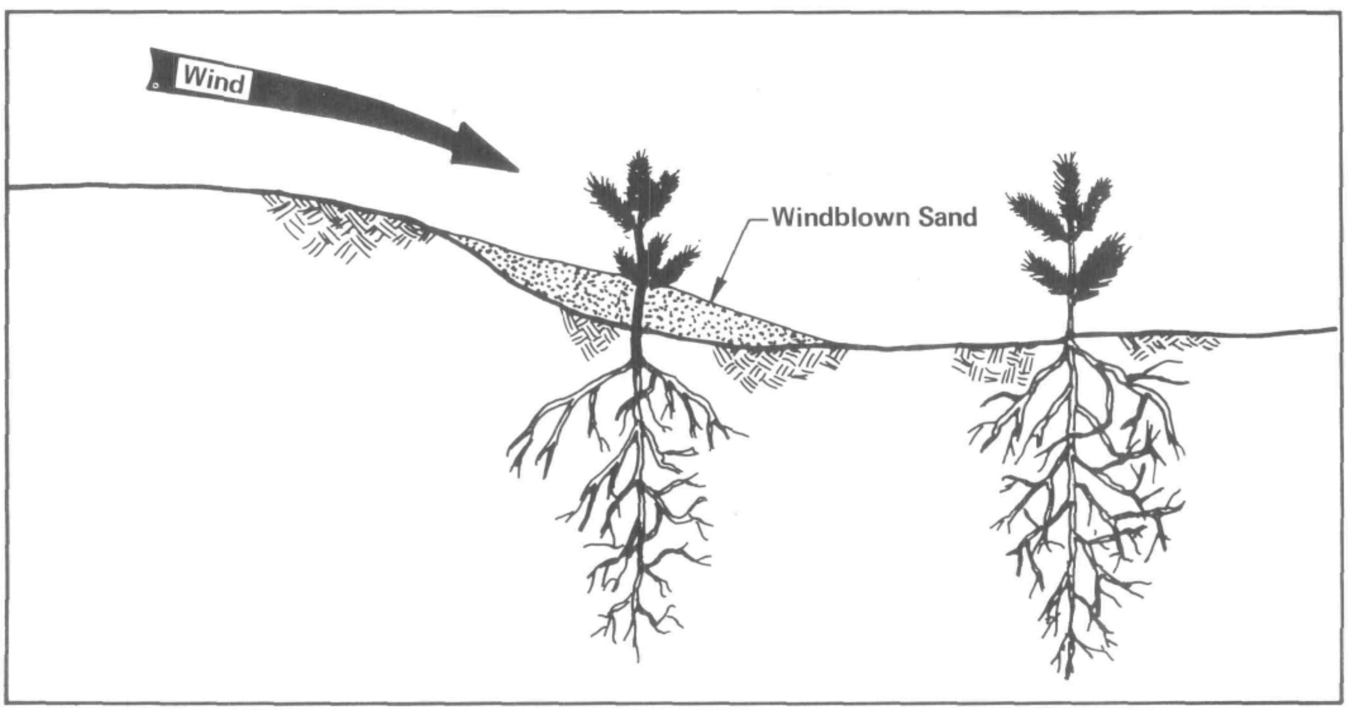


Figure 60.—Seedling covered by wind

Temperature affects the growing season length. Germination or annual growth will not begin until the soil reaches a certain temperature, which differs for different species. The number of days between the last frost in the spring and the first frost in the fall is important to many plants. Some plants are not hardy enough to withstand the long, intensely cold winters on the northern Great Plains, while others do poorly in the long, hot summers of the Southwest deserts. (Problems often arise when unadapted ecotypes of acceptable species are used for revegetation. For example, an ecotype of rubber rabbit-brush *(Chrysothamnus nauseosus)* from the Southwest deserts would, if it survived over winter, begin to grow in the first warm spell in the spring in the northern Great Plains. The normal late spring frosts would severely damage the plant. An ecotype from the northern Great Plains would either not begin growth as early in the spring or would be hardy enough to withstand the late frost. Ecotypes specifically adapted to the climate at the reclamation site are vital.

Topography.— Selected species must be well adapted for the topographic conditions of the site. Slope conditions, including slope length, grade, and aspect, influence soil moisture, temperature, and stability. The erosion potential of a slope increases with both length and percent of grade (Buckman and Brady, 1969). Additionally, as the length and grade of the slope increase, the runoff from the slope also increases. This puts two extra stresses on the plants used on these slopes: they must be able to hold the soil tightly to reduce erosion and they must survive on a reduced amount of moisture. Aspect affects the micro-climate in which the plant must survive. North and east aspects are generally cooler and moister than are south and west aspects. Topography affects drainage and runoff patterns by increasing the available and hill crests. Dumping spoils during the mining process pull large materials in the lower areas where gravity carried them. Then erosion carries smaller materials into the lower areas, covering the large materials in the draws and exposing them on the upper slopes and ridges.

The variety of microsites on a reclamation area changes with the amount of topographic variation on the area. Where the variation is significant it is advisable to use different seeding mixtures on different slopes and soils. Figure 61 shows several species used at a mine in Montana. In this case different sites are considered when determining the species mixes. If different species mixes are not used on the various sites, the single seed mix must include adequate amounts and species of seed to revegetate each of the different micro-sites. Some of the species will not be appropriate for some of the land seeded but will be needed for other areas. The overall use of seed will be less efficient than if the areas were seeded separately, but the entire site can be seeded in one operation.

Native or Introduced Species

When selecting species to be seeded or planted the controversy of whether to plant native or introduced species must be considered. Federal law states that introduced plants may be used under certain conditions.

Introduced species may be approved for reclamation use if they meet qualifications, including: (1) They are desirable and necessary to achieve quick, stabilizing cover to control erosion; (3) they are compatible with plants and animals in the region; and (4) they are not poisonous or noxious (Federal Register, 1979). Many introduced species have been approved for use on mine sites. Some states, most notably Montana, require that some native species be used; none prohibit introduced species. Montana's reclamation law specifies that a diverse, predominately native stand of vegetation be established on reclaimed land (DePuitand Coenenberg, 1979). So, even in Montana introduced species may be used, although dominance by native species is required.

Some researchers agree that introduced species are appropriate for reclamation, and suggest that adapted-versus-unadapted species is a more appropriate concept for species differentiation than is the concept of introduced-versus-native species (Lang, 1976; R. Brown, 1979; Monsen and Plummer, 1978; Thornburg and Fuchs, 1978). Adapted species, according to Land (1976), must meet four criteria: (1) Species must be adapted to the soil, (2) the climate, (3) specific site characteristics such as slope and aspect, and (4) the post-mining land use. If these conditions are met, the species is acceptable for reclamation, regardless of whether it is native or introduced. Other researchers, while not excluding the use of introduced plant species altogether, encourage the use of native species whenever possible (Aldon, 1976; Eddleman, 1979;McKell, 1978).

Native plants are obviously well-adapted to the environmental extremes present at the mining site. The species have evolved under the extremes of heat and cold, wet and dry, wind, snow, and growing season. They have survived and dominated the site because they are adapted for long-term viability under the climatic conditions to which the site is subjected. However, some introduced species, such as crested wheatgrass *(Agropyron cristatum* and *A. desertorum),* have survived for 30 to 40 years without signs of succumbing to the environmental pressures of the northern Great Plains (Vallentine, 1980). It is possible to claim that the persisting introduced species, often called naturalized species, are as well-adapted as the native species. Another argument for using introduced species is that the mined site, even if the topsoil is carefully handled, is not an identical replica of the premining area. Since the soils are disrupted in the mining process, even the native plants may not be adapted to specific post-mining conditions. Those advocating using any adapted plant species may justifiably suggest that naturalized, introduced species are as appropriate as native species for revegetation of these sites.

Introduced species that perform well on disturbed lands generally can survive a wide range of soil and climatic conditions. Many native species, on the other hand, occupy precise ecological niches. Without these niches the species cannot succeed. Using a variety of native species can check the success of a reclamation project. Native species will find their specific niche and show the adequacy of the niche to support vegetation. Eddleman (1979) suggested using native plants with narrow ranges of tolerance to test the quality of reclamation. One possible test proposed for the northern Great Plains would be planting native bluegrass *(Pos sandbergii),* which roots at 2 to 4 feet, and dotted gayfeather *(Liatris punctata),* a deep rooted forb, which roots at 7 to 15 feet in a mixture. If problems establishing one of the species occur, it could indicate a reclamation suitability throughout the year. Introduced species with the ability to handle a broad range of conditions may obscure problems that may be found by using native species. Overlooking present

Western Energy Company
Rosebud Mine

Supplemental Seed Mixture

Species

Grasses
Andropogon hallii
Garden sand bluestem
Bouteloua curtipendula
Pierre side-oats grama
Bouteloua gracilis
blue grama
Calamovilfa longifolia
Goshen prairie sandreed
Oryzopsis hymenoides
Nezpar indian ricegrass

Forbs
Achillea millefolium
western yarrow
Astragalus cicer
Lutana cicer milkvetch
Linum lewisii
lewis flax
Onobrychis viciaefolia
Eski sanfoin
Petalostemon candidum
white prairie clover
Petalostemon purpureum
Kaneb purple prairie clover
Ratibida columnifera
prairie coneflower

Shrubs
Atriplex nuttallii
nuttals saltbush
Atriplex canescens
Wytana fourwing saltbush
Ceratoides lanata
winterfat

Lowland Drainage Cool Season Grass Seed Mixture

Species

Agropyron dasystachyum
Critana thickspike wheatgrass
Agropyron smithii
Rosana western wheatgrass
Agropyron trachycaulum
Revenue slender wheatgrass
Bromus marginatus
Bromar mountain brome
Elymus cinereus
Magnar basin wildrye
Poa pratensis
Troy kentucky bluegrass
Stipa viridula
Lodorm green needlegrass

Uplands Cool-Season Grass Seed Mixture

Species

Agropyron dasystachyum
Critana thickspike wheatgrass
Agropyron smithii
Rosana western wheatgrass
Agropyron spicatum
Secar bluebunch wheatgrass
Agropyron trachycaulum
Revenue slender wheatgrass
Poa compressa
Reubens canada bluegrass
Stipa viridula
Lodorm green needlegrass

Figure 61.— Seed mix at Western Energy Co.'s Rosebud mine

reclamation problems may cause reclamation failure. Using native species for reclamation is more likely to point out problems than using introduced species. Of course, all failures of native species cannot be assumed to be reclamation failures. Some native species will not establish and grow due to changes in the soil from homogenizing the spoils. Some ecological niches will be eliminated entirely and cannot be restored even under the highest qulaity reclamation. Therefore, any native species failures must be carefully evaluated to determine their cause.

Introduced species are usually extremely vigorous competitors both as seedlings and mature plants and aggressively occupy the site. They resist disease, insects and livestock grazing, produce large amounts of seed, and invade new areas (Eddleman, 1979). They are often highly palatable early in the new growth stage and often during late fall, when a late green-up period occurs. However, many species become quite unpalatable throughout the remainder of the year. This feature is very different from the palatability of desirable native forage species. Many introduced species cause problems in maintaining stable, diverse plant communities because of the different preferences livestock and wildlife have for native and introduced species. Where both native and introduced species are available for grazing, animals usually prefer one over the other. When natives are preferred, as is usually the case, the aggressive introduced species often quickly dominate the site. Since the introduced species are so competitive naturally, any advantage provided them by preferential grazing of the native species is capitalized upon. Many introduced species are recommended for use in relatively pure stands; seeding one or two introduced grasses and an introduced legume together might be an alternative. The stand should be fenced away from other stands and from native range, so it can be managed as an individual unit (Interagency Forage, Conservation, and Wildlife Handbook Coordinating Committee, 1977). Using competitive, relatively un-palatable native species leads to a nearly pure stand of introduced plants, especially when the stand is subjected to grazing (DePuit, and others, 1978; DePuit and others, 1977; Vallentine, 1980). If both introduced and native species are seeded together, continued intensive management is required to maintain the stand composition.

Economic factors are also involved in choosing introduced or native species. Introduced species for reclamation are bred for easy collection, production of large amounts of highly viable seed, and adaptability to commercial seed harvesting equipment. Seeds for most of the introduced species are relatively common and inexpensive when compared to native seeds. This is changing somewhat as plant breeders work more with native species. Some cultivated varieties (cultivars) of native species are becoming more reasonably priced all the time. Increased demand for these species will continue to bring the prices down as more work is concentrated on the natives. Of course, any cost comparisons should include the marginal cost of increased management requirements, seeding costs, and finally, the value of the reclaimed land.

Plant Ecology

Ecological factors have a major influence on plant species selection. The species used to reclaim a site must be compatible with the other plants and animals in the area. Plants that are more or less palatable to the major grazing species than other plants on the site will lead to differential grazing and ultimately to a shift in plant community composition. Some plants have special relationships with soil microbes that are vital to the plant's survival. Some plants may have antagonistic effects on other plants, causing problems of plant establishment and continuing plant viability. Species that compete with each other for the same ecological niche, either in space or in time, will not completely occupy the reclamation area. Species that complement each other—shallow and deep-rooting, warm and cool season, shrubs and grasses—more efficiently and completely vegetate the site.

Plant/Animal Relations. — Post-mining use of mined land in the arid and semi-arid West is usually for wildlife habitat and domestic livestock grazing. Provisions must be made to provide adequate food and shelter at the appropriate times of the year. Using the land as spring pasture means that plants grown must be capable of maintaining vigor under early grazing. If the land is to be used as one of several pastures in a rest-rotation grazing system, the plant species must be capable of providing feed at various times throughout the grazing season. The planned grazing system will influence which species are chosen for revegetation. Class of stock, desired wildlife species, seasons of use, and intensity of use all affect which plants will successfully reclaim an area. Even the combination of use is important. Low-growing shrubs that blow clear of snow can be an important source of protein for pronghorns in the winter, but may not provide adequate shelter for sage grouse. The decision of what is grown will favor some wildlife species to the detriment of others. The selection process must include consideration of these differential treatments so the effects are planned rather than a matter of default.

Competition.— If a cover crop designed to temporarily stabilize and protect the soil is planted or seeded, careful selection of the cover crop is required. Several sterile grasses are available; annual grains are also used. Weed-free seed should be used for all seedings, but especially for the cover crop. The cover crop should compete aggressively with the pioneer weedy species that invade the spoils. It should not, however, be a long-lived species nor a prolific seeder that will compete with the species chosen for permanent revegetation of the site.

Species Diversity.—The nutrient values of plant species vary by season. Shrubs provide winter nutrition unavailable from most herbaceous vegetation: forbs are desirable, succulent foods in the spring and early summer; grasses are most nutritious during spring and summer, with declining value after plant maturation. Shrubs loose their nutritive value more slowly and to a lesser degree than do grasses, with forbs midway between the two. Figure 62, taken from a paper by C. Wayne Cook (1971), shows four nutrients required by large herbivores. When comparing the information and the graphs, recognize that forbs are usually very short-lived, weather quickly, and generally are totally unavailable by late summer.

Grasses mature at various rates, but reach annual maturity before late summer. Shrubs mature at various rates also, but commonly reach annual maturity in late summer or early fall. Some species like some members of sagebrush (Artemesia) and rabbitbrush *(Chrysothammus)* do not mature until late fall or early winter. Therefore, grasses may have ample supplies of a nutrient such as phosphrous for a longer period of time than will forbs, because the forbs may mature much sooner than the grasses.

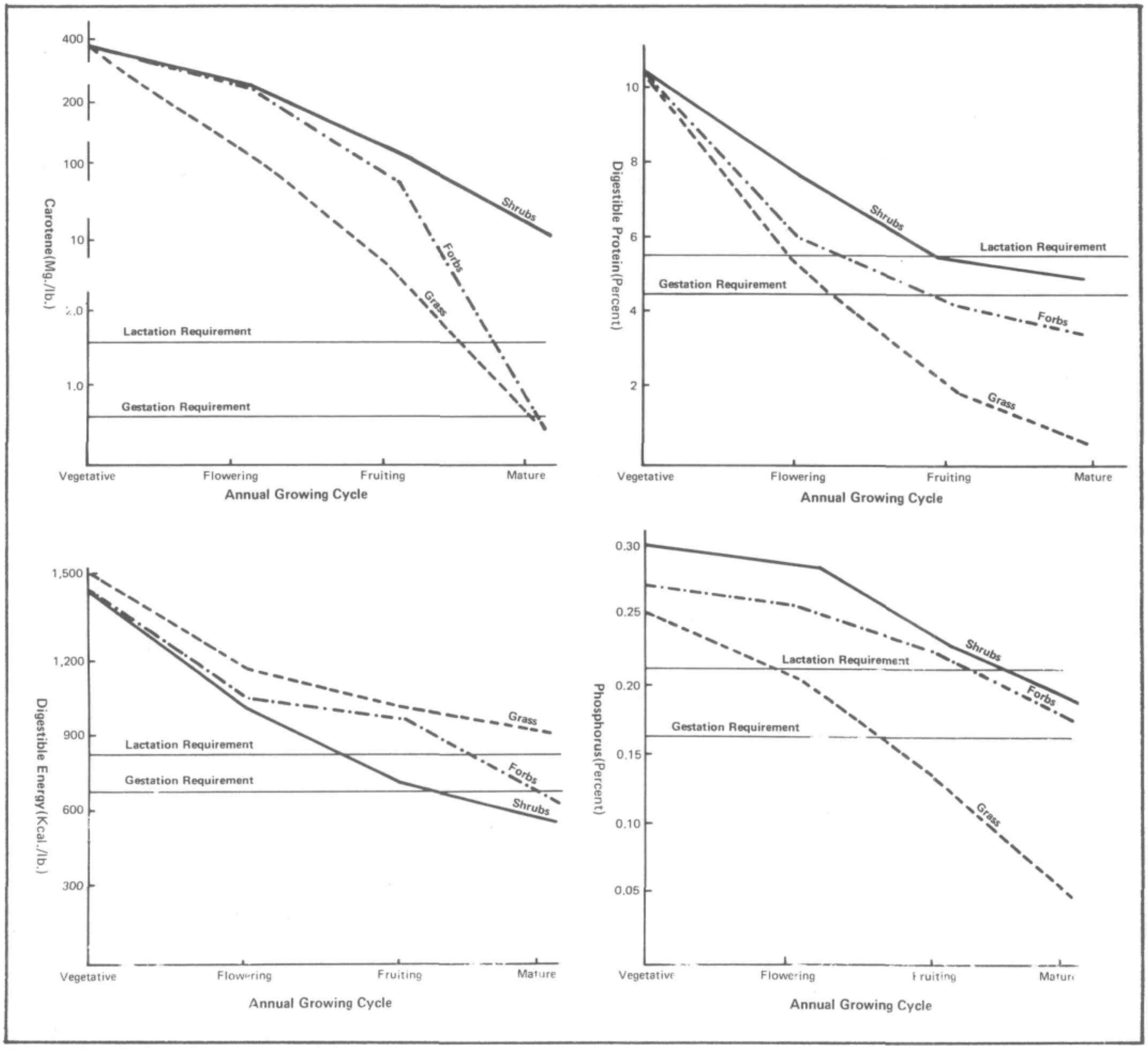


Figure 62.— Selected nutrient values of grasses, forbs and shrubs

Rangeland being used to winter herbivores will be deficient for gestation needs unless: (1) the rangeland contains both grasses and shrubs or; (2) supplemental feeds are provided. Shrubs, while providing sufficient carotene, digestible protein, and phosphorous provide inadequate amounts of digestible energy. Of the four nutrients, digestible energy is the only one that grass provides in adequate quanitites after maturation. The complementary qualities of these two life forms of plants show one reason a diverse plant community is important on rangelands.

Species diversity, in addition to being a legal requirement of reclamation (Federal Register, 1979), is an ecologically desirable goal. By attaining sufficient diversity, the plant community will fully occupy the reclamation site. Different types and species of plants have varied rooting depths, foliage patterns, growing seasons, and nutrient demands. By having varied rooting and foliage patterns, the community can more fully occupy the physical space of the site. Fiberous and tap-rooted plants growing together can use water and nutrients available throughout the soil profile, while a community containing plants with only one type of root uses only a portion of the profile (Fig. 63). Not only is this inefficient use of the site, the chance of soil erosion is greater with a single root type. By filling the profile with roots, the diverse community holds the soil more securely.

A diverse community affords greater variety of both food and shelter for wild and domestic animals. As previsouly discussed, the nutritional needs of herbivores are better provided for on a year-long basis when the plant community has a combination of plant types. Similarly, at any given time of year, the diversity in the community directly influences species that can be supported. Different animal species have different nutritional needs, food preferences, and cover requirements. Increased diversity in these factors increases the number of animal species that can use the community. A wide variety of plant species should be selected for revegetation if reclaimed land will support a wide variety of organisms.

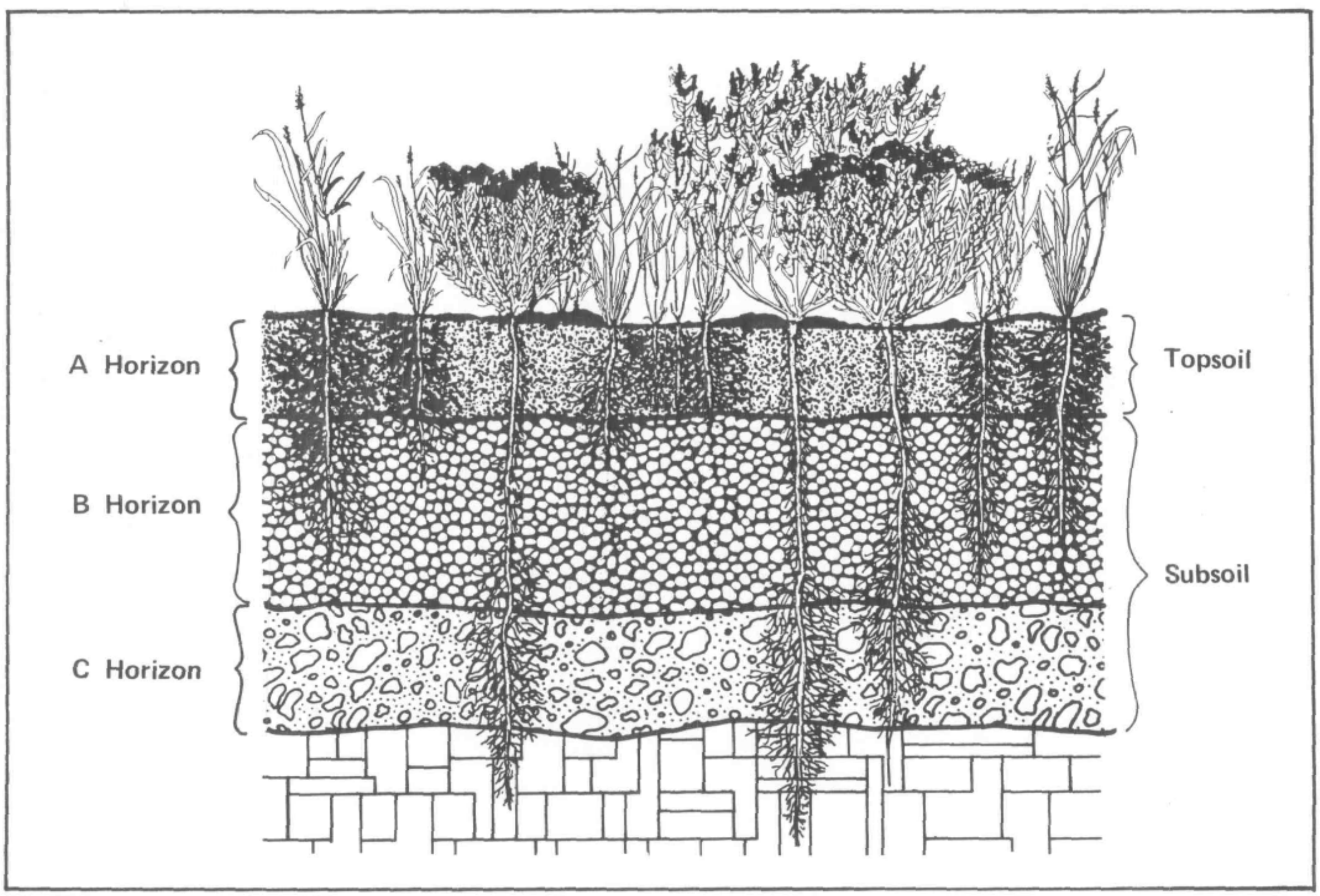


Figure 63.—Soil profile with root systems

Obtaining Seeds and Plants

Seeds and plants for reclamation can be bought from commercial suppliers or collected privately. Commercial suppliers provide seeds, bareroot seedlings, or containerized seedlings of a variety of commonly used species. Mining or reclamation companies can also collect their own seeds or plants. Seeds can be produced under cultivation or can be gathered from naturally occurring stands. Seedlings can be grown in greenhouses or nurseries or can be collected from wildlands.

Commercial Seed Sources

Purchasing seeds from commercial sources exposes the buyer to many potential problems. Since many suppliers have entered the market in recent years, the first task of the buyer is to ascertain whether each potential supply source is reliable. It is easy for an unscrupulous dealer to misrepresent the materials supplied, which can result in a reclamation failure, even when all other practices are done perfectly. Sowards and Balzer (1978) state "the quality of plant materials used in reseeding disturbed lands probably has as much impact on the success or failure of a revegetation project as any other factor subject to the control by the reclamation specialist." The supply of native species is more uncertain and risky than the supply of introduced species. Most introduced species used for reclamation are bred for production of large, viable, easily harvested seed crops. They can often be grown on cultivated soils where they are cared for as any other farm crop. The quality and quantity of these species are dependable and predictable. Suppliers are willing to expand production because they can predict the success of these species. The seeds are cheaper than those of species that are riskier to grow; more ecotypes of each species are often available; problems of low viability are seldom encountered.

Native species, however, are more difficult to grow for seed. Many species produce large seed crops only occasionally. The seed must be checked to determine viability; a large seed crop may not mean a large crop of viable seed. The risk of growing the more difficult species is a hindrance to increased availability. Some native species are adapted to conventional farming techniques. Indian ricegrass *(Oryzopsishymenoides],* for example, can be grown and harvested with relative ease. The supply of Indian ricegrass is predictable and dependable as a result of its ability to be cultivated. Other species, such as western wheatgrass *(Agropyron smithii)* and some salt-bushes *(Atriplex sp.),* have varieties that are adapted to commercial growing. These species are relatively inexpensive and the supply is usually adequate. However, many native species are not so easily adapted to seedcrop production. Seed for species such as bluebunch wheatgrass *(Agropyron spicatum)* and galleta grass *(Hilaria jamesii)* are expensive and sometimes wholly unavailable. Such species have characteristics that hinder mass harvesting of viable seed. Producers are inclined to expand production of such species as Indian ricegrass rather than experiment with more difficult species. The uncertainty of supply of the more difficult species encourages buyers to order the easily grown species so that seed shipments will not be missed. This, in turn, further encourages development of "safe" crops at the expense of developing the riskier crops.

Many native species produce seedcrops that vary widely from year to year. Lack of moisture during seed development, hot, dry weather early in the year, or a cold snap at a critical development stage, can all result in a poor seed crop. When seed production is high, a strong wind can shatter the seed before it can be collected, a hail storm can knock the seed heads to the ground, or insects or disease can destroy the seeds. Many uncontrollable factors can affect the quantity of live seeds obtained from an area. Some natural characteristics of the species may also make seed harvest difficult. For example, galleta grass seed matures from the bottom of the inflorescence to the top, shattering as it matures. This makes it difficult to harvest a large crop, as timing of the collection period must be precise (Sowards and Balzer, 1978).

Precautions must be taken to minimize the problems with seeds that are delivered. Supplies should specify when the seeds were obtained. Some species should not be used if greater than 1 year old. Others have longterm viability and can be used for seeding more than 3 years after harvesting. When ordering seeds, specify the maximum acceptable age of seed by species.

The location of the seed collection site must be specified. Generally, seed should be collected in the area of the mine so that ecotypes are adapted to local conditions. Moving plants to an area where the growing season is shorter will cause the plant to use more of the growing season and will produce a leafier plant. However, if moved where the growing season is too short, plants will winter-kill or fail to produce mature seed. When moved to a longer growing season, ecotypes will grow a shorter period of the season than will local ecotypes and will be overcome by the local plants. Most seeds should not be moved more than 200 to 300 miles north or 150 to 200 miles south of their origin. East or west movements are restricted by precipitation zones, soils, and elevation (Thornburg and Fuchs, 1978; Interagency Forage, Conservation and Wildlife Handbook Coordinating Committee, 1977). Seed users should specify that the ecotypes supplied be from within an acceptable distance of the mine site. Elevations, latitude, longitude, and precipitation ranges should be specified when ordering the seed.

Seed handling by the supplier must be done correctly. When the seeds are dewinged by using a hammermill or other special machine, the seedcoats are susceptible to damage.

Cleaning the seedlot removes seeds of other plant species, dirt, pieces of leaves and stems, insects, and other plant and animal debris. Cleaning methods for most domestic crops are well established and quite dependable. The methods to clean native species, however, are not so well developed. The purity (percentage, by weight, of the seed lot that is seed of the desired species) is a measure of seed lot cleanliness. High purity assures the buyer of freedom from contamination with undesirable species. All seed lots should be tested for purity.

Seed germination should also be tested. Germination tests determine the percentage of seed in a seed lot that will germinate under certain standard conditions. Other measures of seed viability include back-lighting the seed and counting the number of filled seeds by selecting a sample of seeds, cutting them open, and counting those with embryos. High visibility assures optimal germination to establish good stands.

Any purchase of seeds or determination of amount of seed needed should be based on percent pure live seed (PLS) in a seedlot. Percent PLS is determined by multiplying the percent purity times the percent viability. All prices and seeding rates should be multiplied times the percent PLS to put all seed lots on a common base. Calculations (Fig.64) show how to use PLS to determine the relative costs of different seed lots.

Seed lot	Percent Purity	Percent Viability	Cost/Pound (Bulk)	Seeding Rate (PLS)
1	80	50	$3.00	4 lb/acre
2	95	60	4.50	4 lb/acre
3	70	70	4.00	4 lb/acre

These figures will be known for all seed lots. Purity and viability are determined by test, cost per pound on a bulk basis is set by the supplier or is negotiated, and seeding rate on a PLS basis is determined experimentally or on the basis of experience.

To put all the seed lots on an equal basis calculate percent PLS of each.

Seed lot	Percent Purity x Percent Viability = Percent PLS
1	.80 x .50 = .40
2	.95 x .60 = .57
3	.70 x .70 = .49

On a percent PLS basis, Seed lot 2 is the best, 3 is second, and Seed lot 1 is the worst. But since the bulk prices differ the seed lots must be put on a comparable price basis in order to evaluate their relative costs. Cost per pound of PLS is the most feasible base.

Seedlot	Cost/Pound (PLS) = Cost/Pound (Bulk)
1	$\frac{\$3.00}{.40} = \$7.50$
2	$\frac{\$4.50}{.57} = \$7.89$
3	$\frac{\$4.00}{.49} = \$8.16$

This calculation shows that Seed lot 1 is the most inexpensive on a PLS basis, Seed lot 3 is the most expensive, and Seed lot 2 is intermediate in price.

Since seeding rates are based on the amounts of viable seed of the desired species put on or in the ground, seeding rates must be determined on a PLS basis and then applied on a bulk basis. Therefore seeding rates must be converted to a bulk basis, by individual seed lot.

Seed lot	Seeding Rate (PLS) / Percent PLS	=	Seeding Rate (Bulk)
1	$\frac{4 \text{ lb/acre}}{.40}$	=	10 lb/acre
2	$\frac{4 \text{ lb/acre}}{.57}$	=	7.02 lb/acre
3	$\frac{4 \text{ lb/acre}}{.49}$	=	8.16 lb/acre

If Seed lot 1 is purchased, 10 pounds per acre of the seed would be seeded, 7 pounds per acre of Seed lot 2 would provide the same amount of PLS, as would 8.16 pounds per acre of Seed lot 3.

The cost per acre of seeding 4 pounds per acre of PLS is a major concern for reclamation purposes. The cost can be computed on either a bulk price or PLS price basis.

Seed lot	Cost per acre = Cost/Pound (Bulk) x Seeding Rate (Bulk) or Cost/Pound (PLS) x Seed Rate (PLS)
1	10 lb/acre x $3.00/pound (bulk) = $30 per acre or 4 lb/acre x $7.50/pound (PLS) = $30 per acre
2	7.02 lb/acre x $4.50/pound (bulk) = $31.59 per acre* or 4 lb/acre x $7.89/pound (PLS) = $31.56 per acre*
3	8.16 lb/acre x $4.00/pound (bulk) = $32.64 per acre or 4 lb/acre x $8.16/pound (PLS) = $32.64 per acre

*Difference due to rounding.

This calculation shows that Seed lot 1 is the most inexpensive seed lot in a cost per acre basis, with Seed lot 2 and Seed lot 3 successively more expensive.

Figure 64.—PLS calculations

They also show how to determine the amount of bulk seed to use to get desired seeding rates based on PLS and how to compare the costs of seeding each seed lot. These calculations ignore such indirect costs as those incurred from using an impure seed lot that has many weed seeds in it. Use of seed lots with viability rates well below normal for the species is not recommended, even if the seed is relatively inexpensive. Many factors that affect viability rates also reduce the quality and vigor of the viable seeds. As a result, stands established with the low-viability seed lot may be weak and uncompetitive (Interagency Forage, Conservation and Wildlife Handbook Coordinating Committee, 1977). Any decision on seed lot economics must consider not only prices based on PLS percentages, but also indirect costs of purchasing seed lots with large amounts of undesirable seed and the possibility that an unsuccessful stand may result from defective, yet viable seed.

Storage problems often arise if the seeds are kept under moist or hot conditions. Storing seeds with a moisture content of 8 percent or greater promotes various forms of biological life. According to Sowards and Balzer (1978). "at 8 to 9 percent moisture, insects become active; at 12 to 14 percent, fungi become active; at 18 to 20 percent, heating may occur; and at 40 to 60 percent germination may begin." They state that even a few hours at greater than 20 percent moisture may reduce seed viability. The moisture content is affected by the maturity of the seeds, by the time the seeds were dried, and by storing and handling conditions. Most dry seeds are stored best at temperatures between 33˚F and 38˚F (Monson, 1979). For most species storage should be in an airtight container and in a cool, dry environment. Deviations from these conditions reduce viability or reduce storage life. There are exceptions to these requirements, however, so each species should be handled according to its specific needs.

Private Seed Sources

Purchasing seeds or seedlings from a commercial supplier is not always an option. Commercial sources may not be acceptable for a number of reasons. The cost may be too high, supplies may not be adequate, or the mining company may simply wish to have greater control over what they plant. The alternative is to collect seeds privately. To insure the optimum chance of collecting high quality, viable seed, several guidelines should be followed. The foremost requirement is that.the seed should be collected from an area as similar to the revegetation site as possible. One of the greatest benefits of collecting seed privately is that the seed source can be closely controlled. By collecting seed near the revegetation site, where the climate, soils, and plant and animal communities are similar to those on the mined area have influenced and directed the evolution of certain ecotypes, ecologically adapted seeds are insured.

The timing of seed collection operations is vital. Some seed has a short life span; winterfat *(Ceratoides lanata)* seed, for example, should not be used if it is more than 1 year old (Soward and Balzer, 1978). Collection of seed with short-term viability must be scheduled every year. Species whose seeds remain viable for several years may only need to be harvested during years when the seed crop is good. Stockpiling seed from good years eliminates the need to search for seed during years when the seed production is low or of poor quality.

Stands to be harvested should be located well before collection operations begin. The stands should be vigorous, with many healthy, productive, competitive individuals of the desired species. Seed should be collected from a number of individuals of each species, or even from individuals on several different collection sites. Collecting from several sources will improve genetic variability on the reclamation site (Monson, 1979). Plant phenology observations conducted throughout the growing season indicate the proper time for harvesting seed, Eddleman (1978) states that there is a continuum of seed shatter patterns ranging from rapid total seed shatter, represented by Idaho fescue *(Festuca idahoensis)*—(Fig. 65), to slow dispersal over a longer period of time, as shown by Indian ricegrass (Fig. 66). In rapid total seed shatter, virtually all the seed of all the plants on a site mature at the same time. Seed is dispersed over a very short period, sometimes as short as 1 week. Seed collection from plants with this dispersal pattern will yield large amounts of seed if the collection is done at the precise time the seeds are ready. If the collection is done a week earlier, the seeds will not be mature; a week later and the seeds will be gone. Only by close observation of stage of maturity can seed collection be correctly timed.

Species that disperse seed slowly over a long period of time present an altogether different problem. Collecting mature seed can be done over a long period so timing is not as vital; however, the amount of seed available and mature at a single collection time is small. Therefore, seed must be collected from a large number of plants or must be collected several times thoughout the period in which the seeds are ripe. Since different species have different dispersal patterns, the pattern employed by each species to be collected must be determined by observation or by literature research. A schedule to collect the necessary seeds can be designed using phenology data and knowledge of each species dispersal pattern.

Equipment and labor for seed collection must be ready as soon as the seed crop is ready to be harvested. Many species' seeds become loosened on the receptable and are easily dispersed as soon as the seed ripens. A severe rainstorm or strong winds can cause the loss of an entire crop (Plummer and others, 1968). Collections should be done before, not after storms (Monsen, 1979).

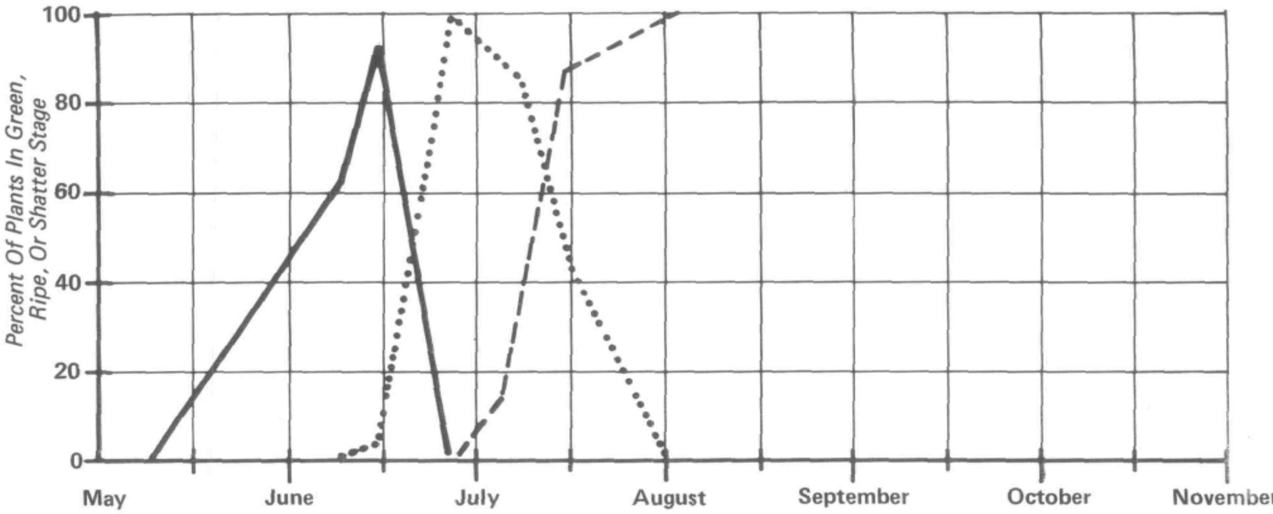


Figure 65.—Idaho fescue seed shatter

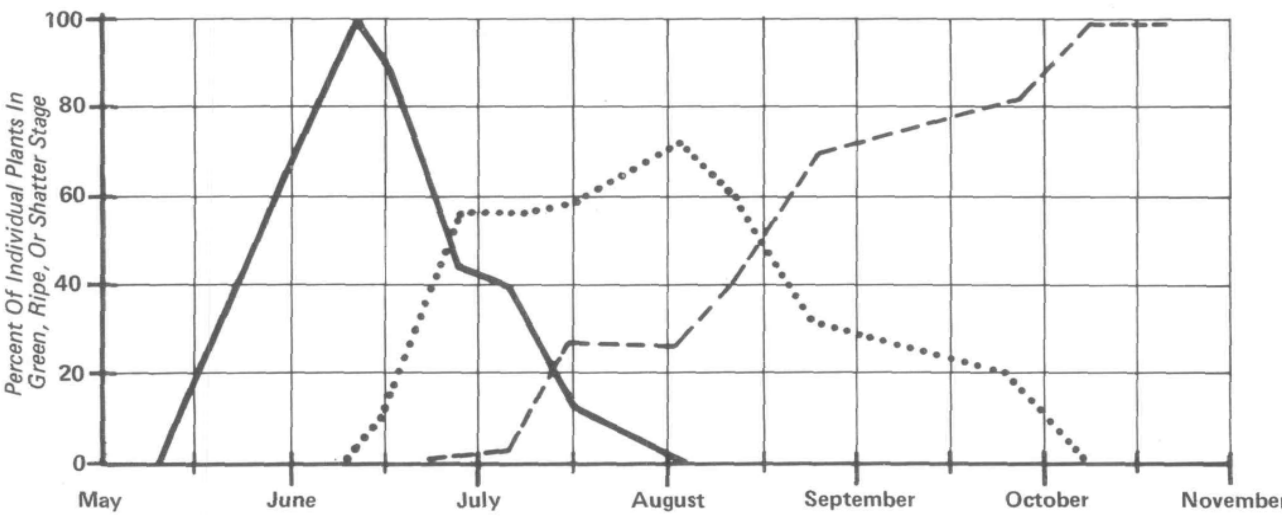


Figure 66.—Indian ricegrass seed shatter

Very few native species produce abundant viable seed crops from year to year (Eddleman, 1980). Phenological observations will provide information about the current year's crop, so that the collection schedule can be adjusted in time to insure collection of enough seeds of the proper species. Collecting a surplus of long-lived seed in years when the seed crop is abundant can safeguard against the lack of seed in years when production is low.

Collected seed should be carefully handled from the time of harvest until it is seeded. Cloth bags are preferable to plastic bags when collecting seed. The seed must be cleaned, dried, and dewinged or deawned. Cleaning, dewinging, or deawning requirements are species specific and should be investigated before the seed is collected. Commercial seed dealers often have specialized equipment to clean and dry native seed. Equipment designed to handle small seed lots is available and can be appropriate for handling native seed.

Seed should be stored in a dry cool environment. Airtight glass or metal containers are preferable to plastic or porous containers (Monsen, 1979). Seeds must be thoroughly dried before they are put into containers for storage. Of course, there are exceptions to these guidelines, so each species should be researched to determine the optimum storage conditions to maintain its viability.

All seed should be properly labeled. Labels should be placed on the outside and inside of each container of seed. Each label should include species name (including the scientific name), suppliers's or collector's name, the date the seed was collected, and detailed information about the location of the seed source. A complete, permanent file kept on each seed lot should include all label information, information about seed purity, viability, and PLS percentages, site characteristics about the collection site, precisely where and when the seed was planted, and dates the collector recommends for future collections (Monsen, 1979). The file should also contain information about the success or failure of the seeding. Any data that could help evaluate the quality of the seed source for reclamation use should be included in the file.

Seed Collection Equipment

Seed collection equipment ranges from conventional farm combines for harvesting uniform stands of grass to sticks and cloth bags for collecting shrub seeds from individual plants. The collection equipment can be purchased or handmade; it can be designed to harvest enough seed to sell commercially or a small amount to seed an experimental plot.

Combines.—Combines (Fig. 67a, b, and c) are machines that cut a crop, thresh it, and store the seed in a bin. The bin can be unloaded into a truck or seed bags. Combines range from very large, expensive grain harvesters used on conventional farms to small machines used to harvest experimental plots. The larger combines are inefficient for harvesting native seeds, but can collect seed from pure stands of such species as crested wheatgrass on a large-scale commercial basis. The smaller combines, particularly those that are towed or attached to a tractor, are more appropriate for harvesting naturally occurring stands, although level, uniform stands of grasses or shrubs can be harvested. Plummer and others (1968) suggest field plantings of native forbs to enable use of combines for harvesting. McKenzie (1977) and Larson (1980) provide further information on small combines.

Figure 67a.— Combine

Figure67b.—Combine

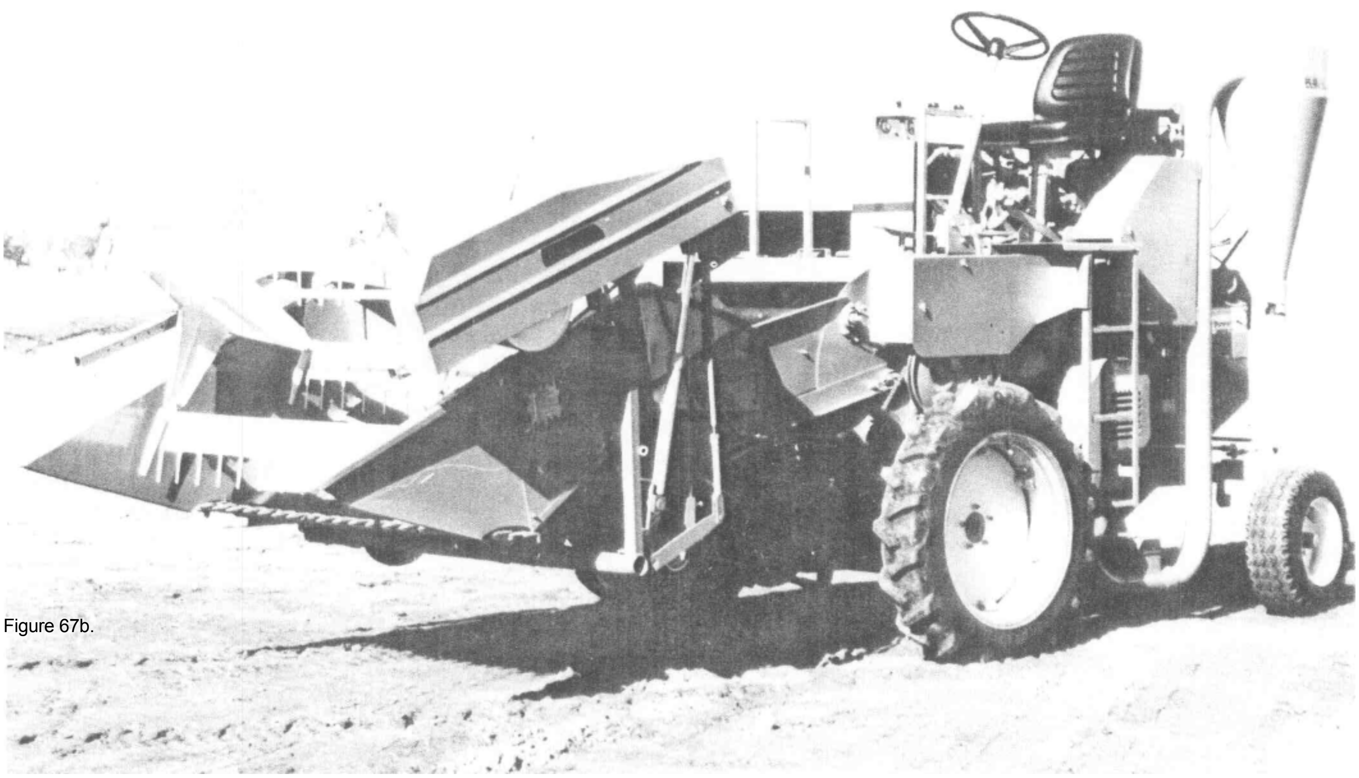


Figure 67c.—Combine

Seed Strippers.—These (Fig. 68) machines strip seed from plants, usually grasses, without cutting the plants. They use brushes, beaters, or reels to knock the seeds off the seed stalks. The seeds are mechanically or pneumatically carried to storage bins or sacks. Strippers collect a variety of seed at the same time; different size, maturity, and species of seed are collected, including small, chaffy seed (Larson, 1980). Since a variety of seeds is collected, seed cleaning and processing must be extensive to produce relatively pure seedlots. Seed strippers are not efficient for large-scale seed collection operations. They are generally used for small plots or native stands. When collecting seed from a winterfat stand, Plummer and others (1968) found strippers lost more seed than did either combines or handpicking.

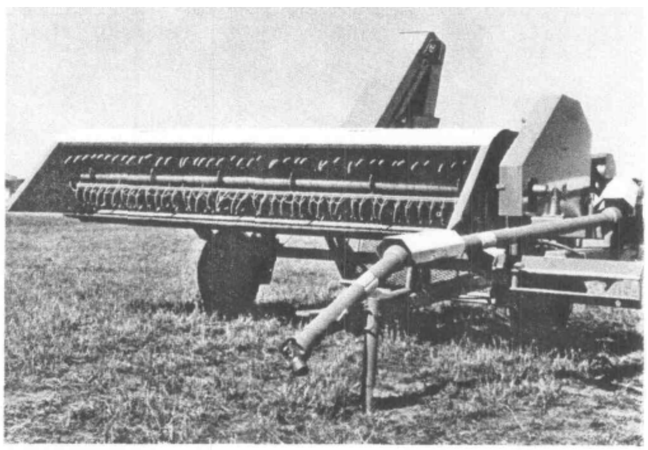


Figure 68.—Seed stripper

Vacuum Seed Collectors.—Collectors range in size from battery-powered, hand-held vacuums to large tractor- or truck-mounted machines with flexible hoses (Fig. 69a and b).

Figure 69a.—Vacuum seed collector

Figure 69b.—Jeep-mounted vacuum seed collector

Vacuums collect seed that is easily dispersed or is on the ground. They do not injure the plants as do combines and seed strippers. Portable vacuums, whether hand-held or backpack models, are not limited by rough terrain. They are well-adapted to collecting seed from plants that are mixed with other species in a stand. Eddleman (1978) used vacuum collectors to gather small seed at or near ground level. Vacuums are ineffective for collecting seed that is firmly attached to the plant seed head; many plants require more force to remove the seeds.

Headcutters.—Headcutters are hand-held shears or clippers used to clip the inflorescences of plants. Rechargeable electric shears or hedge trimmers are lighweight, portable, easy-to-use headcutters. These products, which have gained popularity as lawn-care tools, rapidly and easily cut through dense stands of plants. The inflorescences are clipped, gathered, and stored in paper bags until they can be threshed. Conventional hand-powered clippers can also be used, although they can be fatiguing and are not as productive as the electricity-powered models. When working away from a power source, interchangeable, rechargeable battery packs are essential. Head-cutters are not effective for mass production of seed as they are labor-intensive.

Hand Flails.—Flails are sticks used to hit the limbs of trees or shrubs to dislodge seeds. The seeds are collected in cloth bags or hoppers or by spreading cloth on the ground under the shrub or tree. Hand flails are labor-intensive tools that are most appropriate for collecting seeds from individual plants or plants too large to harvest with mechanical equipment.

Hand Picking.—This method is simply stripping or picking seed by hand and placing the seed into a basket or bag. Eddleman (1978) used handpicking or harvest seeds when the inflorescence was mixed in with the plant leaves or when a low percentage of ripe seed was available at any one time. Plummer and others (1968) suggest handpicking for several shrubs in the composite family and for many native forbs. By definition, handpicking is labor-intensive, with little potential for large-scale collection.

Seed Processing Equipment

Seed process!ng equipment ranges from blowers to macerators to dryers. All are designed to physically prepare the seed for seeding, whether it is to be done aerially, by hand, or through a farm drill.

Seeds must be dried before processing or storage. Different species have different moisture requirements, depending on whether the seed will be stored, the length of time the seed will be stored, and the unique physiological requirements of the species. Seeds are cleaned after they have been dried. Macerators remove pulp from fleshy fruits and berries, dewingers remove awns or utricles, and separators remove empty seeds and trash.

Seed processing equipment for trees and common ornamental shrubs is commercially available. They have been well-designed and used for years. Equipment for processing seeds of native forbs, rangeland shrubs and many native grasses, however, has not been developed. These seeds must be processed with equipment designed for other kinds of seed.

Dryers.—Dryers reduce the moisture content of seeds to the optimum level for storage or planting. The optimum level is different for different species, but for most range species a moisture level below 8 is desired (Sowards and Balzar, 1978). Kilns and ovens can dry seed, but usually native seed collected in relatively small amounts will be air-dried. Drying should take place in a cool, shaded, well-ventilated area. The seeds must be well protected from heat and moisture to prevent molding or other seed degeneration.

Dewingers.—Dewingers break off appendages attached to the seed (Fig. *70s* and b) to assist in natural dispersion. These appendages inhibit broadcast or drill seeding. Hammermills, threshers, debearders, or other dewingers (Fig. 71) break seed wings, plumes, or other extraneous materials away from the seed. They usually have revolving shafts with brushes or rubber flails to rub the seeds against each other or against the inner surface of the dewinger cylinder (Fig. 72). After the trashy materials have been broken or rubbed off the seed, the seed and trash is carried across an airstream. The airstream carries the trash away to a collection receptical and the heavier seed falls into a bin or box. Thus the dewinger can often be used to separate trash from seed as well as dewing the seed. Seeds from species like cliffrose *(Cowania sp.),* saltbush *(Atriplexsp.*), and mountain mahogany *(Cercocarpus sp.)* cannot be completely separated from the utricles that enclose them; only the plumes and outer portions of the wings are removed in dewinging (USDA Forest Service, 1974). Hand rubbing the seed in a sack is the safest way to dewing seed, but it is not practical for any but the smallest seed lots (Lowman, 1975). Dewinging is harmful to some seeds, but the damage can be minimized by choosing dewingers with care and by minimizing the time seeds are treated.

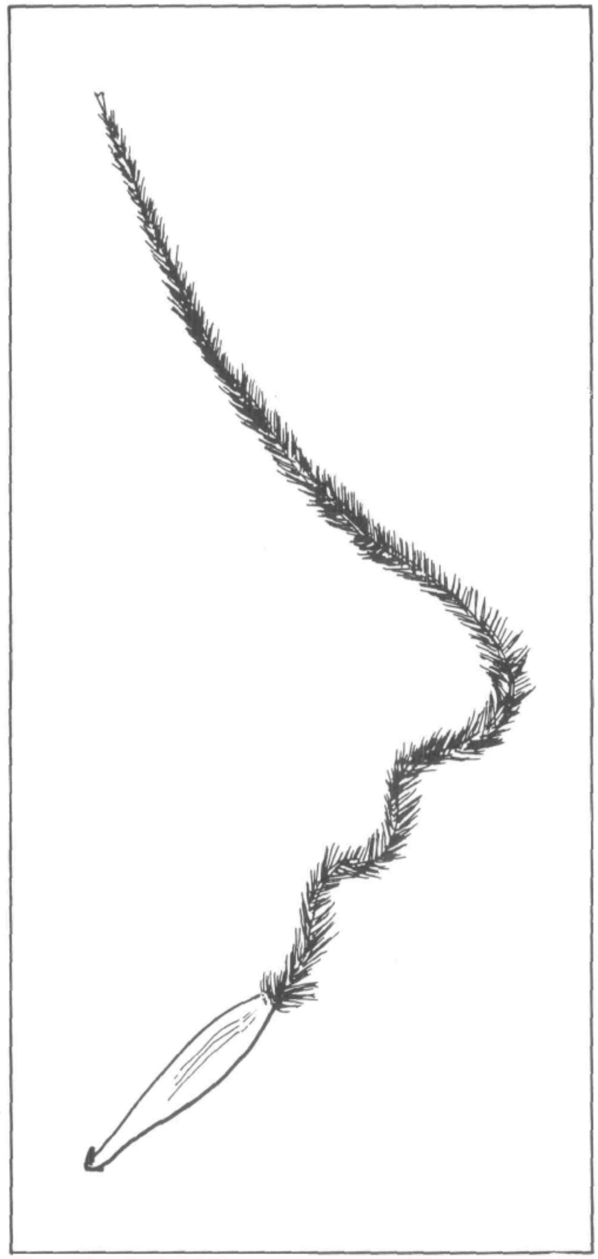


Figure 70a.—Seed with appendages

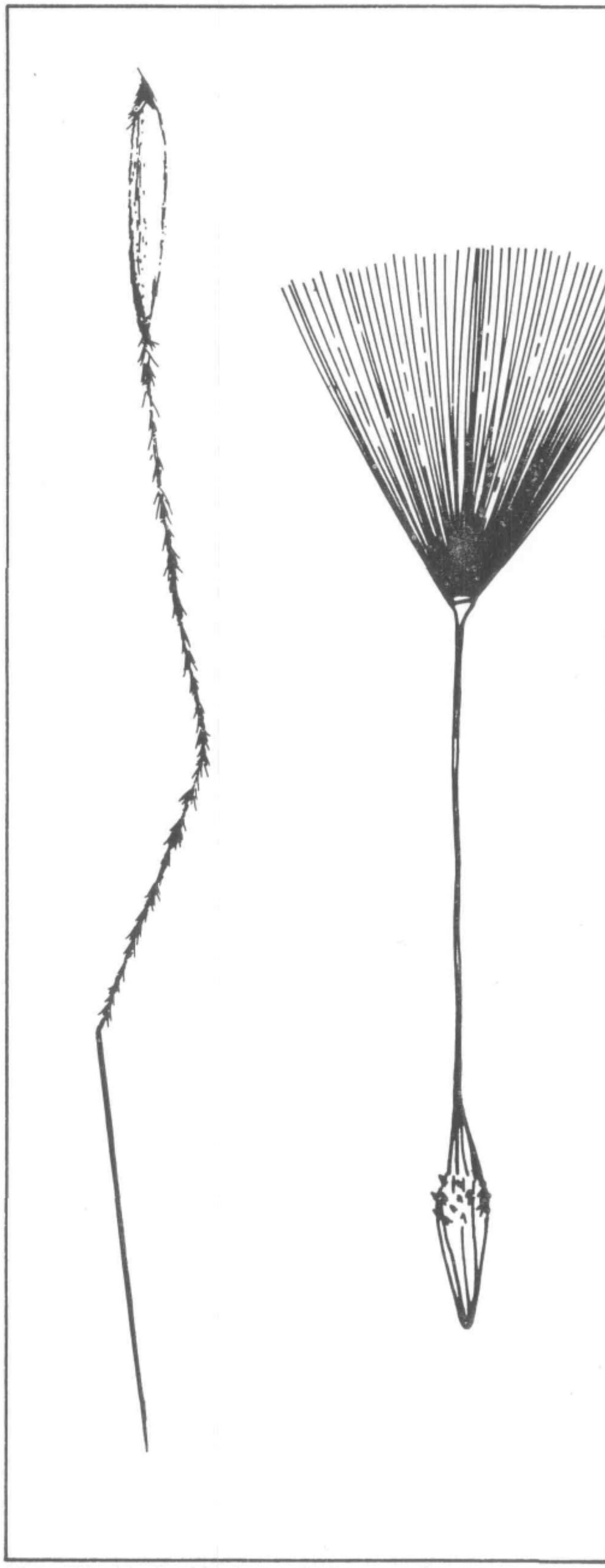
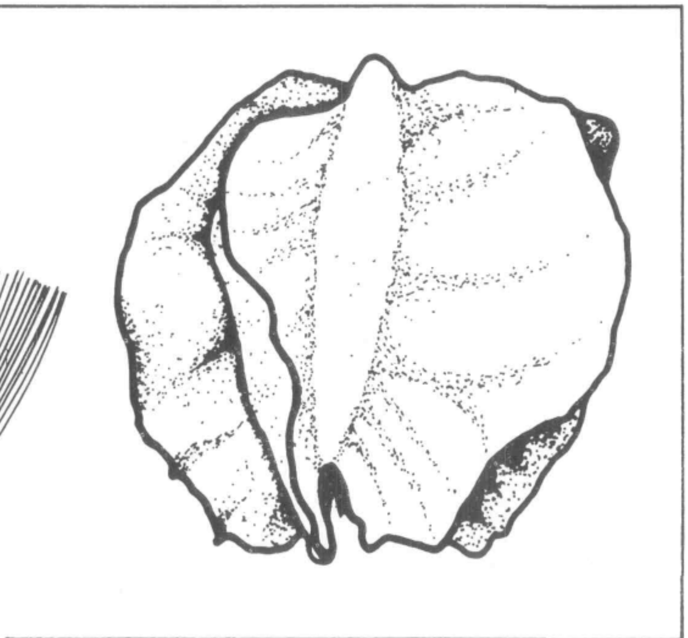



Figure 70b.—Seeds with wings and other appendages

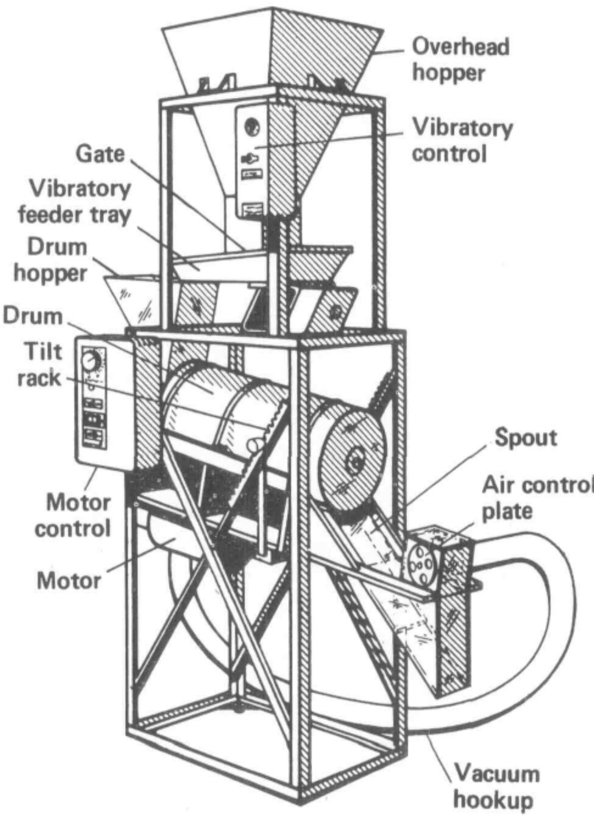


Figure 71.—Dewinger

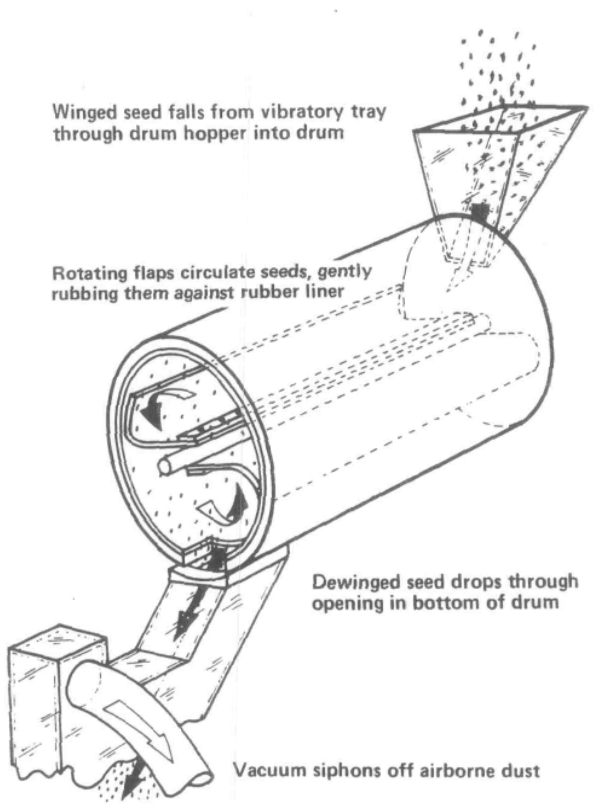


Figure 72.—Dewinger

Cleaners and Separators.—This equipment separates filled seed from empty seed, chaff, and other extraneous materials. Some cleaners can also separate seeds of different species. Cleaners are screens, pneumatic blowers, specific gravity separators, or vibrating separators. Many use two or more methods to improve their cleaning abilities. Figure 73a, b, and c shows several basic methods for cleaning seeds with screens and blowers. The separators are generally used to segregate several different kinds of seed, when the seed collection harvests undesirable seeds along with the desirable seed. Both cleaners and separators improve seed lot purity.

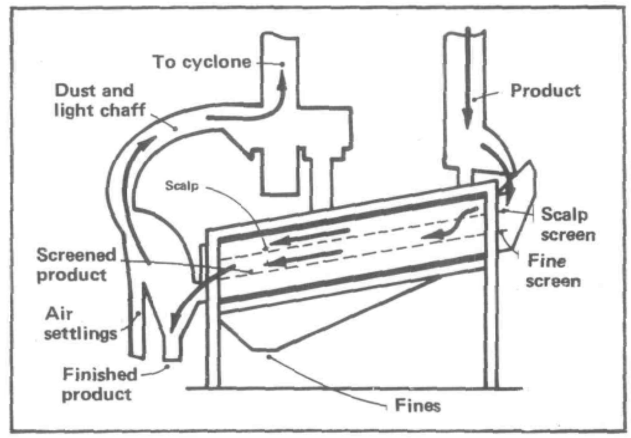


Figure 73a.—Screeners and blowers

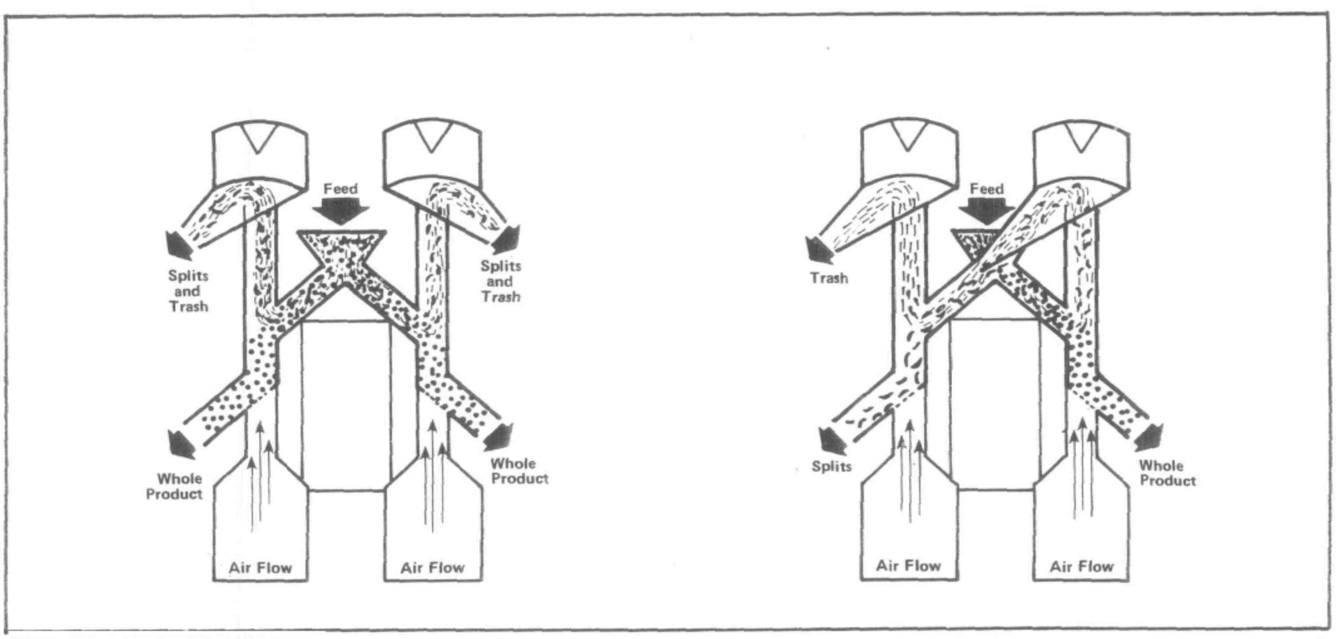


Figure 73b.—Screeners and blowers

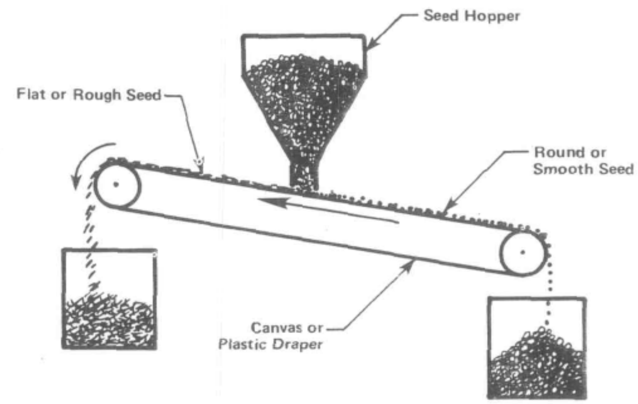


Figure 73c.—Screeners and blowers

Macerators.—Macerators (Fig. 74) clean the seed of pulpy or fleshy fruits. The fruits are put in the macerator, where they are mashed to break up the pulpy materials. Water is flushed through the macerator to carry away the ground pulp. After the maceration is completed, the seeds are left in the bottom of the machine and the pulp is washed away. Plummer and others (1968) report that seeds can be cleaned to 90 percent purity by macerating them and then blowing away the trashy material.

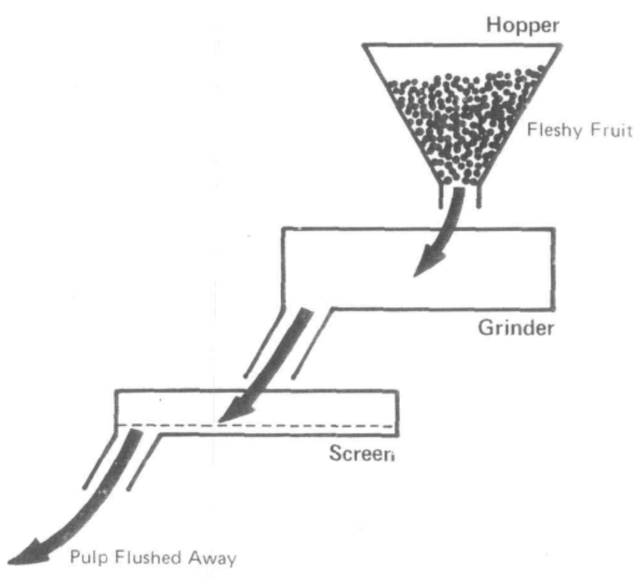


Figure 74.—Macerator

Storage Containers—Containers should keep seed dry, cool, and pest-free. Insects, rodents, and birds will all feed on seeds if given the opportunity. Seeds can be protected in metal cans, granaries, or glass jars. The seed must be dry before closing the containers. Storage in airtight, dry, cool conditions will promote optimum long-term viability. Even so, some species will not be viable after 1 year; most will not maintain viability for more than 5 years. Before collecting seed, the expected storage life of the seeds must be determined.

Lowman (1975), USDA Forest Service (1979b), Eddleman (1978), and Plummer and others (1968) describe equipment for processing seeds. Sources of equipment are cited in these references.

Topsoil As A Seed Source

Topsoil holds a multitude of seeds, bulbs, rhizomes, and roots. Since federal law requires that most mine spoils be covered with topsoil before revegetation, the topsoil is an obvious seed source. The seeds are from species adapted to the site, species that have been on the site prior to mining. The seeding mix is broader than even the most ambitious reclamation project's, but the quality of the seed mix may not be adequate. Topsoil from poor quality range will carry seeds of poor quality species. These species are usually weedy, very competitive, rapidiy spreading pioneer species, and are seldom desirable for reclamation. Poor quality topsoil is not only a poor source of seed, but may actually hinder reclamation efforts. Aldon (1975) reported that most of the seeds germinated from a topsoil study were annuals. Even good quality topsoil may not provide an adequate seed source. Beauchamp and others (1975) found that "although viable seed in the top 2 inches is plentiful,... seeding or transplanting of desired species on strip mine spoil areas would be required." The study showed that the dominant species on the topsoil prior to mining seldom produced the greatest numbers of seedlings when the topsoil was the only seed source. Successful use of topsoil at a time of year when the desired seeds, bulbs and other propagules will be best able to compete with propagules of undesirable species will improve success. Only in very rare cases, however, should supplementary seeding be neglected.

Plant Sources

Plants are available in four forms—bareroot seedlings, containerized seedlings, cuttings, and full grown plants. They are all established plants moved to and planted on the mine site. Problems involving seed germination are eliminated by using plants rather than seeds to revegetate a site. This is particularly important on sites where microclimatic conditions seldom favor germination of desirable species. In the Southwest deserts, on steep slopes, or on other hot, arid sites, seed germination and establishment is particularly difficult. To avoid these problems, plants with established root systems and adequate size are sometimes used. Although seeding is much less expensive than planting, planting is required for some species and on some sites because of the poor results achieved with seed. All plants and ecotypes must be adapted to the sites on which they will be planted.

Bareroot Seedlings. —Bareroot seedlings (Fig. 75) are trees or shrubs that have grown naturally or in a nursery, are dug out of their soil and transplanted on a new site. Most are grown in nurseries. Bareroot seedlings are usually taprooted shrubs or trees. They are seeded in a closely controlled bed, and are grown for 1 to 2 years. The seedlings are removed from the nursery bed while dormant and are kept in a cold storage facility until the site is ready for planting.

Handling and storing bareroot seedlings must be done carefully to preserve seedling viability and vigor. Seedlings should be kept at 32˚F and 35˚F and between 90 and 95 percent humidity. Most seedlings will not survive if they have broken dormancy or have dried out before they are planted. The plants should be allowed to warm slowly the day before they are planted. This acclimatization reduces the shock of planting for the seedling. Seedlings should never be exposed to direct sunlight or to wind.

Containerized Seedlings. —Containerized stock (Fig. 76) are seedlings planted with a soil "plug." The plug is the soil in which the seedling roots have been growing. Containerized seedlings have plugs from 2 inches long to 36 inches long. They are grown in nurseries or greenhouses, then transported to the planting site in the container in which they were grown. Containerized roots are not subjected to the same shocks as bareroot seedlings. Container seedling roots are planted with soil attached to them, allowing them to continuously supply nutrients to the plant. Bareroot seedlings must first penetrate the soil before transporting nutrients. Containerized seedlings are more expensive than bareroot seedlings, therefore they should be used for species that are relatively difficult to establish and for sites that are difficult to vegetate.

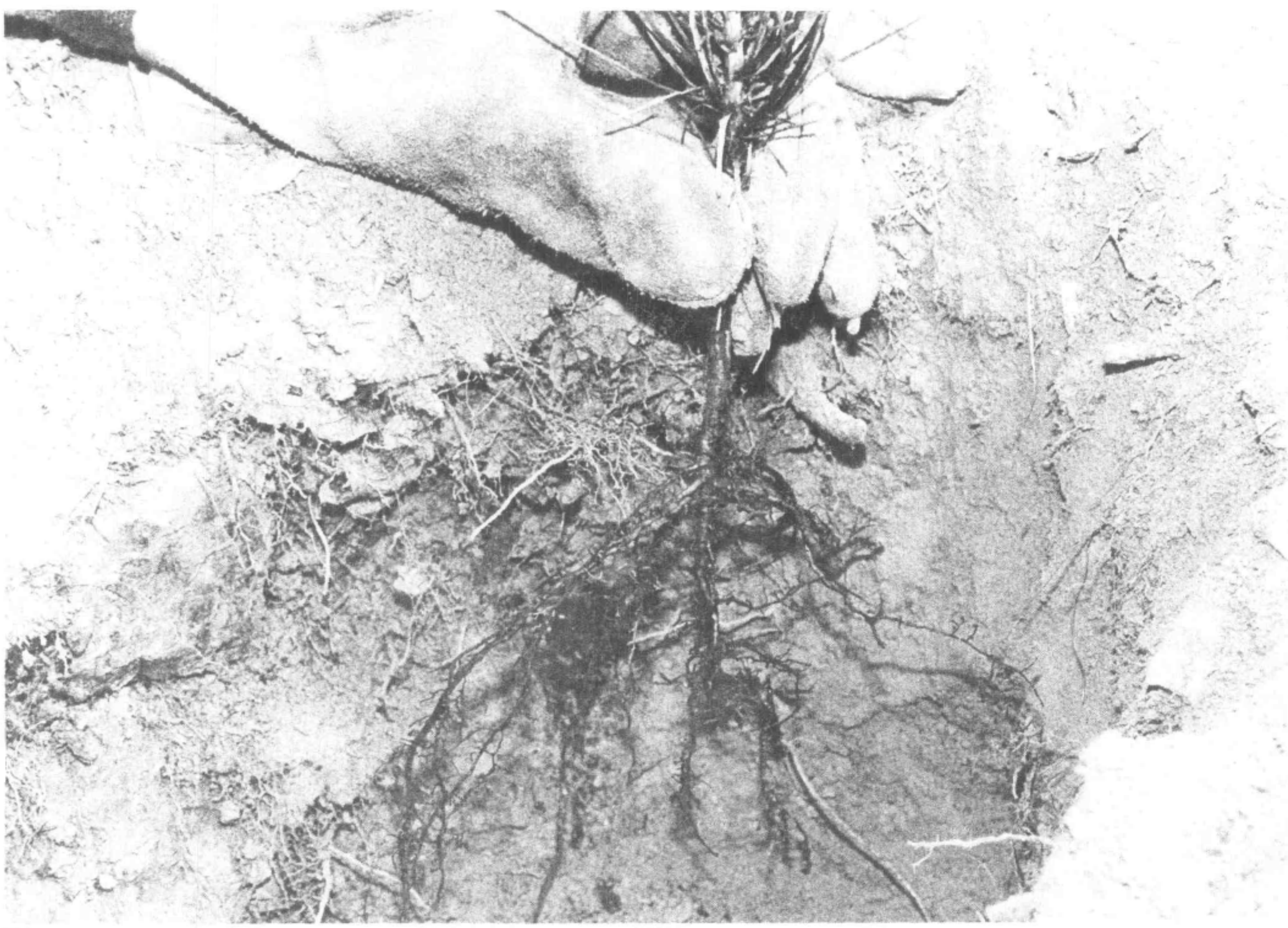


Figure 75.—Bareroot seedlings

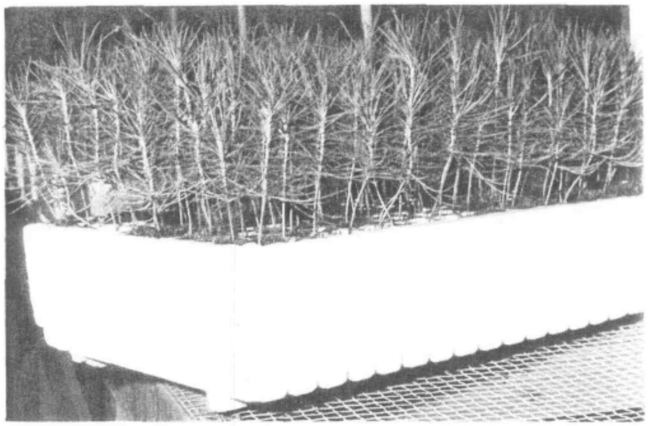


Figure 76.—Containerized seedlings

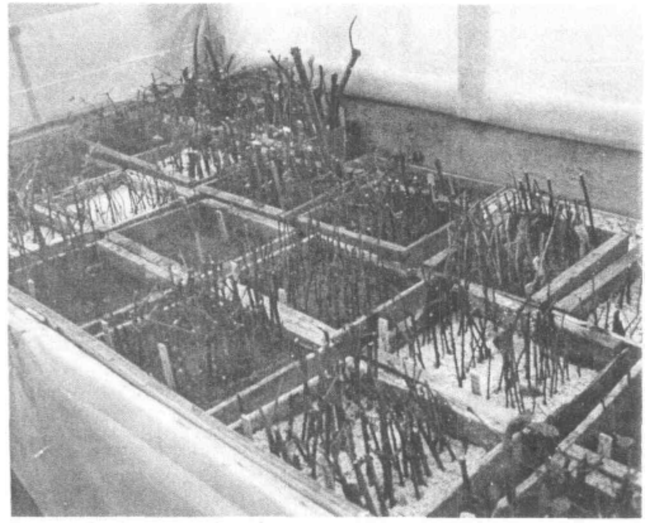


Figure 78.—Cuttings placed in soil

Cuttings. —Cuttings are pieces of plants that can root and grow into a complete plant. Stems of shrubs, clumps of grasses or forbs, rhizomes, or chunks of root mats can all produce complete plants of some species (Fig. 77). Cuttings are obtained from natural stands near the site to be revegetated. The cuttings may be rooted and grown in a nursery or greenhouse (Fig. 78) or may be transplanted immediately to the revegetation site (Fig. 79). Many cuttings are included in topsoil that is moved directly from unmined areas to mine spoils.

Figure 77.—Cutting stems of sprouting shrubs

Figure 79.—Cuttings to be incorporated into spoil

Native Plants.-Native plants are mature plants that occur naturally on the mine site or the surrounding area. These plants are moved as whole plants from unmined areas to mine spoils (Fig. 80). They are adapted to the site because they are living and reproducing on the site. They are ready to move at any time, without any handling or storage problems prior to replanting.

Figure 80.—Root mat on mine site

Seeding and Planting Methods

The purpose of seeding or planting is to place the seed or plant in the soil at the correct time and place to improve chances for successful establishment and growth. The species to be grown and the type of propagule used to vegetate the site will affect the method of seeding or planting. The method will also depend on the climate, soil conditions, and topography of the site. Economic factors also play a part in determining appropriate methods.

Successful planting or seeding depends on proper timing, proper technique, and an understanding of the relationship between plant establishment and planting environment. This section describes and discusses seeding and planting techniques and equipment.

General Principles

General principles for planting and seeding apply regardless of the planting technique or the equipment used. These principles deal with the fundamental plant requirements for establishment and growth and with major factors involving all planting and seeding techniques.

Timing.—Timing the planting or seeding operation is vital to revegetation success. Timing involves the time of year that planting is done, the order in which successive planting operations are carried out, and the relation of planting to other mining and reclamation operations. Planting must be done with seasonal climatic conditions in mind. Packer and Aldon (1978) divide the West into two sections: 1) semiarid region, the Northern Great Plains, and; 2) an arid region, the Southwestern deserts. The optimum planting season for both regions is just before the longest period of favorable growingconditions. This period is the longest period of sufficient moisture, when the soil temperature is high enough to promote germination and not high enough to inhibit growth.

Some species, especially cool season plants, will not germinate at high temperatures. Eddleman (1978) found that temperatures above 59˚F markedly reduced germination of western wheatgrass *(Agropyron Smithii');* he also found that optimum Indian ricegrass germination occurred at 39˚F. Warm season species must have higher soil temperatures than cool season species to optimize germination. Little bluestem *(Schizachyrium scoparium)* and alkali sacaton *(Sporobolus airoides]* showed virtually no germination at temperatures below 68˚F (Eddleman, 1978). When planting, it is obvious that temperature requirements must be considered.

In the Northern Great Plains, precipitation is heaviest from April to September (Packer and Aldon, 1978). Summer rains are mostly short intense thunderstorms that provide relatively small amounts of moisture for plant use. The Southwestern deserts receive 50 percent of their precipitation during the summer months, July through September.

In the Northern Great Plains, with the cold winters, cool springs and falls, and hot summers, cool season plants dominate much of the area. Seeding cool season plants should be done early in the spring before the rainy season begins or late in the fall after the soil has cooled enough to prevent germination. In both cases the seed is intended to germinate in the spring. Seeding in late fall puts seed in the soil where it will germinate as the soil warms in the spring. If seeding is done too early in the fall and germination occurs before winter, the seedlings will not have enough time to harden and will seldom survive until spring. Seeding too late will prevent access to some sites due to snow cover or frozen soils. In southern portions of the region, however, seeding can be done from late fall until February or March. Seeding in the spring is often unpredictable because the time between snow melt and the arrival of spring rains is often quite short. Hodder (1976) states that seedlings must emerge before spring rains begin (Fig. 81). Seeding between snow melt and spring rains severely limits the time available for seeding in some years. Seeding cool season species in the fall is becoming a well-accepted practice in the semi-arid region.

Seeding in the Southwest deserts is more appropriate in early summer just prior to the July and August rains. Warm season plants dominate in this region, where the soil temperatures will be high enough for their germination during the summer. Seeding at other times of the year is seldom successful, due to reduced germination rates or insufficient moisture for the seedling to become well established. Rainfall is unpredictable in this region and moisture is virtually always limiting. Any seeding or planting should be timed to take advantage of periods of moisture.

Time to plant, Northern Great Plains timing matrix

	Spring		Summer		Fall[1]		Winter	
Activity	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**
Direct seeding[2]	Most optimum conditions probable between early March and late April. Seedlings must emerge start of spring rains. Topsoil receives best protection at this time	Access can be a problem		Optimum planting conditions have passed—would require irrigation. Postpone seeding to fall	Provides best access and weather for planting. Stratification important to and shrub seed. More time available to plant	Topsoil and seedbed protection a problem		Seeding on snow is possible but wind may destroy seedling. Seedbed preparation and access are difficult
Bareroot	Essential to plant early between frosts and snowstorms so that roots will develop before buds break dormancy. Plant immediately prior to maximum soil moisture season	Timing is very critical		Storage a problem. Seed dormancy broken. Soil too dry. Plants will burn. Lack of necessary moisture	Plants can be planted when dormant and become better acclimated to site if planted after frost	Some species not adapted to fall planting	Not recommended	
Containerized	Most optimum conditions exist very early in spring between frosts and snowstorms	Disadvantage is that stock is usually not ready or available. Access sometimes a problem	Not recommended		Same as above	Same as above	Not recommended	

Provided by R.C. Hodder

Climate Summary: Considered a continental climate, with warm summers and cold winters. Temperatures can range from -40°F to +105°F. Average precipitation about 12 inches, but can vary from 4 to 18 inches annually in various localities. Precipitation dependent on snowmelt and spring rains that fall between April and mid-June. High wind and high evaporation rates common.

[1] Fall season implies terminal season of the year and that seeds and plants will remain dormant until spring.

[2] Direct seeding involves the use of machinery to place seed in a shallow furrow and cover it with soil. Firming of soil around seeds and placement of fertilizer near to seeds may be accomplished on sites where required. If seeds are broadcast rather than drill seeded, some action to cover them with soil is essential unless it is on freshly graded spoils where natural sloughing will cover the seed.

Figure 81 .—Planting schedule (Packer,1979)

Time to plant, Great Basin Range and Foothills, and Colorado Plateau timing matrix							
	Spring		**Summer**		**Fall[1]**		**Winter**
Activity	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	**recommended**
Direct seeding[2]	Favorable temperature/ precipitation for seedling establishment	Late winter may reduce time available for seeding. Late frost or a short spring may reduce seedling establishment or growth	Not recommended		Seeds may receive needed cold treatment and germinate in late winter	Early winter may prevent completion of seeding operations	Not recommended
Bareroot planting	Plant can establish if planted before summer drought	A short spring season may reduce survival	Not recommended		Plant mid-fall. Avoid late fall planting	Frost heaving in heavy soils. Open winters	Not recommended
Transplanting container-grown plants	Best results for establishment are in spring. Hazards of seed germination and establishment are bypassed	Weather may be a problem in scheduling field work	Possible if can be in moist soil. Long period of planting is possible	High temperatures and drought can be detrimental	Best results for establishment. Plant early to mid-fall	Frost heaving. Open winters	Not recommended

Provided by Cy McKell

Climate Summary: An area of isolated mountain ranges and extensive level valleys where a highly variable frost-free growing season may be from 120-180 days in the valleys and less than 110 days in the foothills. Spring and fall temperatures are generally moderate (50°F), but high summer temperatures may reach in excess of about 98°F. Warm season precipitation from erratic thunder-showers is less than half of the total precipitation of about 6-16 inches annually.

[1]Fall season implies terminal season of the year and that seeds and plants will remain dormant until spring.

[2]Direct seeding involves the use of machinery to place seed in a shallow furrow and cover it with soil. Firming of soil around seeds and placement of fertilizer near to seeds may be accomplished on sites where required. If seeds are broadcast rather than drill seeded, some action to cover them with soil is essential unless it is on freshly graded spoils where natural sloughing will cover the seed.

Time to plant, semiarid timing matrix								
	Spring		Summer		Fall[1]		Winter	
Activity	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**
Direct seeding[2] (grasses)	Cool season species only	Winter moisture variable	Warm season species. More reliable precipitation. Plant prior to July-Aug. rains	None	None	Frost heaving. Limited fall growth	None	Unsuitable for germination and growth
Bareroot (shrubs)	Not recommended		Plant after initiation of summer rains. Soil moisture must be near saturation	Timing critical. Variable precipitation	If summer rains are late, early fall plantings are possible	Frost heaving	Not recommended	
Containerized seedlings (shrubs)	Not recommended		Soil moisture must be near saturation	Variable precipitation	If summer rains are late, early fall plantings are possible	Frost heaving	Not recommended	

Provided by Earl Aldon

Climate Summary: Semiarid mesas and valleys of northwestern New Mexico and northeastern Arizona are characterized by low, highly variable rainfall and high summer temperatures. Highest rainfall months are July and August with occasional late summer storms extending into September. Driest months are May and June. Rainfall varies with elevation, but in lower areas averages 7-10 inches annually. Snowfall light most years and seldom remains on ground. Growing season ranges from 140-180 days.

[1]Fall season implies terminal season of the year and that seeds and plants will remain dormant until spring.

[2]Direct seeding involves the use of machinery to place seed in a shallow furrow and cover it with soil. Firming of soil around seeds and placement of fertilizer near to seeds may be accomplished on sites where required. If seeds are broadcast rather than drill seeded, some action to cover them with soil is essential unless it is on freshly graded spoils where natural sloughing will cover the seed.

Figure 81 .—Planting schedule (Packer, 1979), cont.

On sites where both warm and cool season plants are desired for reclamation, timing planting is very important. One method is to seed warm season plants one year, allow them to become established for a year or two, and then seed again with cool season plants. Competition from the cool season plants may inhibit establishing warm season species. This method is expensive because the area must be seeded twice. Also, seeding into an established stand of plants is more difficult than seeding into a well prepared seedbed.

Seeding warm and cool season species at the same time is a more common practice. Often, however, the climate in the seeding year will favor one type of plant to the detriment of another. Early spring rains without summer moisture will favor cool season plants and reduce the establishment of warm season plants. Seldom will conditions favorable to both types of plants occur. A more intensive method of establishing both warm and cool season species is being used on at least one mine in the Northern Great Plains. A wide range of native shrubs, grasses, and forbs that are difficult to establish are planted and seeded along with a sterile, annual grass cover crop. One to 3 years later, after the difficult-to-establish species have had an opportunity to grow without aggressive competition, a selection of desired grasses specifically chosen for the site are seeded. Small areas within the revegetation site are patch seeded with warm season grasses to simulate small native warm season grass communities within the cool season grass stand. The resultant stand is designed to be ecologically similar to the original premining stand. A diversity of warm and cool season plants, stand variation, in both species and percent composition, on various aspects and slopes, and diversity of plant lifeforms, produce small cornmunities that combine to make the entire stand. Homogeniety is not a normal situation in nature. By intensively seeding and planting, noting differences in site conditions and the species most adapted to the condition, homogeneity is avoided.

Seeding and planting should be done as soon as seedbed preparation is completed. By beginning revegetation immediately, competitive pioneer species will not be given an advantage and the seedbed will not degrade physically or biologically. Quick establishment of a vegetation cover protects the soil from erosion and moderates the soil surface environment, which aids species difficult to establish.

Mining operations usually dictate the timing of soil movement. Often spoils are graded and topsoil spread at times when seeding or planting is not advisable. In these cases, the soil should be seeded to a cover crop or should be stabilized with a mulch. Seeding or planting at inappropriate times, unless the seeding or plantings can be artificially cultured until they are permanently established, is usually an ineffective and costly practice. Seedings made after the period of adequate moisture can be successful if they are irrigated, however the expense of irrigation may be more than that of stabilizing the soil and then seeding at the recommended time. Whenever possible, however, topsoil should be spread on graded spoils at the optimum time for seeding. This will give the best chance of success.

Patterns.—Seeding and planting patterns should be designed to best provide the desired post-mining use. Native range is seldom in symmetrical, well-defined communities with abrupt boundaries between the communities, Native range is a heterogeneous mix of small communities that blend into each other gradually and have few distinct boundaries. The communities are differentiated according to microsite conditions. The heterogeniety of stands is often accented by differences in lifeforms; for example, timber on high slopes, bunchgrass on ridges, shrubs on lower slopes, and rhizomatous grasses in draws. Reconstructing the natural variety and diversity includes seeding and planting species at different rates in various areas. The species and rates chosen are based on site conditions. Trees and shrubs are planted only on sites that would naturally produce them; for example, they are bunched on concave slopes that have increased moisture available. Straight rows and even spacing are avoided. Grasses and forbs are seeded on areas where they naturally occur. For example, western wheatgrass might be seeded in lower areas, on sideslopes, and on ridges. However, mountain brome *(Bromus margmaius]* would be seeded only on low affias, green needle grass *(Stipa viridula)* on sideslopes and ridges, and side-oats grama *(Bouteloua curtipendula)* only on ridges.

Patch seeding, seeding a small area within a relatively homogeneous stand to species different than the majority of the diversity. Patch seeding shrubs into small draws or warm season grasses onto hot exposed slopes are examples of patch seeding that recreate natural conditions found in the Northern Great Plains.

Seeding Principles

Agricultural seeding methods and techniques are well researched and documented. These, however, do not always apply to reclamation of native range. Seeding in straight, well-spaced rows does not duplicate natural conditions. Even so, sometimes the most successful stands are seeded using common agricultural technique modified to reflect the unique characteristics of native seed and mine spoils. Such particulars as seeding rates, seeding depth, seed inoculation, and seed covering must all be determined experimentally for each species. Federal agencies, state agencies, university personnel, and extension services are all currently conducting studies involving various plant species and seeding methods. Requirements for some species may not be available and must be discovered by the reclamation specialist.

Depth.— Seeding depths are controllable only when drill seeding, In general, small seed should be seeded closer to the soil surface than large seed. Valentine (1980) states that ideal seeding depths range from 1/16-inch for winterfat to 1 inch for smooth brome *(Bromus inermis).* Most seeds should be planted from ¼- to ½-inch deep. "Seeding too deeply delays emergence and reduces total emergence. Seeding too shallowly increases desiccation, depredation, and faulty rooting of seedlings" (Vallentine, 1980). Precise seeding depths are determined experimentally.

Covering seed is important in the arid and semi-arid West. Some seeds will not germinate when uncovered; birds and rodents feed heavily on the available seed, and uncovered seed may wash or blow away before it germinates and roots. Drill seeding, by definition, places seed into the soil, with soil over the seed. Broadcast seeding spreads seed on the surface of the soil. Because of this, broadcast seeding has been considered to be inferior to drill seeding (Vallentine, 1980; Packer and Aldon, 1978). Since covering the seed is the important factor, any technique that results in seed incorporation into the soil is satisfactory. Broadcast seeding onto a fluffy, loose, well-broken seedbed often allows seeds to fall into soil cracks, under small clods of soil, or between soil particles. Weather conditions such as frost heaving can sometimes cover seed of equipment such as disk harrows or chains can be used to cover the seed.

Rates.—Seeding rates depend on a number of factors, including soil productivity, available moisture, seeding technique, species being seeded, and desired plant community conditions. Seeding rates that are too low may result in sparse stands that are subject to invasion by undesirable weedy species or may fail to stabilize the site. Excessive rates waste seed and may result in stagnant, overly dense stands with reduced plant vigor (DePuit and others, 1980; Stoddart and Smith, 1955).

Rates must be based on pure live seed (PLS) percentages. Any other method of evaluating seeding rates give rates that do not compare from species to species nor from seed lot to seed lot. Figure 64 on page 49 shows computations to derive and use PLS percentages. The amount of PLS seeded is usually determined experimentally. Depuit and others (1980) report there is little research on seeding rates applicable to revegetating mined lands. Much of the literature recommends rates for species seeded individually, while most mined areas are seeded with mixtures of seed. Cook and others (1974) state that mined sites may require heavier seeding rates than do sites that have not been disturbed.

In a seed mixture, the amount of seed from each species is affected by the intensity of the overall seeding program. If the program calls for a single mixture for the entire area, seed amounts must ensure sufficient seed to establish an adequate stand on all the sites seeded. By including enough seed of species adapted to drainage ways and other low areas, some of the seed will be wasted on dry ridges and steeper slopes. When several seeding mixtures are used, each mixture with species adapted te different specific sites in the area being reclaimed, less total seed is required. Relative amounts of each species will vary depending on the site each mixture is designed to seed. For example, in lowlands in the Northern Great Plains western wheatgrass will often dominate the seed mixture; on ridges, western wheat grass will be a minor component in the mix.

In many areas cool season species are easier to establish than warm season species. To counteract the competitive advantage enjoyed by cool season species, warm season species seeding rates are increased in proportion to the amount of warm season plants desired. Since the seeding rates are computed using PLS percentages, germination advantages are compensated for automatically. Competitive advantages must be accounted for with the proportions of each species in the seed mix.

Scarification.—Some seeds require special treatment to germinate. Scarification of the seed coat, stratitification (subjecting seed to termperatures between 32˚F and 40˚F for 6 to 20 weeks in moist sand, peat moss, or moist newspaper (Plummer and others, 1368)), or both are sometimes required before seeding. Individual species have specific requirements that can only be determined through experimenting. Researchers have published the requirements for some species (Eddleman, 1978; Plummer and others, 1968; Vallentine, 1980).

Inoculation.— Inoculation of legume seeds is important to ensure successful establishment and production in revegetation seedings. Inoculation provides bacteria for nodulation and nitrogen fixation (Valientine, 1980). This is particularly important when dealing with mine spoils. Disruption of the soil, even though the topsojl has been segregated and replaced on the spoil, can result in a reduction or elimination of the specific bacteria needed by each legume. Most commercially available legume seeds have been inoculated; if there is any doubt, inoculate the seeds. The Interagency Forage, Conservation, and Wildlife Handbook Committee (1977) recommends reinoculating any legume seed that has been inoculated more than 48 hours before seeding. Inoculation of native legume seeds is often difficult since many have no commercial inoculant available and the necessary bacteria often differ between species of legume. Hodder (1976) collected topsoil from under undisturbed native stands of the desired legume and spread it on the plots to be seeded. This technique provided adequate inoculant for legume establishment and nodulation for native species with no commercially available inoculant.

Mycorrhizae are fungal mycellium that have a symbiotic relationship with plant roots. They increase the uptake of various soil nutrienis by the roots, In turn, the mycorrhizae absorb carbohydrates from the plant roots. Growth of mycorrhizae-infected plants is superior to that of uninfected plants, especially on low fertility soils (Buckman and Brady, 1969; Black, 1968). Mycorrhizae increased both growth and survival of fourwing saltbush *(Atrip/ex canescens)* on mine spoils (Aldon, 1975). At least 14 shrubs native to the arid and semi-arid West have mycorrhizae associated with them (Aldon, 1976). Assuring that mycorrhizae associated with the seeded species are available on the reclamation site will improve productivity and survival on reclaimed lands. Use of topsoil with the necessary mycorrhizae is usually sufficient, but if the topsoil has lost the mycorrhizae or, if an otherwise acceptable subsoil is used as topsoil, the mycorrhizae should be added to the soil or the seed mixture. Mycorrhizae is seldom available commercially for species other than nursery grown trees. The most practical method of spreading noncommercial mycorrhizae is gathering the puffballs or other fruiting bodies, grinding them and mixing the ground spore with seeds or spraying them on the site in a water solution.

Planting Principles

Planting is moving a plant propagule (other than a seed) or a complete plant to a new site and placing it in the ground to grow. The propagule can be a cutting, sprig, rhizome, or bulb. A complete plant has both roots and above-ground parts, although it can be immature or mature.

Acceptable planting techniques vary by species being planted, time of planting, soil types, and competition present on the planting site. Rhizomatous species generally can be well planted using any techniques. Some shrubs will sprout roots if their stems are cut and placed in a moist soil medium; some trees will die when they are moved, but saplings will sprout from the root mass; some plants must be moved with a massive root ball in order to survive. Planting methods must be matched with the species being planted.

Planting, especially planting young trees or shrubs, must be done so competition from other species on the site is minimized. Special methods for eliminating competition or for increasing the trees' or shrubs' competitive capabilities are often required.

Planting techniques are more expensive than seeding in virtually all cases. Costs of planting vary widely between methods. Therefore, any planting must being considered should be the most inexpensive to produce the desired results. Planting bareroot tree seedlings is much cheaper than using a tree spade to transplant 20-foot high trees. However, if the objective is to have a clump of 20-foot high trees on a site, the long-range costs may dictate use of the tree spade. If establishment of a specific density of trees per acre, regardless of size, is the objective, then planting seedlings would be least costly.

Jensen and Hodder (1979) found that bareroot seedlings and containerized seedlings planted in southeast Montana resulted in significantly different survival rates for some species, depending on the planting method. While bareroot stock is virtually always less expensive to grow and plant, the differences in survival rates justify using container seedlings to establish some species. For other species bareroot stock survive as well or better than container stock, so use of bareroot stock is more cost-effective. The relationships carry through when comparing all planting methods; the most cost-effective method for establishing the desired species in adequate numbers and of adequate size should be used. Care should be used in extrapolating cost figures and plant survival and growth figures from one area to another. Changes in soil, climate, topography, and planting costs can affect the relationships among the various methods.

Seeding Techniques

There are two basic seeding techniques for reclamation sites, drill seeding and broadcast seeding. Broadcast seeding can be divided into ground seeding, aerial seeding, and hydroseeding.

Drill Seeding.—Drill seeding is placing seed in a soil furrow and covering it with a relatively precise amount of soil. This technique is considered by many authors to be the best method of seeding (Packer, 1979; Packer and Aldon, 1978; Larson, 1980; Vallentine, 1980). Drill seeding allows a minimum amount of seed; the seed is well distributed; seeding depth is controlled; and the seed is well covered. Seed germination is more dependable when the seeding depth is precise and the seed is well covered. Drill seeding equipment is common, handles many types of seed, and can drill fertilizer or herbicide while seeding.

Drill seeding is more limited than the broadcast seeding techniques. Seedbed preparation must leave a relatively loose surface for conventional drain drills. Steep slopes cannot be seeded with drills. Drills may not be able to handle small seeds or seeds with awns, plumes, or wings. Seeds of varying sizes and shapes may be unevenly distributed. Drills may need a carrier such as grit, sawdust, or rice hulls to keep small or trashy seed flowing. Seeds should be placed in the bottom of the furrow; if seeds are drilled into the sides or ridges of the furrow, the seedlings will be less likely to survive.

Drill seeding is more expensive than broadcast seeding in most cases. An exception is when seed costs are high; because of the accurate, precise placement and even distribution of seed, less seed is used for drill seeding than for broadcast seeding. This is an important factor when native seed that is difficult or expensive to obtain is being seeded. Drill seeding increases the area a given amount of seed will cover.

Broadcast Seeding.—In most cases, broadcast seeding is an inexpensive, rapid method of seeding land. Inaccessible areas can be seeded by planes, helicopters, or hydroseeders. Any mixture of seed can be seeded; fertilizer can be applied at the same time as the seed.

Ground seeding is the most common type of broadcast seeding. It is done with hand-held or tractor-driven equipment that spreads the seed on the ground. Often a mechanism such as a drag chain covers the seed with soil: Aerial seeding is rarely used for broadcast seeding on mined lands. Results from past aerial seedings have been disappointing. A main reason for seeding failures stems from the inability to cover the seed with soil. Hydroseeders blow seed on the ground in a slurry or water; fertilizers, herbicides, and mulches can be blown at the same time. Hydroseeders are relatively expensive and require large amounts of water. They are used mainly for steep slopes, rough terrain, or other area where access is a problem. Covering the seed is accomplished by spraying mulch in a separate operation after seeding.

Seed expenses are often high with broadcast methods when compared to drilling methods. Various authors suggest using up to twice the recommended PLS amounts for broadcast seeding than for drill seeding (Packer and Aldon, 1978; Plummer and others, 1968; Packer, 1979; Valllentine, 1980; DePuit and others, 1980). Seed distribution is often patchy, especially if a seed mixture of different sizes and weights is broadcast. Broadcast seed, even when pressed or dragged to provide a cover of soil, is susceptible to depredation by birds, insects, and rodents. Broadcast seed is not covered as well as drilled seed.

Planting Techniques

Planting is moving whole plants or pieces of growing plants onto a site and putting them in the soil so they will grow. The plants can be seedlings or mature pieces of roots, pieces of stems, a clump of a root mat, or an entire shrub, with numerous stems and suckers. Techniques range from hand planting to sprigging to transplanting.

Hand Planting. —Hand planting is a common method of planting seedlings and cuttings. Hand planting is by definition a labor-intensive technique. The plants are placed individually, with the planter controlling location of the planting holes. The quality of planting often depends on the competence and concern of the individual planters.

Seedlings are carried onto the revegetation site and are placed in holes dug with handtools, using either manual labor or motorized augers. Bareroot seedlings are planted so that their roots extend downward, roots that are J- or L-shaped will not survive (Fig. 82). Soil is packed in the hole around the roots. Packing must be firm, leaving no airholes (Fig. 83), but care must be exercised so that the roots are not torn or ripped. Containerized seedlings are easier to plant because the roots are extended downward and are protected by the soil in which they were grown. The plug must be well packed in the planting hold. All hand-planted seedlings should be placed so their root crown is at or slightly below the soil surface. The USDA Forest Service (1981) describes general hand planting principles that can be applied to planting on mined lands.

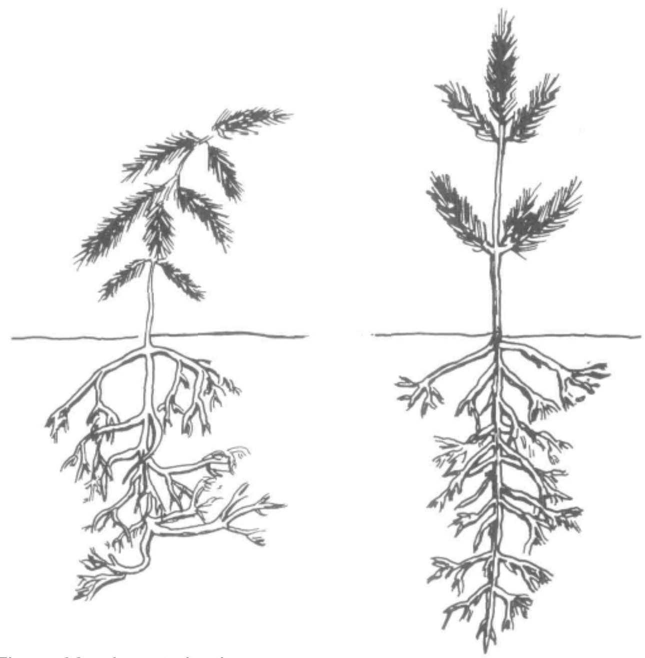


Figure 82.—L-root planting

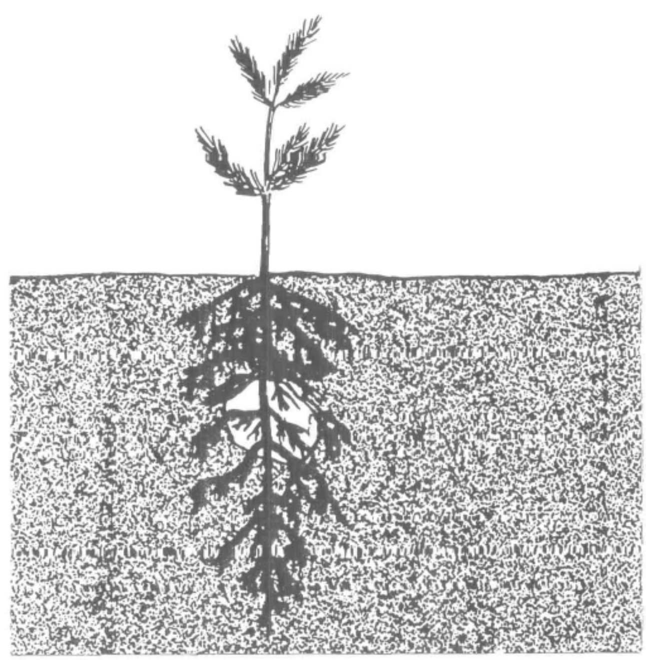


Figure 83.—Airpockets in hand-planting holes

Cuttings, especially stem cuttings of sprouting shrubs, are often hand planted. The cuttings are simply stuck into moist loose soil. They will root from the cut end of the stem and either begin growth by sprouting from the roots or will continue growth with the stem.

Wild seedlings can be hand planted by digging them out of areas that have not been stripped and planting them on top-soiled spoils. The technique is the same as that used for bare-root seedlings. Wild seedlings are sure to be adapted to the area, but are often not as vigorous as seedlings grown in nurseries or greenhouses. Wild seedlings are less expensive than cultured seedlings, but are often not as successful as cultured seedlings grown from seed adapted to the reclamation area.

Machine Planting.—Machines can plant all types of plants, from cuttings to seedlings to mature trees. Machines that transplant bareroot seedlings, containerized seedlings, or mature trees dig a hole, place the transplant into the hole, and then pack soil around the root of the plant. Machines used to plant cuttings, sprigs, or root pads usually move both the plant and some soil to the transplant site (Fig. 80). They lay the materials on the spoils rather than placing the material in a hole.

Machine planting is faster and sometimes more economical than hand planting. Machine planting root pads or small cuttings such as sprigs or rhizomes is much more efficient than hand plantings. Moving mature trees by hand is virtually impossible; if they are to be transplanted, machines are required. Bareroot and containerized seedlings can be well planted by machines, but the cost of the machines and the time required to plant deep-rooted plants may sometimes make this economically undesirable.

Bareroot and containerized seedlings are machine planted using conventional forest tree planters or tubling planters especially designed for mined lands. Tree planters cut a furrow into which the plant is placed. The furrow is then closed around the soil plug or the roots of the plant. Straight rows of plants are planted with no variation in plant density, species diversity, or planting pattern. The result, if all the plants survive is a uniform monoculture of plants. Variations can be made by changing the distance between plants, by planting several species, or by driving the planter so that the plants are not in straight rows. Since most reclamation areas are not uniform, it is often advantageous to confine planting to areas where the species will establish and grow, rather than planting a uniform stand of plants when they will not survive on parts of the area.

Tubling planters drill individual plant holes and drop containerized seedlings into the holes. The planting sites are individually selected and can be closely controlled to optimize the use of the rather expensive seedlings.

Cutting and sprigs are dug with machines that cut under the soil surface, loosening the plant parts and the soil surrounding them. They are then lifted with some soil and carried to the area to be planted. In most cases they are simply spread over the area. Since they seldom grow unless supplied with an ample amount of water at the time they are moved, some machines have watering equipment to moisten the soil and sprigs as they are spread. Watering equipment is not necessary when the soil is wet. Sprigs and cuttings are most successful when planted just prior to the annual rainy season.

Root pads are dug out of an unmined area, carried to an area being revegetated, and laid on the surface of the soil. The pads are dug with broad, flat shovels on mechanized equipment. These shovels cut under approximately 25 inches of soil and lift a pad of sod, with the plants left intact. The root systems hold the sod together. When the pad is laid on the revegetation area, the roots are not disturbed; they continue to grow and supply nutrients to the plants.

Root pads are excellent for planting shallow-rooted plants and plants that sprout from the root crown. They are not capable of planting deep tap-rooted species. The shovel cuts tap-roots, killing the plant. Some tap-rooted plants that sprout from the root crown can be transplanted. The stem that is moved often dies, but the sprouts take over the site.

Mature trees are moved with large transplanting machines. The machines dig under the tree to loosen a large ball that contains enough roots to keep the tree alive. The ball is placed in a hole dug on the site to be reclaimed. The tree is supplied with nutrients by roots in the ball until the roots penetrate new soil. Trees up to 6 inches in diameter can be transplanted. Tall trees that might blow down can be held erect with guy wires until the roots have penetrated far enough into the spoil material to firmly anchor the tree.

Mature trees with shallow tap-roots will be more likely to survive than will plants with deep tap-roots. Although the root ball may be more than 40 inches deep, cutting the main stem of tap-rooted species will reduce their survival capacity.

Seeding and Planting Equipment

Seeders

There are two types of seeders, drill and broadcast seeders. Drill seeders place seed at a precise depth in the soil and cover the seed with soil. The seeds are placed in individual rows, with bare ground between rows. Broadcast seeders spread seed on the soil surface. The seed is distributed randomly, without rows or precise seed placement.

Grain Drills.—Grain drills (Fig. 84) are conventional farm equipment that plant grain or grass on well prepared seedbeds. They can also apply dry chemical fertilizer as they seed.

Grain drills consist of plows that open furrows, seed hoppers that carry seed and fertilizer-metering devices that control the flow of seed and fertilizer, and packers that cover and sometimes pack the furrow after it has been seeded. The drills are pulled behind a tractor. They should be pulled along slope contours so that the furrows do not create or accelerate erosion. The seedbed should be relatively smooth, free of rocks, and should be loose enough that the drill can pass easily through the soil.

Grain drills place seed quite precisely. Depth-regulating bands control planting depth, the metering devices vary the rate of seed flow, and furrow spacing can be changed. The furrows can be packed after they are covered or can be covered with loose soil.

Grain drills are not suited to rough, rocky terrain nor areas with brush or stumps. They are not rugged enough to withstand sustained rough treatment. Seedbeds must be smooth and loose for effective use of these drills.

Pasture Drills.—Pasture drills (Fig. 85) are essentially rugged grain drills. They are designed to seed into stubble, pasture, or rangeland and are therefore capable of seeding areas that are not as well prepared as those seeded with grain drills. They drill light, fluffy or chaffy seed, which is desirable when seeding many native seeds·

Pasture drills are not able to work very rough, rocky sites.

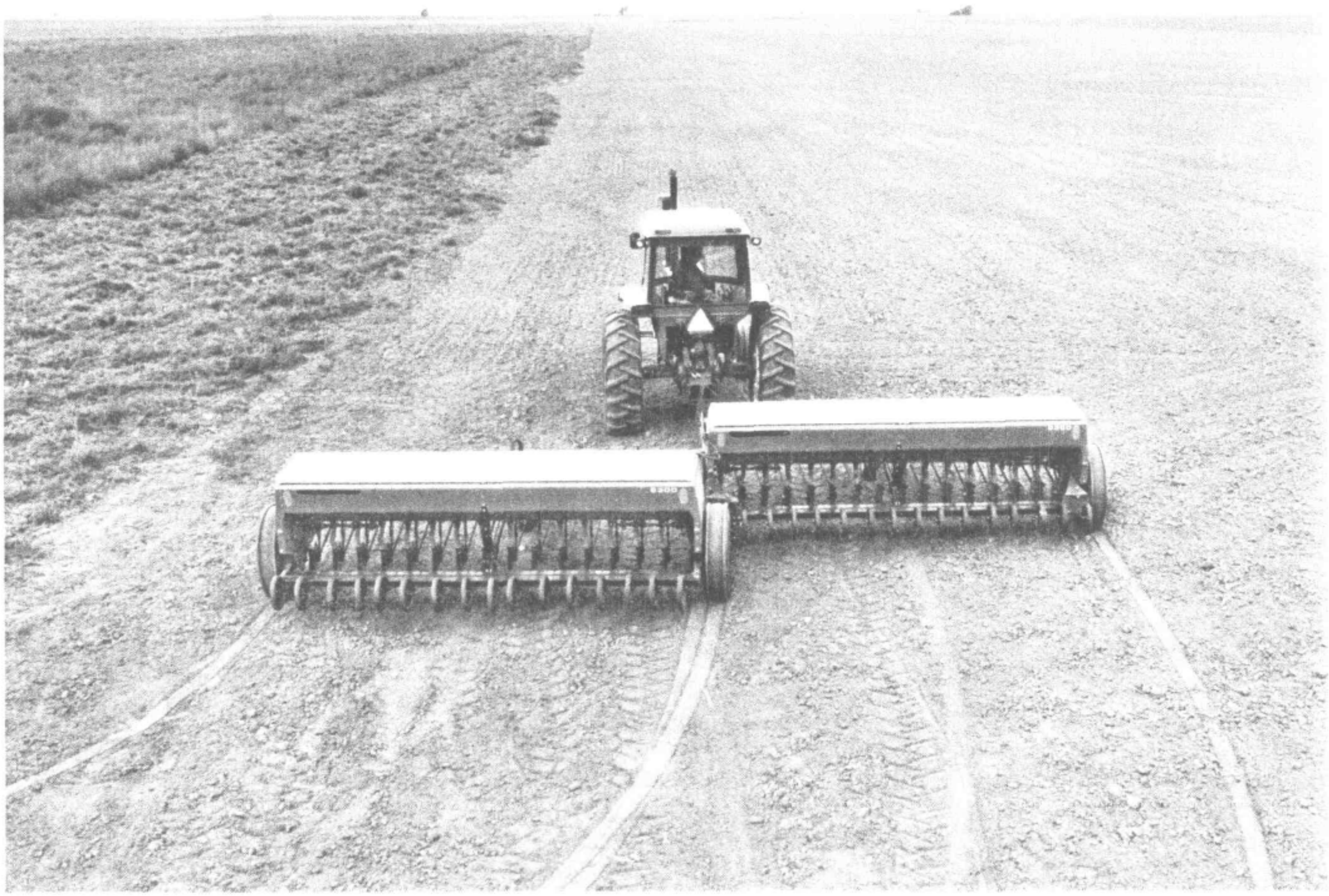


Figure 84.—Grain drill

Figure 85.—Pasture drill

Rangeland Drill.—The rangeland drill (Fig. 86) is a heavy, rugged drill especially designed to seed rough, rocky, or brushy areas. The drill has large wheels, a high clearance reinforced frame, and independently suspended furrow openers. Drag chains close the furrows after seed has been dropped in the furrow. The design of the drill is particularly adapted to very rough conditions. High clearance allows it to go over most obstructions; independently suspended arms can ride over obstructions without interrupting seeding by the other arms; rugged construction absorbs punishment from rough terrain. The drill can plant trashy or fluffy seed at a precise rate and a precise depth. Two species of seed and a fertilizer can be drilled at the same time.

The rangeland drill should not be used on slopes too steep for drilling along the contour. It is more efficient when used on well prepared seedbeds even though it is rugged, rough seedbeds will increase maintenance problems. The drill is difficult to transport without special equipment.

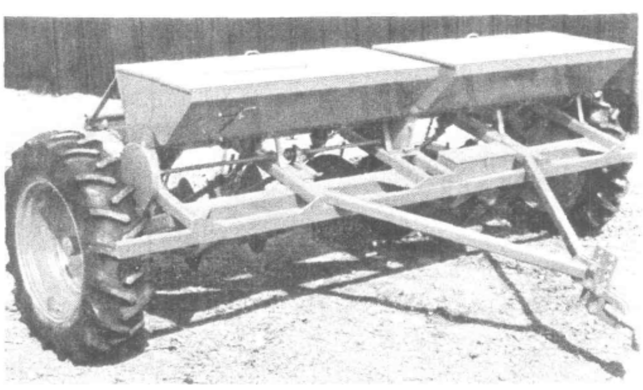


Figure 86.—Rangeland drill

Oregon Press Seeder.—The Oregon press seeder (Fig. 87) is designed to seed on a loose, prepared seedbed. Presswheels create furrows, seed tubes drop seed into the furrows, and drag chains cover the furrows with loose soil. The seeds are dropped onto a firm seedbed that is excellent for rooting, while the loose covering does not impair shoot growth. The presswheels are suspended independently, so the seeder can be used on rough, rocky soils.

The seeder is not designed for heavy, compacted soils nor for deep furrowing or plowing. It is susceptible to breakage when used on rough sites. The implement is heavy, bulky and difficult to transport.

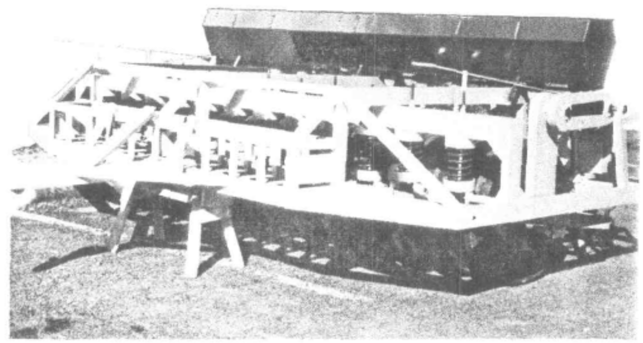


Figure 87.—Oregon press seeder

Standard Unit Planters.—Standard unit planters (Fig. 88) are separate drill seeding units that are mounted on a toolbar. Each unit opens a furrow, meters seed into the furrow, closes and packs the furrow. Seeding depths, seeding rates, and row spacing can be varied. The planters are designed to plant row crops at precise intervals. They can be used to plant shrub or tree seeds on relcamation sites. Since each unit has an individual seedbox, a variety of species can be seeded in one pass, each at its desired rate.

Unit planters are adapted to well prepared seedbeds and are not suited to rough, rocky, or steep areas. They are only needed when precise seed spacing is necessary. They are not useful for establishing a closed grass stand.

Interseeder.— Interseeders (Fig. 89) are drill seeders that scalp rows of bare ground or intermittent patches of bare ground, cut furrows in the scalped areas, seed into the furrows, and cover the seeds. They are designed to seed on vegetated lands without plowing and disturbing most of the vegetation.

Interseeders are only useful when seeding is to improve the quality and quantity of the present vegetation. They are inefficient when the entire site is to be revegetated or an entire vegetative community is being replaced.

Figure 88.—Standard unit planters

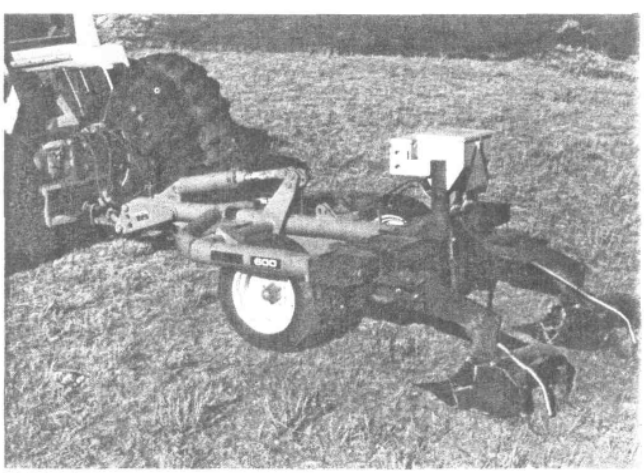


Figure 89.—Interseeders

Seed Dibbler.—Seed dibblers (Fig. 90) drop seeds onto the tracks of crawler tractors. The tracks carry the seeds to the ground and press them into the soil. Problems with wind or water movement of the seed are reduced because they are firmly in the soil. Seeding large areas is inefficient. The seeds are placed only under the tractor tracks.

Rotary Spreaders.— Rotary spreaders (Fig. 91) broadcast seed or dry fertilizers or herbicides over an area. They consist of a hopper, a fan or spinner, and a power source to turn the spinner. Seed or fertilizer falls onto the spinner and the power source turns the spinner. The seed or fertilizer is thrown out from the spreader. Spreaders usually have shields that direct the seed in a semi-circular pattern away from the spinner. The spreaders can be hand-carried, pulled behind tractors or other prime movers, attached to a prime mover, or suspended beneath an aircraft.

The spreaders have no topographical limitations. Pulled models must be used on accessible lands, but hand-operated models and aerial models can seed any area. The seed is well distributed, with no bare spots, a random distribution, and an absence of linear rows. The seeders are reliable, simple machines, with few maintenance or operational problems.

Precise seed placement is impossible with rotary spreaders. The seed should be covered after it is seeded to reduce depredation by insects, birds, and rodents, and to reduce erosion losses.

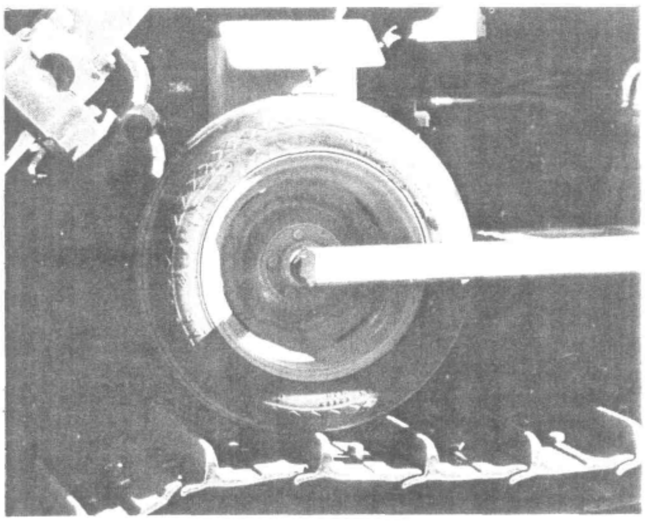


Figure 90.—Seed dibbler

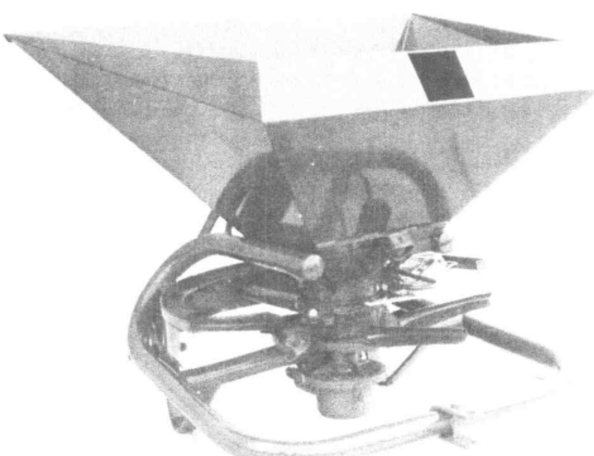


Figure 91.—Rotary spreaders

Hydraulic Seeder-Hydraulic seeders (Fig. 54, 92), or hydro-seeders, apply seed in a hydraulic spray. They consist of a large tank, a pump, and a discharge nozzle. The seed is put in the water tank, often along with fertilizer, soil inoculants, mulches, or herbicides.

Agitator paddles or centrifugal pumps keep the seeds and other substances in suspension in the water. The slurry is sprayed onto the seeding site through the discharge nozzle. The seeder operator controls the spray volume and pressure. A green dye is often included in the slurry so that the operator can be assured of completely covering the area.

Hydroseeding is most appropriate for seeding steep, inaccessible sites or trouble spots that will not be well handled by on-site vehicles. They seed large areas quickly, with good seed distribution. Covering the seed with a separate spray of wood fiber mulch protects the seed from depredation by birds, insects, and rodents.

Hydroseeding has several disadvantages that inhibit its widespread use in the West. Hydroseeding uses large volumes of water, a limited resource in many areas. Various types of hydroseeders have significantly reduced grass seed viability. Kay (1977) found that hydroseeders damaged 5 to 15 percent of grass seed immediately after the seed was placed in the slurry and circulated through the seeder. More significantly, hydroseeders with centrifugal pump agitation reduced seec germination 90 percent in 1 hour when seed and water we; *t* the only components of the slurry. When seed, water, and wood fiber were in the slurry, germination was reduced 50 percent in 1 hour. A seeder with gear paddle agitation did not significantly reduce seed germination after 1 hour in the machine, either with water alone or with water and wood fiber. Kay suggests that: (1) a gear pump with paddle agitation be used for hydroseeding; (2) if a centrifugal pump is used, the time between addition of seed to the slurry until the tank is fully discharged should be less than 20 minutes; (3) wood fiber should be in the slurry if a centrifugal pump is used; and (4) seeds should be put into the slurry just before beginning seeding; they should be in the slurry for a minimum amount of time.

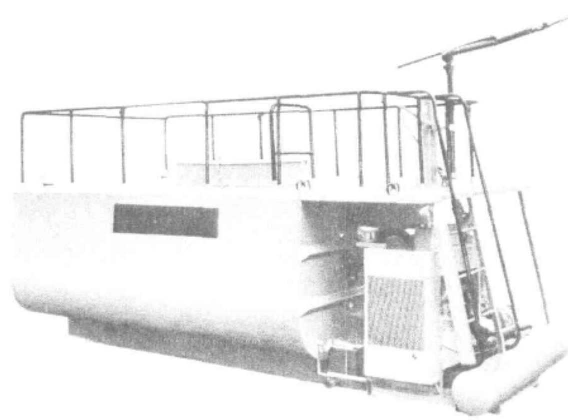


Figure 92.—Hydroseeder

Planters

Planting equipment moves entire plants or propagules other than seeds onto the revegetation site. The plants can be either precisely placed or randomly dispersed over the area.

Hand Planting Tools.—Hand planting tools are tools for planting either bareroot or containerized seedlings. Various types of tools are available. All excavate holes large enough to hold plant roots. The tools range from planting hoes to reinforced shovels, from straight bars with planting blades to specialized container planting tubes that displace soil with a foot lever and place the seedling through the hollow handle (Fig. 93a-f).

Both site conditions and the type of planting stock determine the tools used. Planting hoes and planting bars are used on most sites. Planting bars are often used on rockier sites. Planting tubes and dibbles that punch holes the size of the seedling container are used to plant containerized seedlings. Dibbles are more effective in rocky soil, planting tubes are used on the less rocky sites.

Hand planting tools allow the planter to precisely place the seedlings. Each microsite is selected individually. Seedling survival is enhanced by careful choice of planting sites. These tools allow planting on inaccessible sites or on sites where vehicle traffic is not desired.

Hand planting tools are not well suited to rocky areas. They are labor intensive and severity of the site often affects the quality of planting. Hand planting costs can be quite high if a large area is being planted.

Figure 93b.—Hand-planting tools. Adze hoe

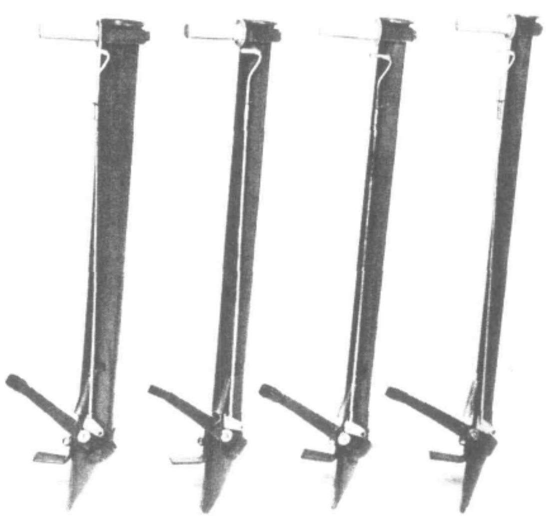


Figure 93a.—Hand-planting tools, planting tubes

Figure 93c.—Hand-planting tools, planting hoe

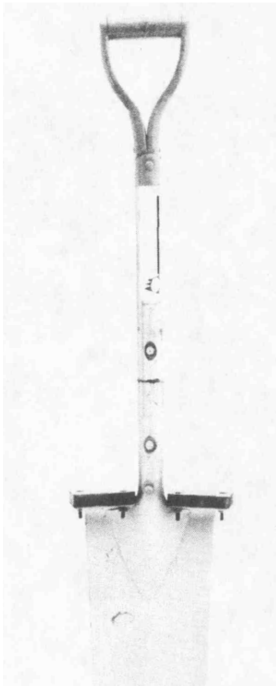


Figure 93d.—Hand-planting tools, planting spade

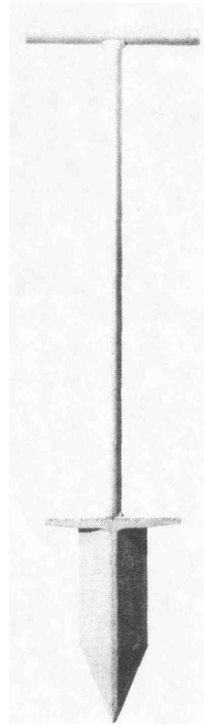


Figure 93e.—Hand-planting tools, KBC planting bar

Figure 93f.—Hand-planting tools, OST planting bar

Planting Auger.—Planting augers (Fig. 94) are portable, powered augers to dig holes for planting seedlings. The augers consist of a power unit, a gear box, and an auger bit. Power units are lightweight handheld or backpack units that, through the gear box, drive the auger bits. Planting augers excavate holes into which seedlings are planted.

Figure 94.—Planting auger

Planting augers are fast, efficient tools for digging planting holes. Auger bits can be tipped with carbide chips that wear longer and dig faster than hardened steel tips. They are portable so that inaccessible areas may be planted. Planting augers drill large, deep holes that are usually more favorable for planting than holes created by hand tools. Soil excavated from the planting hole is usually heaped near the hole, where it is readily available for packing around the seedling roots. Planting augers are heavy, fatiguing tools. They are difficult to use in heavy clay soils and are not adapted to very rocky soils. All hard planting is labor-intensive, therefore auger-planting can be very costly when applied to a large area.

Seedling Planter. — Seedling planters (Fig. 95) are tractor-drawn implements that open furrows into which bareroot or containerized seedlings are placed. Packers close the furrows around the seedling roots. The seedlings are placed either manually by an operator or automatically by a mechanized arm.

The seedlings are planted in rows, usually at regular spacing. Planters are most applicable for high-speed, large-scale planting projects. The seedlings are planted deep and the soil is well packed around the roots.

Seedling planters are limited by terrain and site conditions. They can only be used on slopes traversable by tractors, and should be pulled along slope contours. They are not well adapted to very rocky sites.

Tree Spade.—Tr*ee* spades (Fig.96) are machines designed to transplant large, mature trees. They have digging blades that excavate a tree with a root ball to minimize root damage (Fig. 97). Trees up to 10 inches in diameter can be transplanted, although the tree's root system affects the stem diameter of the trees that can be moved. The root ball must contain enough of the plant roots to enable the tree to root successfully and survive at the transplant site. The tree can be transported either individually in the tree spade or loaded on a truck or trailer (Fig. 98).

Plants are placed in holes that have been previously excavated on the reclamation site. They are transplanted with a minimum of root disturbance. Shrubs can be moved as well as trees.

Tree spades are limited to slopes less than 15 percent. Tree spades with large taproots are difficult to transplant because much of the root system must be cut off when the root ball is excavated. Tree spades are expensive to use and their use should be reserved to transplanting hard-to-establish trees or to achieve an objective of immediate stocking with mature trees. Shrubs moved with tree spades usually survive well but the cost is higher than using front-end loaders or sod mover buckets.

Figure 96.—Tree spade

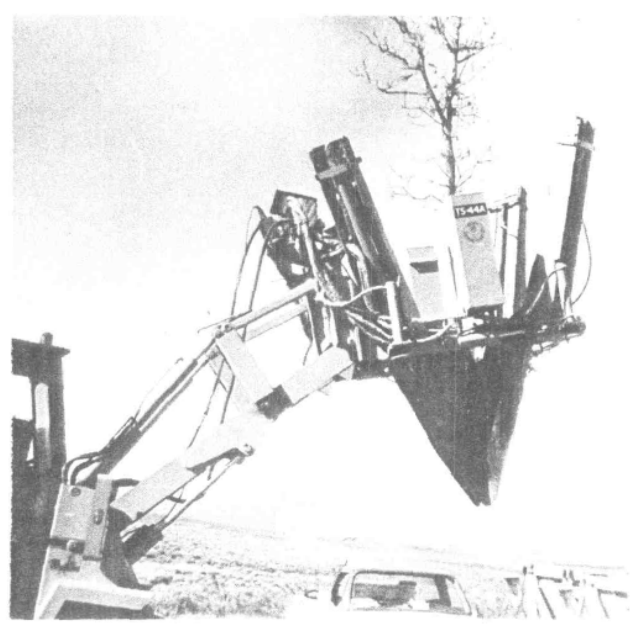


Figure 95.—Mechanized seedling planter

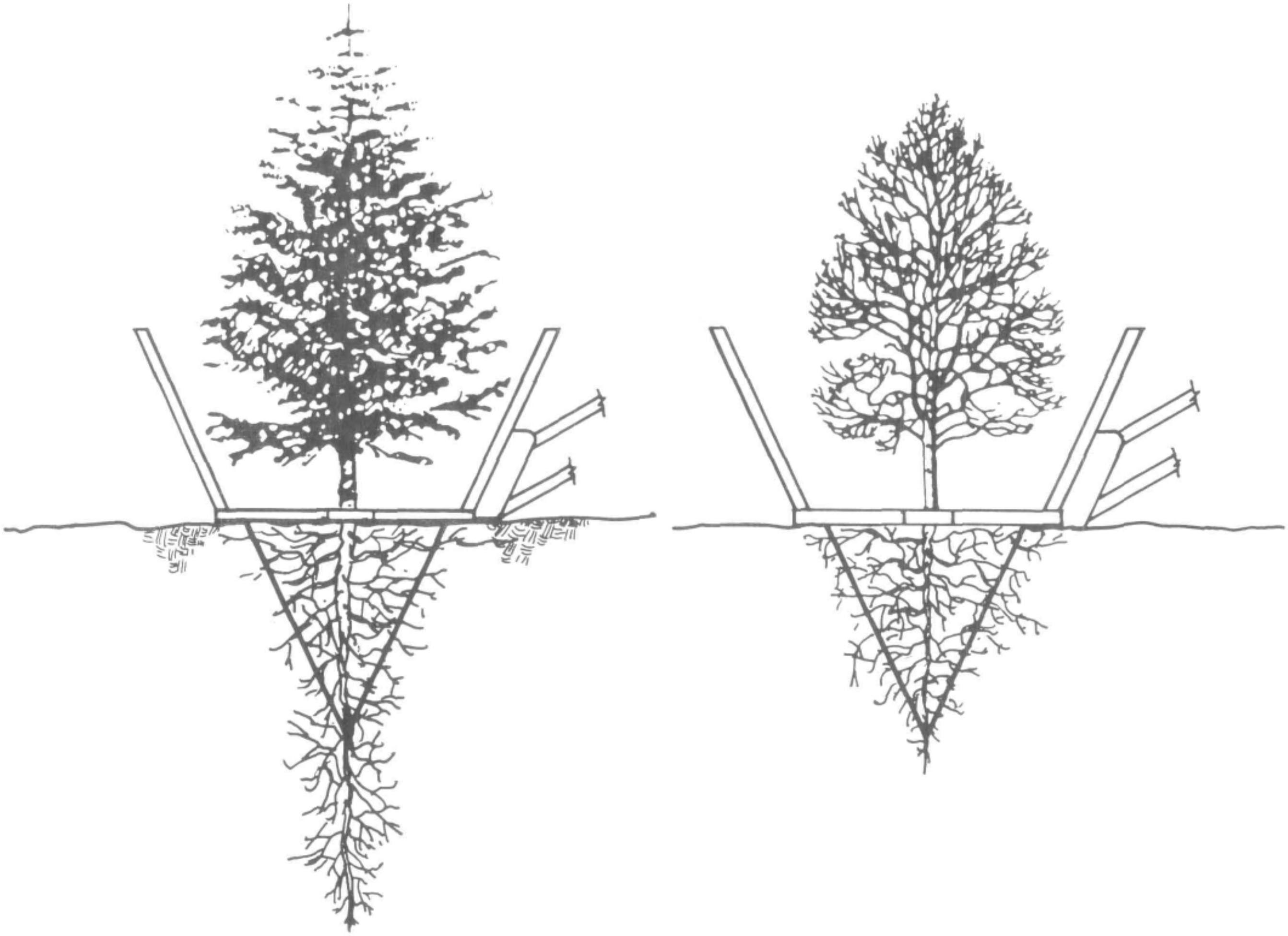


Figure 97. —Tree spade cutting a root ball

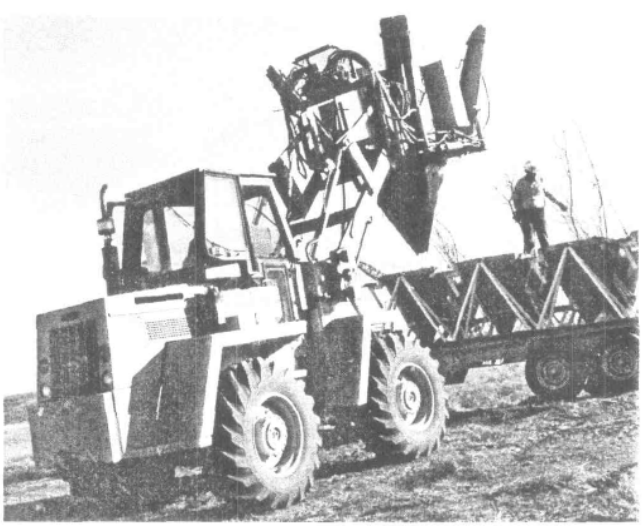


Figure 98.—Tree spade trailer

Front-end Loader.—Front-end loaders (Fig. 99) can transplant trees, shrubs, and root pads. They are common equipment on virtually all surface mines and are often readily available for part-time reclamation work. They dig, transport, and plant on the reclamation site.

Front-end loaders can move shrubs and root pads efficiently and quickly. They are well equipped to dig species with shallow roots that do not require a deep root ball. They are not suited for moving trees with tap roots. Trees that sprout from the root crown, such as quaking aspen *(Populus tremuloides),* can be moved successfully by front-end loaders. Often the original stems moved will not survive, but sprouts from the root crown will occupy the site. End loaders are limited to slopes under 20 percent because they are unstable on steep slopes.

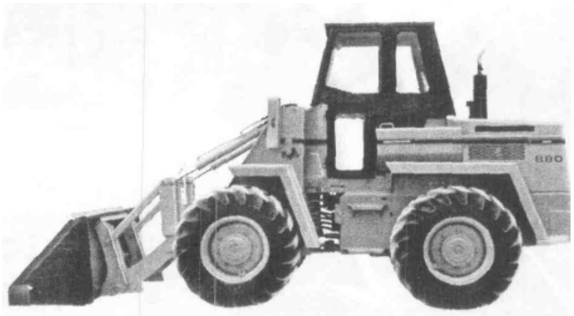


Figure 99.—Front-end loader

DrylandSodder.—The dryland sodder (Fig. 100) is a special bucket for a front-end loader. It was designed specifically for digging pads of sod on unmined land, carrying them to a reclamation site and laying them on the site. Shallow-rooted species of all types of plants are successfully transplanted. The soil horizons down to 2 feet are carried intact, eliminating mixing the topsoil and preventing destruction of the soil.

The sodder is expensive to use for large-scale operations. It is most suited to critical areas with high erosion potential.

Figure 100.—Dryland sodder

Tubling Planter.—Tubling planters (Fig. 101) are especially designed implements that automatically plant containerized seedlings. The planter is a trailer unit towed by a tractor. An auger digs a planting hole as a scarifying blade scalps competing vegetation from around the hole. A containerized seedling is automatically dropped into the hole where a packing spade firms soil around the seedling.

The planter quickly and efficiently plants large containerized seedlings. The size of the seedlings, which have 24-inch roots, and the size and quality of the auger-drilled hole increases the survival rate of the seedlings over the survival rate of smaller, hand-planted seedlings. The planter is self leveling and can be used on moderate slopes up to 30 percent grade.

The planter is an expensive implement and the seedlings which it plants are costly to grow. The planter is appropriate for planting difficult-to-establish species or for planting on critical sites.

Figure 101.—Tubling planter

Sprigger.—Spriggers (Fig. 102) are modified potato harvesters that gather rhizomatous or sprouting root material for transplanting shrubs. The harvester has an undercutting blade that loosens and cuts roots of native range. The soil that is disturbed, which includes root material, is conveyed to a truck bed or to a trailer. The soil and root material are spread on the surface of areas to be revegetated using a modified manure spreader.

The sprigger can quickly plant a large number of shrubs on a large area. Rhizomes and sprouting root materials are wetted and can begin to grow immediately.

The sprigger does not work well in heavy clay spoils. It is efficient in planting rhizomatous plants or plants that will sprout form the root crown, but does not work well for deep tap-rooted species (Larson, 1980; Brown, 1977).

Figure 102— Sprigger

V. Irrigation and Fertilization

After the mined area has been seeded and planted, efforts must be concentrated to assist in seedling establishment, growth, and survival. Reclamation is not successful until the vegetation on the site can grow and reproduce under the normal management of similar undisturbed sites. In the West, native rangeland management usually consists of regulation of the number and species of animals grazing the site and regulation of the seasons of use of the land. Irrigation, fertilization, or use of herbicides and pesticides are not usually used on western rangelands. However, such cultural techniques are sometimes used to promote the establishment and growth of plant communities on mined lands. The vegetative community must meet reclamation success criterion after these cultural techniques are discontinued before the mining company can be released from its reclamation responsibility.

Use of intensive cultural techniques help establish plants. Many desirable species would not establish for many years or even decades if the techniques are not employed. By using these methods, succession is advanced. Where weedy pioneer species would occupy a site for years, intensive management techniques establish long-lived perennials that can occupy the site indefinitely. Site productivity, diversity, and stability are promoted.

Acclerating succession through irrigation, fertilization, and pest control is considered undesirable by some. Artificially induced succession may not proceed in the same direction as natural succession, possibly resulting in a vegetative community that will not be capable of maintaining itself without continued manipulation. Legal requirements state that reclamation on rangeland can only be considered successful when the vegetation community maintains itself for 5 to 10 years after the last seeding, irrigation, or fertilization. Because of this, cultural methods must be used only for establishing the community. Therefore, these cultural techniques should be used sparingly.

Irrigation

Irrigation provides plants with water they would not obtain naturally, Irrigation is controversial. While it is not always necessary or even beneficial, it is used regularly and is necessary in some cases. Different methods of irrigation have different advantages, disadvantages, and appropriate situations in which they are employed.

Irrigation should provide adequate amounts of water but should not cause undue runoff or erosion, nor should it waste water. Because water is a limited resource in much of the West, irrigation must be as efficient as possible. Techniques that allow water to penetrate deeply into the soil excessive (Fig. 103). Evaporation will occur each time the site is irrigated. If water is deep in the soil, a small percentage evaporates. Water that is all near the surface will suffer a much higher percentage evaporation. Deep moisture will last longer in the soil and will reduce the need for irrigation frequency.

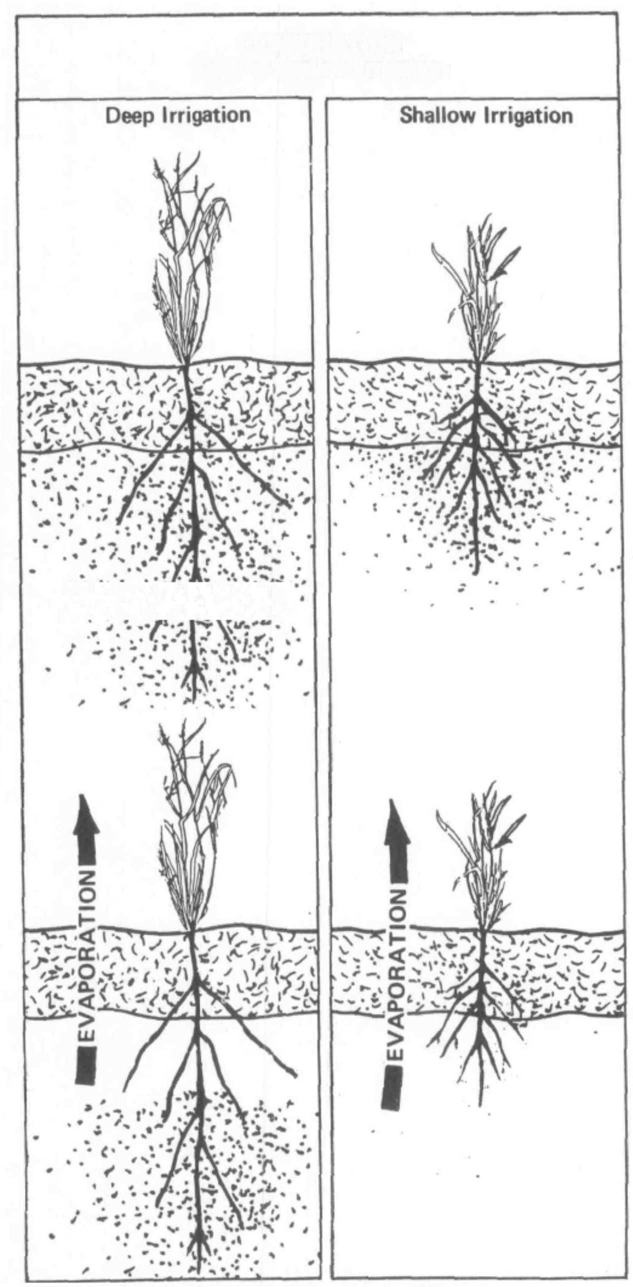


Figure 103. —Effects of deep vs. shallow irrigation

A further advantage of deep watering is the response it elicits from the plant roots. By irrigating deeply, the roots are encouraged to penetrate deeper into the soil to remove all the usable moisture. This is especially beneficial when irrigation is concluded. The plant roots will have expanded so they can obtain water out of a relatively large volume of space.

Irrigation should not cause excessive runoff. Erosion caused by irrigation is related to application rates, soil infiltration rates, and irrigation frequency.

Sprinkler

Sprinkler irrigation uses pumps to push water through metal pipes. Sprinklers spray the water over the desired area. Several sprinkler systems are available. Hand-carried, self-powered linear, and center-pivot systems are now being used. All spray water and sometimes fertilizer. Self-powered linear or center-pivot systems move with water power. Hand-carried systems are moved manually. All must be on relatively level areas. Sprinkler irrigation systems are common agricultural tools in the West so obtaining and servicing the system is relatively easy. Sprinklers can precisely meter water to the soil.

Sprinkler irrigation is inefficient when used in hot, dry, windy weather. Evaporation is very high when these conditions prevail. Because the sprinklers create a spray of relatively small drops, evaporative surface area is greatly increased by the sprinklers. Sprinkler application rates should be closely controlled to prevent surface runoff and erosion.

Flood

Flood irrigation is spreading the water over the surface of the site. If often involves a network of irrigation ditches along the ridges and benches. The ditches are dammed at intervals and the water in the ditches floods over the surface of the land below the ditch level (Fig. 104). This technique is a common method of irrigating native and domestic pastures in the West. The ditches used are seldom deeper than 2 feet and should not present a hinderance to livestock or wildlife. They often promote a land of lush growth of vegetation along their banks that can be a benefit as wildlife habitat. The ditches are a hinderance to vehicle traffic.

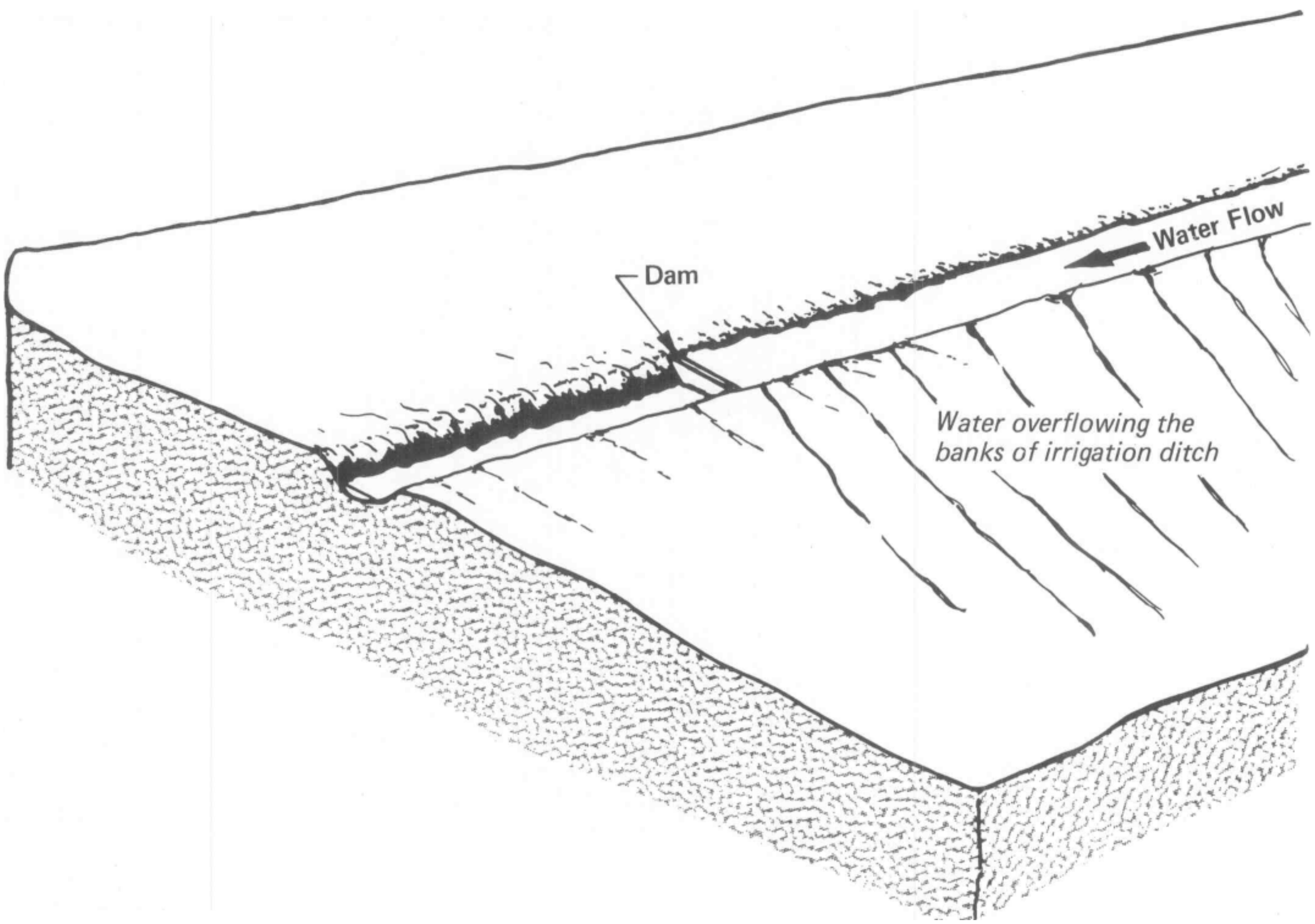


Figure 104.—Ditch irrigation

Ridge and furrow irrigation techniques are appropriate for flood irrigating rows of plants, such as windbreaks. The plants are located on the ridges, and the furrows on each side of the plant now irrigate the plants (Fig. 105). This technique usually will not be used for irrigating a large area, but is very effective to irrigate specific plants. The water is not flooded over the plants as in ditch irrigation. Rather, the water percolates under the furrows and is carried by capillary action under the ridge to where the plant roots can reach it.

Overland flow irrigation is using sprinklers to spray water faster than it can be absorbed into the soil. The excess water runs downhill, flooding areas below the sprinkler (Fig. 106). The runoff is collected at the base of slope in a small furrow. Overland flow is not acceptable on easily eroded slopes before the vegetation has begun to grow. Overland flow on bare slopes will erode and create hills and gullies. This irrigation technique should only be used after the site has been vegetated.

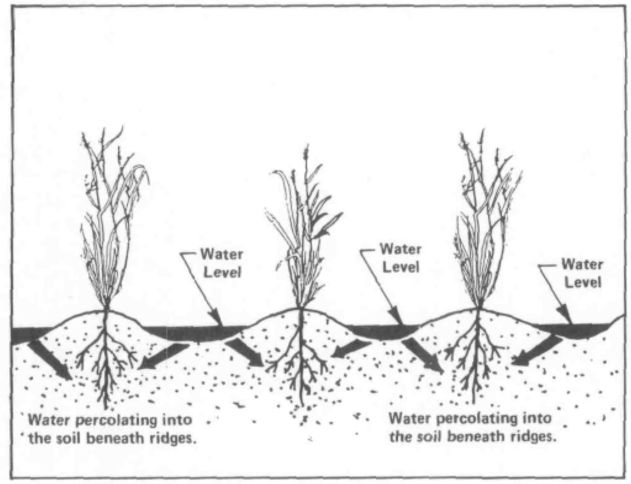


Figure 105.—Ridge and furrow irrigation

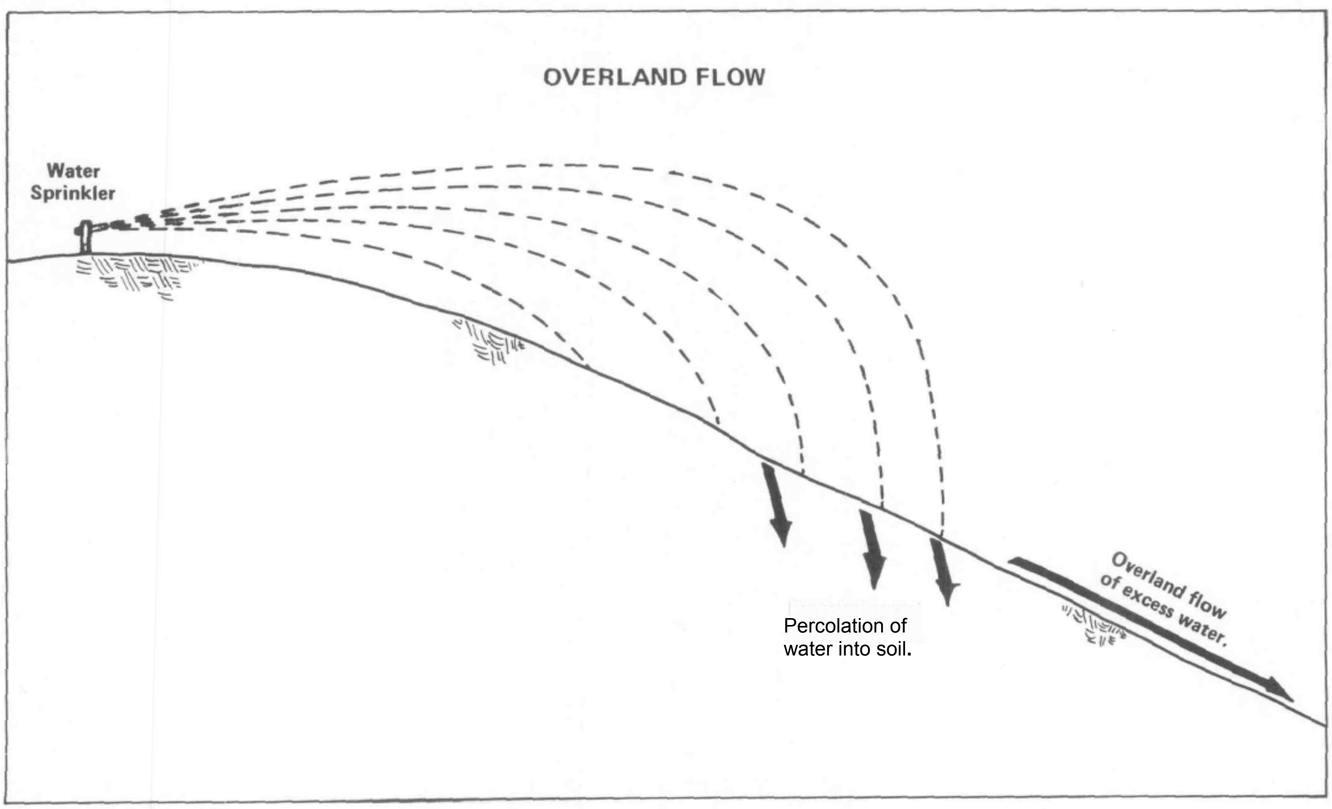


Figure 106.—Overland flow

Drip Irrigation

Drip irrigation is an intensive irrigation system that waters individual plants or small clumps of plants. Small diameter tubes carry water to selected site. They are often used on moderate to steep slopes, where horizontal tubes with variously placed water outlets irrigate individual plants. Watering rates must be regulated to prevent runoff and erosion, especially since most of these systems are on slopes.

A major advantage drip irrigation has over flood or sprinkler irrigation is that drip irrigation can be regulated to maintain soil moisture at an optimum level. Irrigating with sprinklers or flood systems provides moisture levels from saturation to near wilting point. At the time of irrigation, saturation levels, which exclude oxygen from the root zone, occur; between irrigations, soil moisture often becomes limiting. Drip irrigation can be done as often as necessary to keep soil moist and can be done slow enough to avoid saturation (DeKemer and Back, 1977). Drip irrigation uses water efficiently. The watering rate can be regulated so it is absorbed into the soil as quickly as it is emitted from the tube. Since it is carried to the plant in a tube it cannot evaporate or be lost into the soil where it is not desired. Other forms of irrigation expose water to the air and therefore have much more evaporative loss. Drip irrigation can leach soluble salts or other soluble toxic materials before planting an area.

Drip systems are not appropriate for full coverage of an area. The cost of achieving total coverage would be prohibitive. Adequate filtration is essential to prevent clogging in the tubes and emitters.

Fertilization

Most fertilization is done before or concurrently with seeding. After an area is seeded and the soil is susceptible to damage from vehicular travel, fertilization is done through the irrigation system. Where the water is pumped onto the area, in sprinklers or drip systems, fertilizer is added to the water at the pump. A solution of fertilizer dissolved or suspended in water is added at a regulated, uniform rate to the water supply pumped through the system.

Fertilization during flood-irrigating is less precise and is not often attempted. Since the water is usually free-flowing, there is no convenient place to add fertilizer. Furthermore, the water is not as well controlled as it is with sprinkler or drip irrigation, so fertilizer may be applied too heavily in some areas and not applied to others. This problem seldom occurs with drip or sprinkler irrigation systems.

Water Harvesting

Water harvesting is catching or concentrating natural moisture to increase moisture in desired areas. The techniques range from spreading impervious materials over the soil surface and channeling the subsequent runoff to a desired site to placing snowfences that catch blowing snow.

Impervious materials can be used on a large scale to seal off large areas and direct the runoff to a pond or a lower area where stands of trees or shrubs can use the water. If the runoff is directed to a pond, water is usually used for irrigation when needed. In cases where the water is desired to stands of vegetation, the runoff is used by the plants as it occurs (Fig. 107a and b).

Impervious materials that cover large areas and create runoff include latex emulsions, paraffin wax, emulsions, butyl rubber, sheet metal, and plastic film. They range from relatively inexpensive to extremely expensive, with

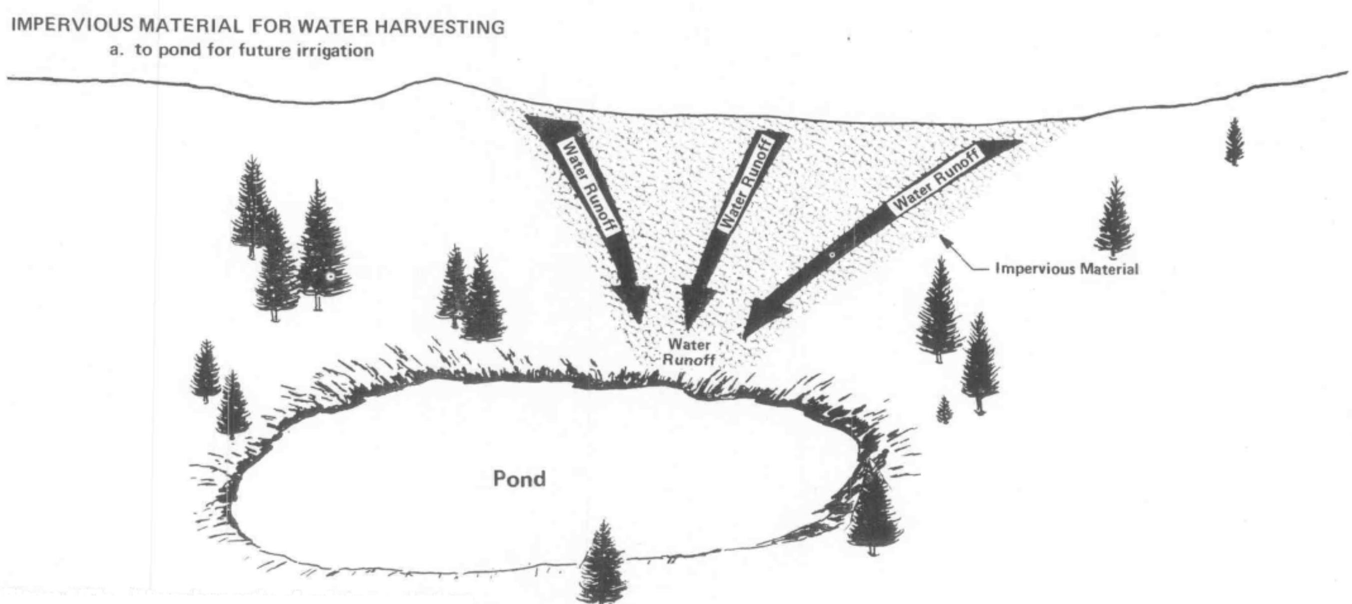


Figure 107a.-Water harvesting for future irrigation

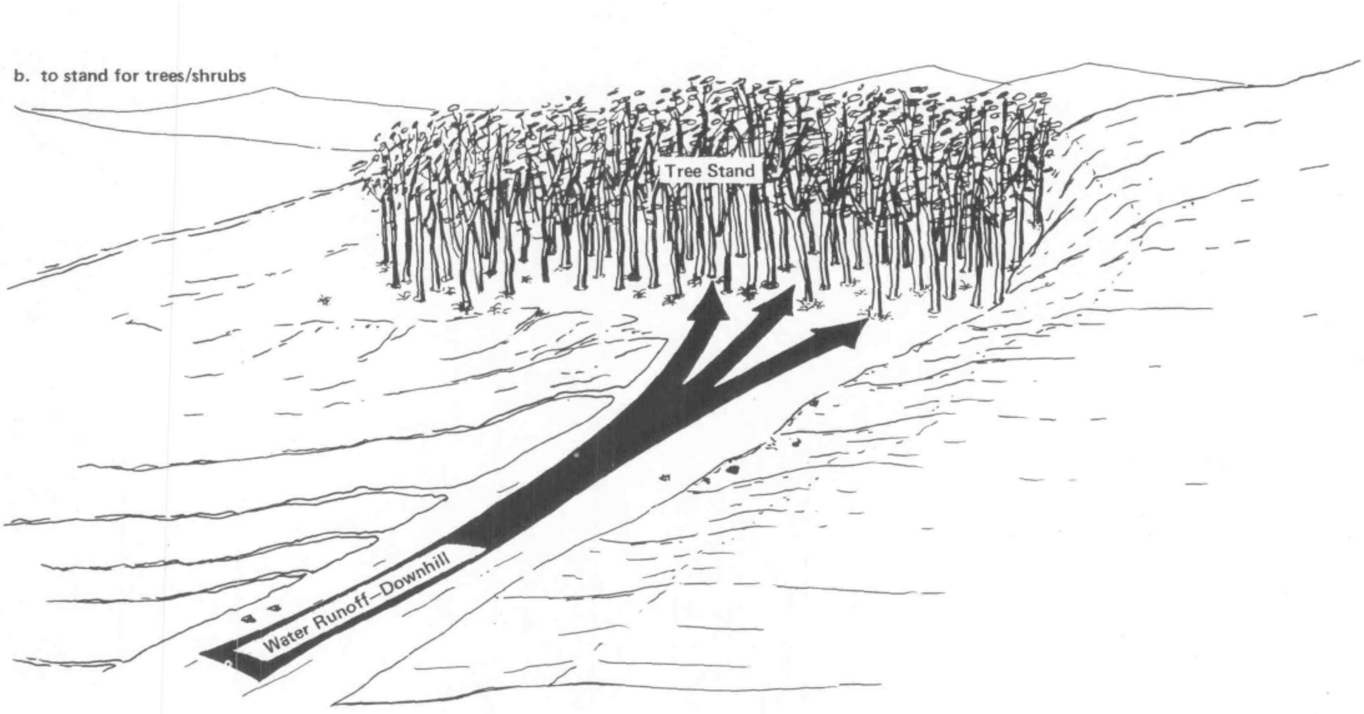


Figure 107b.—Water harvesting for runoff to tree stand

the lifespan of the materials often inversely proportional to its cost. The various materials must be carefully applied to the soil. Any that rest on the soil must be well anchored from wind; those that bind the soil surface (such as the latex or wax) are easily broken up by animals or vehicles and therefore must be carefully protected from disturbance.

Covering large areas with impervious materials is seldom desirable. The land covered with the material will not support vegetation and is susceptible to massive wind and water erosion. The covering, if maintained for a long period, is quite expensive. This technique is more applicable for providing water for domestic animals or wildlife than as a common revegetation technique.

Condensation Traps
Small scale use of impervious materials has more applicability for revegetation on arid and semi-arid sites. Condensation traps made with polyfilm have been used to collect and concentrate moisture for individual plants, especially to help individual plants become established (Jensen & Hodder, 1979).

The condensation traps catch soil moisture as it evaporates. The moisture condenses on the underside of a plastic sheet and then runs down the sheet to the base of a plant. The basic design (Fig. 108) has an excavated basin, approximately 5 feet in diameter and 1 foot deep. A tree or shrub is planted in a small mound in the center of the basin. Plastic film is placed over the basin, with the edges anchored with dirt along the edge of the basin. A hole is cut in the center of the plastic so the plant can poke through. Finally, rocks are placed around the plant at the base of the small mound. The rocks keep the plastic taut, with the plastic at an angle adequate to make the water run down to the mound around the plant.

Traps increase available moisture for the plants, are relatively inexpensive, and can be easily modified to handle bareroot or containerized seedlings, trees, shrubs, or grasses. The plastic film breaks down after several years. Colored film, especially black film, breaks down faster than clear plastic. Weed growth is inhibited by black plastic.

These traps must be well built. The plastic should be at a minimum of 25 degrees from the horizontal so that the moisture travels all the way to the plant. If the plastic is not taut it will be susceptible to tearing. Traps built on open slopes may fill with eroded soil which destroys the trap and covers the plant. They should not be built on slopes where erosion will be a problem.

To facilitate construction of the traps, Jensen and Hodder (1979) designed prefabricated traps using wooden sides and plastic sheets. These proved to be easier to install and more reliable than the original basins when relatively unskilled personnel installed the traps. Jensen and Hodder also described variations of the basic trap designed for ease of installation or longer life (Fig, 109a and b).

Snow Traps

In much of the arid and semi-arid West, snow is a major component of the annual precipitation. However, much of the snow blows off and is trapped in areas where it is not needed. Snow traps are designed to catch the snow on specific areas where it is needed for reclamation purposes.

Snow traps are snow fences, standing mulch, or wind-breaks that reduce wind velocity and cause snow build-up. These will increase moisture from snow-melt by catching snow and reducing the snow that is blown away.

As winds blow the snow, snow traps reduce the velocity near the ground. Snow falls and drifts against the trap. When snowmelt occurs, increased snow cover will increase available moisture.

Snow traps should be constructed or grown perpendicular to the prevailing winter wind. They should be on the windward side of the area to be affected. Snow traps are usually long-lived and a low maintenance means of water harvesting.

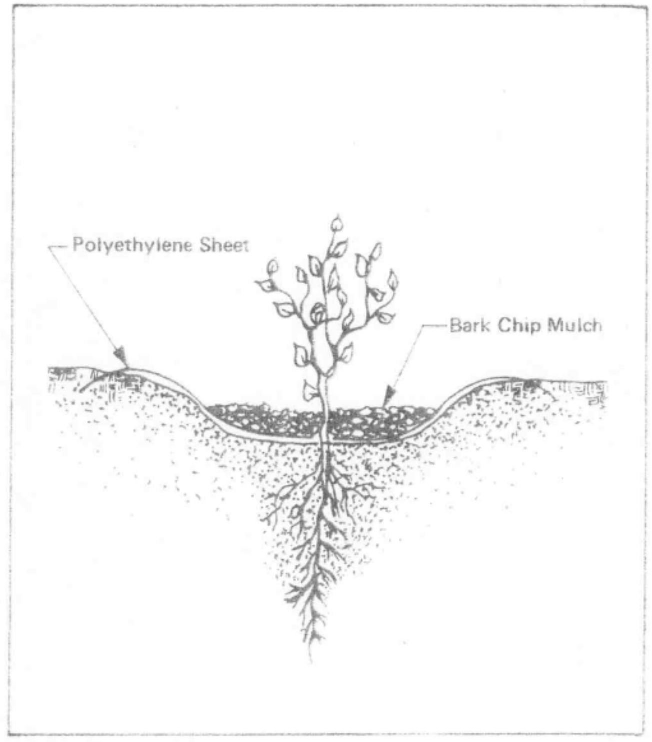


Figure 109a.—condensation trap design for ease of installation

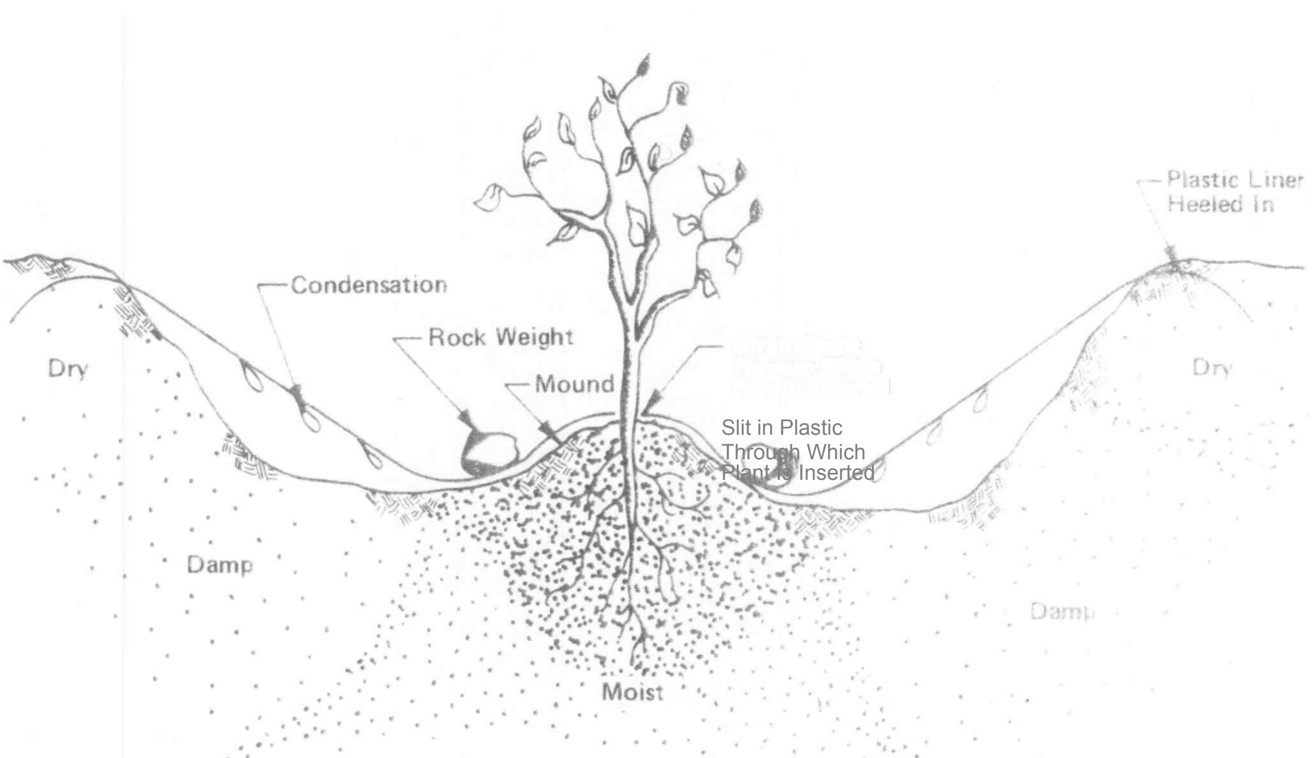


Figure 108.—Condensation trap

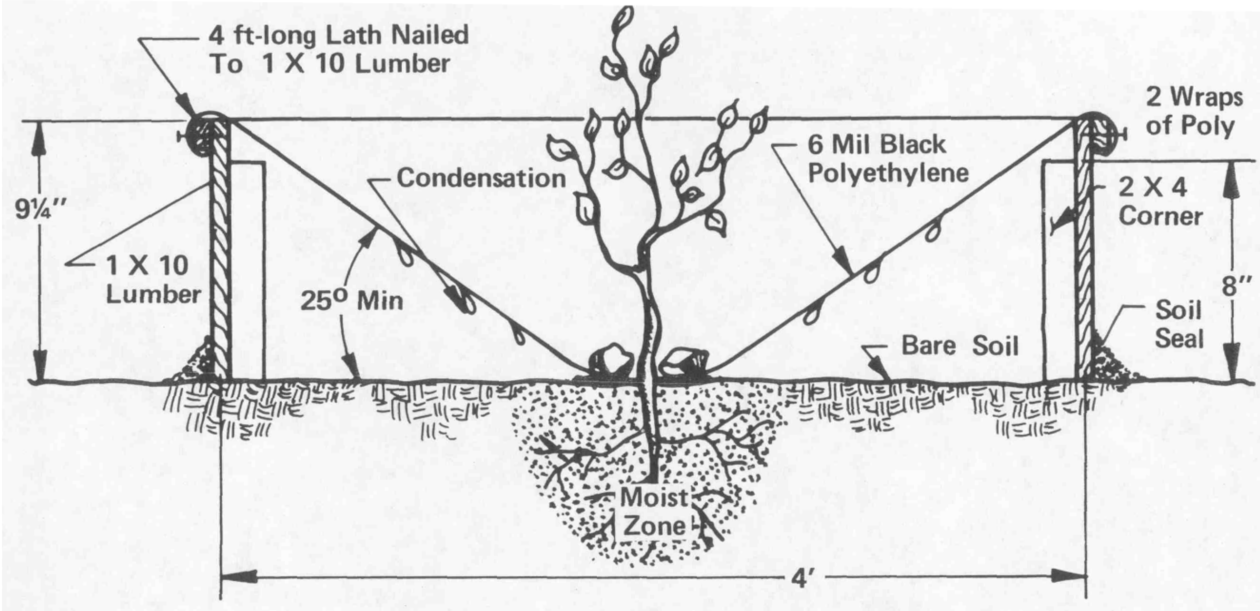


Figure 109b.—Pre-built condensation trap

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