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A Guide for the Use of Organic Materials

As Mulches in Reclamation of Coal Minesoils in the Eastern United States

Bernard M. Slick
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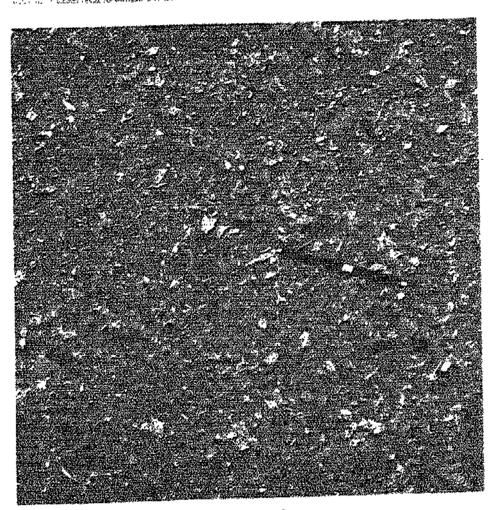

Foreword

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Extracting, processing, converting, and using energy and material resources create pollution. Because pollution impacts our environment and our health, new and increasingly more efficient pollution control methods are needed. Surface mining of coal results in the denuding of the ground surface. Without amendments and the rapid development of a vegetative cover, erosion from the mined area will occur. This report describes various organic materials and how they can be used in reclamation to better protect the surface and to speed the establishment and enhance the growth of vegetation. It also describes the physical and chemical changes that the organic materials impose upon spoils.

English units are used in deference to the majority of the readers for whom this guide is intended. An English to metric conversion table is on the inside back cover.

Information contained herein should interest surface-mine operators, land owners, reclamation contractors, reclamation associations, land resource managers, as well as local, State and Federal regulatory agencies. For further information, contact U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Resource Extraction and Handling Division, Extraction Technology Branch.

This report was reviewed by the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency. The contents do not necessarily reflect the views and policies of the U.S. Environmental Protection Agency.

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Abstract

This guide includes a brief description of the environmental impacts of coal surface mining, the problems associated with disposal of organic wastes and a discussion of mulch in relation to erosion, soil properties, and plant growth. Organic materials that have potential use as mulches for revegetating surface-mined lands are identified and described. Selection criteria for organic materials, application methods, equipment, and requirements are explained. The principles and guidelines are applicable to past and current surface-mining operations; they may also apply to surface disturbances caused by surface mining for other minerals and by underground mining. This guide is not directed to the establishment of agricultural crops on areas designated as "prime farmlands", although much of the information herein will apply.

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Coal Surface Mining

Much of our need for electrical energy is currently being supplied and will continue to be supplied from our coal reserves. As a result, each year in the humid Eastern United States, thousands of acres of land are surface mined for coal. Because of the current demand for energy, the foreign source of much of our oil, and the increasing prices of that oil, we are striving for energy independence by placing a greater reliance on coal as a fuel. Demand for coal is expected to more than double in the next decade. This will accelerate the growth of surface mining for several years to come and, at the same time, will continue to cause environmental disturbances.

Ecosystems in surface-mined areas are drastically altered and traditional land use patterns disrupted. Existing plant communities are removed from the mine site. Valuable soil and soil organisms often become buried or mixed during the movement and placement of overburden. Surface and ground water systems are polluted and flows disrupted. Wildlife habitat is eliminated or, at least, temporarily disturbed, and landform and vegetative modifications impact the visual quality and character of the landscape.

During surface-mining operations, the forces of nature are at work to destroy the mine site before it is ready for revegetation. The bare spoils are subjected to full exposure of the sun, wind, and rain. These forces, coupled with the constant pull of gravity, work very rapidly to tear down cut slopes and fills and to break up flat surfaces through water runoff and erosion.

One of the more serious impacts of erosion and sedimentation is degradation of the water resource. Results of hydrologic studies in mined watersheds have shown that before vegetation is established, erosion may contribute large quantities of sediment and toxic chemicals to various water courses, often resulting in a degraded aquatic ecosystem.

Organic Wastes

Approximately 800 million dry tons of organic waste materials are produced annually in the United States (Table 1) with almost half this amount generated in the East. Storage or disposal of concentrated quantities of some of these wastes is detrimental to the environment and poses an increasing problem and economic burden to our society. With continued growth in the population and in per capita waste generation, the volume of waste will increase considerably in spite of rising costs of energy and materials used in making products that generate wastes. This will increase the demand for better pollution control technology, better resource use and recovery, better disposal methods and sites, and more rapid improvement in environmental quality.

Table 1. Annual production of organic wastes in the U.S. (USDA 1978)

Organic waste	Total production	
	Thousand dry tons	Percent
Animal manure	175,000	21.8
Crop residues	431,087	53.7
Sewage sludge and septage	4,369	.5
Food processing	3,200	.4
Industrial organic	8,216	1.0
Logging and wood manufacturing	35,714	4.5
Municipal refuse	145,000	18.1
Total	802,586	100.0

In the past, many wastes have been dumped on the land, emitted into the air, and discharged into waters. Improper disposal has led to adverse effects on our health and safety from fires and explosions; litter; breeding of disease vectors; deterioration of clean air by chemical emissions, particulate matter, or odors, and contamination of our surface and ground waters with toxic and pathogenic effluent discharges, landfill leachates, and acid rain. Overall, national efforts of the past decade and enactment of stringent laws such as the Clean Air Act and Federal Water Pollution Control Act to improve air and water quality are beginning to show results. However, increased emphasis has been placed on disposal of more of the wastes on land. This has become increasingly difficult due to scarcity of space for landfills, higher costs of land and disposal, tightening environmental standards, and increasing public opposition to disposal sites. Therefore, any economically feasible and environmentally constructive uses (such as mulches) that can be found for these waste products will be advantageous.

Definition of Mulch

A mulch is any suitable protective layer of organic or inorganic material applied or left on or near the soil surface as a temporary aid in stabilizing the surface and improving soil microclimatic conditions for establishing vegetation. This is in contrast to an amendment, which is an organic or inorganic material, such as lime, fertilizer, or manure that is incorporated into the soil "root zone" to make it productive or more productive of vegetation.

Reasons for Organic Materials on Mined Lands

Mulching has been used for years to protect the soil from erosion and excessive drying in agriculture, highway construction, roadside stabilization, and landscape development. However, mulching has been used in recent years in surface-mine reclamation to help establish optimum vegetative cover for site stability and productivity.

In the East, it has long been recognized that quick revegetation of freshly graded slopes or of any disturbed surface-mine areas is one of the most important means for effective control of excessive runoff, erosion, and sedimentation. However, physical and chemical characteristics of minesoils can cause adverse environmental and microclimatic stress conditions that hinder establishment and growth of plants.

The following stress conditions are the most detrimental to seed germination and subsequent plant growth: erosion, extreme diurnal surface and soil temperatures, lack of available moisture, and extremes in pH. These factors, along with lack of nutrients and organic matter, make it difficult to establish and maintain a diverse productive vegetative cover that will meet reclamation standards. To alleviate these conditions and make the minesoil more favorable for plant establishment and growth, the disturbed area microclimate must be modified. In addition to the usual fertilizers and lime used in the revegetation process, the application of a surface mulch can be used to modify plant growth conditions. The protective layer should maintain soil stability within acceptable levels during the time it takes the seedlings to emerge and become established, and then continue to enhance vegetative growth until the treated area is permanently stabilized. Also, mulches can be used on any disturbed and unprotected mined-surface area for temporary erosion protection. For example, when reclamation grading is completed and planting conditions are unfavorable for seeding, mulch can be used.

Organic mulches stabilize soils, reduce losses to erosion, enhance plant growth conditions, and aid in the construction of an improved minesoil profile. Straw, hay, and some hydromulches are most commonly used. However, recent restrictions on the disposal of various types of organic wastes (crop and wood residues, municipal and industrial wastes) have generated interest in their use as mulches or amendments for surface minesoils. Use of these resources in mine-reclamation systems will help not only to alleviate a disposal problem for the various residues and wastes, but also to control erosion while simultaneously protecting or enhancing the quality of our environment.

Scope of Guide

The guidelines, criteria, and information provided in this publication are directed primarily toward the use of organic mulches as an aid in preventing excessive soil loss and in revegetating lands disturbed by coal surface mining in the Eastern United States. More specifically, this area includes 19 states associated with the Appalachian, Eastern and Western Interior, Anthracite, and Lignite coal regions (Fig. 1). Organic wastes that have been used as mulches on mined lands are described. The selection and use of organic wastes for conservation purposes, mainly soil and watershed protection and enhancement of plant growth, are emphasized. The principles set forth in the guide apply mainly to current mining operations but are also applicable to revegetation of abandoned mine lands and other disturbed lands.

The information in this guide was derived from numerous sources, including research and administrative publications of Federal, State, and private agencies and organizations; direct communications with reclamation specialists in the surface-mining industry and with others involved in surface-mine reclamation research, administration, and application. Some of the mulching recommendations are based upon research conducted over the past several years by the USDA Forest Service scientists. References are listed in a bibliography and are not cited in the text.

The guide should aid in the revegetation of final graded slopes. Information contained herein should be used in conjunction with local expertise. The scope of this report is limited by available information on use of various organic wastes in surface-mine reclamation and is based on current understanding.

Revegetation Planning and Regulations

Mine operators should be aware of Federal and appropriate State regulations that pertain to the revegetation, mulching, and other soil-stabilizing practices of lands disturbed by coal mining. For example, Section 816.114 of the regulations promulgated under the Surface Mining Control and Reclamation Act of 1977 requires that each permit application contains a plan for revegetation, including mulching techniques, of the mined area. The plan should include a schedule of mulching activities such as the type of mulch to be used, the rate of application per acre, and the application time, method, and equipment.

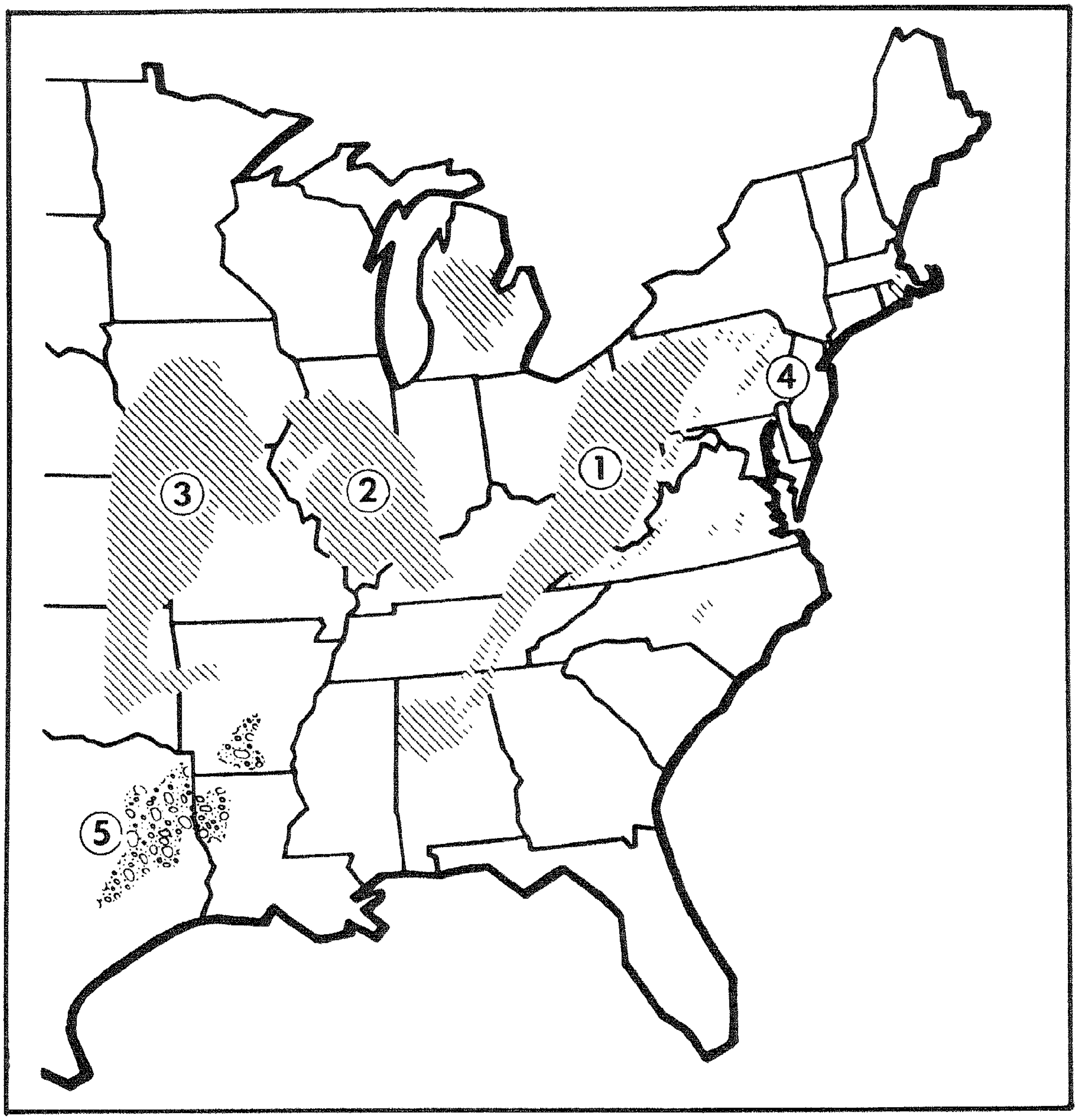


Figure 1.--Coal regions of the Eastern United States: (1) Appalachian, (2) Eastern Interior, (3) Western Interior, (4) Anthracite, and (5) Lignite.

The regulations also include requirements for timely reclamation, period of operator responsibility, topsoil removal and redistribution, tree and shrub stocking standards, mulch anchoring, in situ mulch, chemical soil stabilizers, and land use considerations. These requirements may vary by State but will be at least as stringent as the Federal requirements. Thus, operators should consult State and Federal regulations as their first step in soil stabilization planning and revegetation.

ORGANIC MATERIAL FOR MULCHING MINED LANDS

Types and Sources

A wide variety of materials has been tested for mulching effectiveness. Organic mulches are usually preferred to inorganic mulches because they are nature's own materials, sometimes providing needed microflora and fauna, seeds, organic matter, and nutrients to the often sterile heterogeneous minesoils. Organic matter is recognized as one of the most important factors in building a good soil structure capable of retaining moisture and plant nutrients. Soil scientists have long recognized the importance of manure, crop residues, and other organic materials in maintaining or improving soil tilth. Very extensive literature exists on the effects of organic mulches on cropland soil conditions, runoff, erosion, and yield of crops, but considerably less information has been published on their use in mine reclamation.

Straw, hay, wood chips, bark, and some hydromulches are most commonly used in reclamation. All of these materials have been tested or observed on surface mine spoils and have been found to be effective in promoting plant growth. They are applied as surface mulches or incorporated into the rooting zone depending, primarily, upon the severity of the revegetation problem and site accessibility.

Available mulching materials can be identified (on the basis of their physical character) as fibers, solids, or liquids. Fibrous mulches are usually classified as long- and short-fibered. The long-fibered mulches are materials like straw, hay, shredded hardwood bark, and composted municipal waste. Short-fibered mulches are hydromulch, wood fibers and cellulose, paper, and agromulch. Solid mulches include animal manure, wood bark, wood chips, sawdust, shavings, and sewage sludge. Liquids are usually associated with hydromulch and animal, municipal, and industrial sewage wastes.

The various fiber, solid, and liquid mulches have specific attributes and limitations. Materials behave quite differently under different soil and climatic conditions. Long-fibered crop residues decompose rather rapidly but are generally more effective in reducing surface flow and trapping sediment than short-fibered mulches. However, the effectiveness of short-fibered mulches can be improved by combination with a tackifier or soil stabilizer. Softwood bark mulches enhance legume establishment and last longer than hardwood bark mulches that adhere better to the soil providing improved erosion control. Liquid sewage effluent lowers soil temperature as it evaporates but it has little or no erosion control potential compared to the more solid sewage sludge. Materials with desirable attributes can be combined to attain specific chemical and physical properties and to equalize cost and availability.

Four major categories of organic wastes are considered here: agricultural (crop and livestock residues), silvicultural (logging and wood manufacturing wastes), industrial, organic wastes and municipal (refuse and sewage sludge), or combinations of these. Each type functions in its own way to protect and build the soil and establish vegetation. For each kind of waste, information is reported on quantity generated, usage, and problems and constraints affecting usage. The data are presented for each major farm production region (Fig. 2) by summarizing information on organic waste materials from individual states. Information on those farm production regions east of the 100th meridian are applicable to this guide.

The following section lists and describes the mulch types in each category. Only those materials that are available in sufficient quantities to meet surface-mine reclamation needs will be reviewed in depth. Availability and distribution of materials vary with the distance from the source of supply and reasonable cost. However, one should be able to find one or more of the materials in any project area.

This information is provided to give the user a general idea of the type and effectiveness of organic waste products available for mulching minesoils. The basic characteristics of the most readily available materials are evaluated for erosion control and on-site physical, chemical, biological, and climatic variables that may affect soil stabilization, the establishment of vegetation, and the cost of achieving protection objectives after the site is mined.

Agricultural Residues

In the future, as U.S. farmers increase food and fiber production to meet domestic and world needs, greater volumes of livestock and cropland wastes will be produced (current annual volume is more than 600 million tons). Returning these agricultural wastes to the land has been a traditional practice of American agriculture. About 75 percent of the total annual production of organic wastes is associated with crop residues (53%) and animal manures (22%). About three-fourths of these two wastes is currently being applied to the land. It would be feasible and economical to use the remaining waste for surface-mine mulch.

Crop Residues.--Crop residues of cereal foods and fodder crops include stalks, stems, leaves, roots, cobs, hulls, chaff, pulp, and any other plant parts that remain after agricultural crops are harvested. According to a recent USDA survey, more than 430 million tons of crop residue are produced in the United States annually by 15 major crops (Tables 2 and 3). These crops account for more than 80 percent of the total crop residues produced. Of these, field corn, soybeans, and wheat account for 75 percent. Although most of these residues are returned to the soil, some could be available for use as surface-mine mulch.

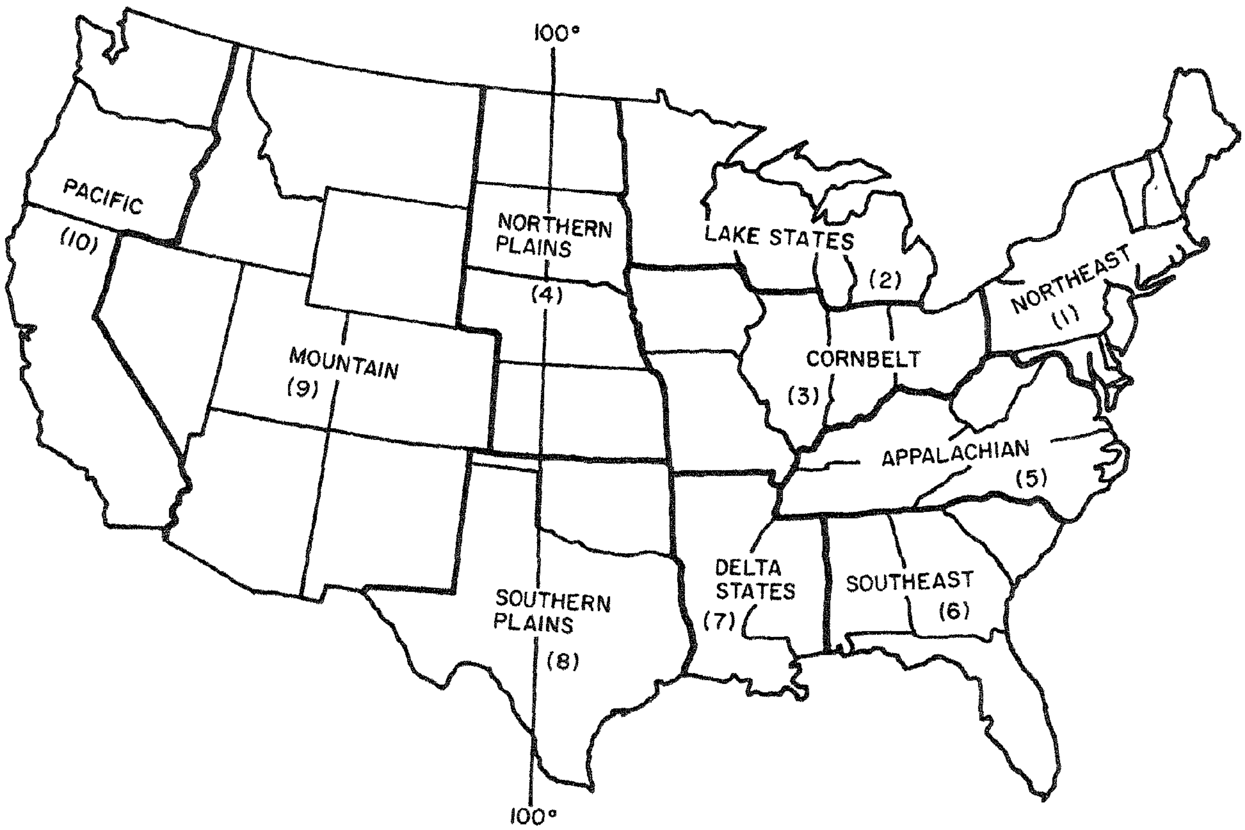


Figure 2.--U.S. farm production regions (USDA 1978).

Table 2. Production and disposition of crop residues, by region (USDA 1978) (Includes animal bedding wastes)

Region	Total annual production	Sold	Fed	Fuel	Returned to soil	Waste
	Million tons	---------------	-------	Percent	-------	---------------
Northeast	11.183	3.8	29.3	0.0	66.4	0.5
Lake States	44.494	5.2	29.9	.0	64.8	.1
Corn Belt	173.011	.9	37.7	.0	61.4	.0
Northern Plains	81.526	3.0	21.3	.0	75.7	.0
Appalachian	17.279	.8	29.0	.0	69.8	.4
Southeast	13.530	1.3	19.6	9.0	59.1	11.0
Delta States	15.121	5.0	2.2	5.3	62.9	24.6
Southern Plains	32.728	2.1	25.9	.1	63.9	8.0
Mountain	20.002	4.3	6.3	.0	89.2	.2
Pacific	20.213	7.6	3.9	.0	81.5	7.0
National average		2.7	26.2	0.5	68.2	2.4
Total	431.087					

Table 3. Percentages of animal bedding wastes, by source and region (USDA 1978)

Region	Sources							Total annual production
	Dairy	Feeder beef	Sheep	Swine	Layers	Broilers	Turkeys	
	Percent							Million dry tons
Northeast	94.1	1.2	0.9	0.1	0.8	2.7	0.2	3.206
Lake States	93.3	4.1	.6	.5	.3	.0	1.2	4.612
Corn Belt	65.3	24.4	3.2	4.2	.6	.0	1.3	3.518
Northern Plains	64.5	16.1	13.9	4.7	.8	.0	.0	.712
Appalachian	82.6	3.1	1.5	1.4	1.0	7.6	2.8	1.399
Southeast	64.1	5.3	.0	1.2	3.0	25.7	.7	.853
Delta States	60.1	2.2	.0	.3	3.0	32.2	2.2	.642
Southern Plains	54.6	12.6	23.8	.4	.9	5.1	2.6	.740
Mountain	23.3	13.3	60.3	.3	1.6	.0	1.2	.577
Pacific	48.7	9.3	23.1	.2	6.2	6.0	6.5	.536
Subtotal								16.804
Additional bedding wastes (geographical distribution data not available):								
Beef cows								4.000
Horses								3.000
Total								23.804

Most of the crop residues listed above are grouped as straw, stalks or stover, corn cobs, stems and leaves, and hulls:

Straw

- Barley
- Flax
- Oats
- Rice
- Wheat

Stalks or stover

- Broom corn
- Castor bean
- Field corn
- Hemp
- Kaffier
- Pop corn
- Sorghum
- Sugar cane
- Sunflower
- Sweet corn
- Tobacco

Corn cobs

- Field corn
- Pop corn
- Sweet corn

Stems and leaves

- Dry beans
- Peanut
- Potato
- Soybeans
- Sugar beet

Hulls

- Buckwheat
- Cocoa
- Cotton (seed and lint)
- Peanut
- Rice (whole or ground)

Straw comes from various cereal crops. Stalks or stover are usually the residue of corn, cane, sorghum, and similar whole or shredded stalks. Hulls are usually by-products from industry and come from such plants as cocoa, cotton, and peanut.

Many of these materials need to be reprocessed before they can be used as a mulch. Bulky pieces, such as corn and cotton stalks, can be reduced in size by grinding, crushing, flailing, shredding, or milling (hammer mill). Others need to be dried before being transported and applied. Packaging is expensive and may not be justified unless there exists a well-developed market for the mulch.

It may be necessary to restrict the use of crop residues if: (1) the danger of transmitting a plant disease is high; (2) they contain undesirable seed that will compete with the desired species; and (3) they have an excessive quantity of noxious weed seeds, that could be a menace to surrounding farmland.

Straw is the crop residue most commonly used for mulch. Other residues yielding varying degrees of success include bran, crushed corn cobs, rice, straw, cocoa, and peanut hulls. The use of these materials is limited, and their importance will be restricted to areas in which they are produced.

Hay.--Hay is a production resource and not considered a waste unless there is a surplus due to extremely favorable growing conditions and lack of demand. It is included here because various grass and legume crops are commonly used as mulches:

Grass

- Bluegrass
- Coastal Bermuda
- Orchardgrass
- Perennial rye
- Redtop
- Tall fescue

Legume

- Alfalfa
- Birdsfoot Trefoil
- Cowpea
- Crownvetch
- Lespedeza
- Peanut
- Red clover
- Soybean
- Sweet clover
- Timothy

In addition to hay that may be purchased, many mining companies are using cuttings of herbaceous plantings from their own previously reclaimed areas as mulch for new reclamation projects (Fig. 3).

In-Situ Vegetative Mulches.--In-situ vegetative mulches are a special category of crop residues. Quick-developing annual grasses such as Japanese and pearl millet, rye, sorghum, and wheat can be used alone as in-situ mulch or in conjunction with another mulch. The grass provides a ground cover while it is growing and continues to protect the site after it has matured and died. In-situ mulches may provide effective protection for a year or more. A disadvantage is that this type of mulch cannot be established in all seasons or on all areas.

Figure 3.--Baling hay on reclaimed land.

Animal Wastes.--Animal waste refers to feces and urine (manure) excreted by various livestock (about 89 percent of all manure is produced by dairy and beef cattle and horses) and poultry produced by the United States agricultural industry. Bedding and litter sometimes used to absorb moisture and facilitate handling manure as a solid material were considered under crop residues (Tables 2 and 3).

Livestock and poultry manure represent about 22 percent of the total of all organic wastes produced in the United States or 176 million tons on a dry-weight basis (Table 4). About 70 million tons (39 percent) of this are produced under confined conditions. The remaining 105 million tons (61 percent) are excreted on pasture, rangeland, or cropland.

Approximately 90 percent of all manure generated under both confined and unconfined conditions is used as a production resource on land. Most of the remaining 10 percent or about 18 million dry tons is disposed of as waste and could be used on minelands.

Manures are available in solid, slurry, or liquid forms depending on the type of waste-management treatment system used to collect, treat, and store waste. "Solid" is defined as having total solid content greater than 25 percent (wet-weight basis); "slurry", 8 to 30 percent; "liquid", less than 10 percent.

Manure has been used as a production resource on land for many years because it improves soil fertility and tilth when applied at rates within crop fertilizer requirements. Land application of manure is limited primarily by the economics of collection, storage, transportation, and application. Transportation costs and land availability are important constraints on efficient use of manure as a mulch and fertilizer.

Silvicultural Residues

The growing demand for all timber products increases volumes of logging and wood manufacturing residues, which presently amount to about 100 million tons a year. A good share of this is generated from the growing stock of hardwood and softwood commercial timberland in this country. Three-fourths of this growing stock is in the Eastern United States (about equally divided between north and south).

Logging Residues.--Logging residue is the debris left in the woods following intermediate cuttings, understory removal, salvage operations, and the removal of marketable products. It includes limbs, needles, leaves, diseased or decayed wood, and noncommercial residual stands. Each year over 26 million tons of logging residues are generated in the United States with over 70 percent of it in the East (Table 5). In the East, residue volumes average about 700 cubic feet per acre. Residues from a logging operation in the area of active mining could be used for mulch if the residues could be collected and transported economically.

Table 4. Annual production of animal manures, by region (USDA 1978)

Region	Dairy cattle	Beef cattle	Horse	Sheep and goat	Swine	Broiler	Chicken other than broilers	Turkey	Duck	Total
	Thousand tons									
Northeast	5,666	1,317	1,555	26	177	1,223	586	54	26	10,631
Lake States	8,536	3,887	1,782	58	804	25	298	406	4	15,800
Corn Belt	4,400	18,874	2,646	149	4,041	59	645	318	10	31,143
Northern Plains	1,458	18,451	1,430	163	930	2	117	32	0	22,584
Appalachian	2,424	7,904	2,848	42	711	494	423	375	1	15,221
Southeast	1,227	8,679	1,994	1	432	1,001	943	56	0	12,332
Delta States	860	5,384	1,184	3	128	869	468	138	0	9,034
Southern Plains	1,193	20,660	3,494	472	160	210	192	141	0	26,522
Mountain	1,307	12,810	2,800	558	110	0	112	82	0	17,777
Pacific	2,987	5,521	3,501	192	42	142	619	261	2	13,265
Alaska, Hawaii, and Puerto Rico	266	508	64	1	14	2	15	0	0	870
Total	30,323	101,994	23,296	1,664	7,549	4,026	4,418	1,863	43	175,176

Table 5. Logging residues generated annually, by region[a] (USDA 1978)

Region	Logging residues		
	Softwoods	Hardwoods	Total
	Thousand tons		
Northeast	1,006	2,639	3,645
Lake States	49	661	710
Corn Belt	5	983	998
Northern Plains	Trace	24	24
Appalachian	516	3,647	4,163
Southeast	2,209	2,203	4,412
Delta States	1,113	1,773	2,886
Southern Plains	308	274	582
Mountain	1,462	7	1,469
Pacific	6,508	656	7,164
Hawaii, Alaska	74	0	74
Total	13,250	12,867	26,117

[a]Regional estimates were obtained from the 1976 Resource Planning Assessment (RPA) data. The RPA data were transformed from volume to mass by a conversion factor of 30 lb/ft^3 for softwoods and 44 lbs/ft^3 for hardwoods. These data do not include stumps, residues more than 4 inches in diameter, and rough and rotten trees.

Another potential source of residue is the waste generated from mine-clearing operations. It has been estimated that approximately 90 percent of surface mining in Appalachia occurs on forested lands. Most of this timber removed during mining has been wasted. The Federal Surface Mining Control and Reclamation Act limits the options available to a surface-mine operator for the disposal of woody vegetation removed during the clearing operation. Pushing vegetation over the outslope for a sediment filter at the toe of the slope is no longer permissible. Burying on the bench next to the highwall is wasteful and can reduce stability in fills.

All commercially attractive timber should be removed during site preparation. Woody residues (tops, branches, under brush) remaining could be chipped on-site for use as mulching material in reclamation operations (Fig. 4). The main drawback to this practice is that it may not be economical.

Wood Manufacturing.--Over 70 million tons of residue--slabs, edgings, chips, shavings, bark, sawdust, and other unused wood wastes--accumulate in this country each year (Table 6). Much of this material is allowed to remain where it accumulates. The problem of disposal has plagued wood-utilizing industries across the country. In the past, sawmill operators disposed of their surplus residues by indiscriminate dumping or burning. Since 1970, the burning and dumping of waste have been eliminated by emission and sedimentation standards. Most sawmills, however, continue to dump their waste in unused areas. Properly utilized, those residues could be of considerable value to reclamation and would help alleviate disposal problems. Wood residues could contribute much-needed organic matter and should be utilized for humus maintenance in every location where economically feasible.

Wastes generated in the manufacture of paper and paper products are considered industrial organic wastes. More than 85 percent of these residues are utilized for a variety of products by the pulp and paper, particle board, and fiberboard industries. However, the annual production of over 10 million tons is available for other uses and has greater potential than that of logging residues (except those from mine clearing) for use as mulches.

Wood organic matter has been used for over 20 years. However, only recently has there been a rapid, widespread and increasing interest in the utilization of silvicultural residues for mulching in reclamation. The following is a list of silvicultural residues by type and form:

Bark (hardwood, softwood)

- Ground (soil conditioner)
- Shredded
- Chunk
  - Small (chip)
  - Medium (nugget)
  - Large (chunk)

Woodchips (hardwood, softwood, mixed)

- Small (chip)
- Medium (nugget)
- Large (chunk)

Figure 4.--Whole-tree chipper.

Table 6. Wood manufacturing residues production in the United States and how these residues were used in 1970 and 1976[a] (USDA 1978)

Item	Softwoods		Hardwoods		All species	
	1970	1976	1970	1976	1970	1976
Total wood manufacturing residues	45,540	52,140	16,918	17,336	62,458	69,476
Used for pulp	22,710	28,560	5,698	7,876	28,408	36,436
Used for fuel	8,985	10,230	2,794	2,552	11,779	12,782
Used for other products	3,615	8,175	1,584	2,486	5,199	10,661
Unused	10,230	5,175	6,842	4,422	17,072	9,597

[a]Estimates were obtained from the 1976 Resource Planning Assessment (RPA) data. The RPA data were transformed from volume to mass by a conversion factor of 30 lb/ft^3 for softwoods and 44 lb/ft^3 for hardwoods.

Sawdusts and/or shavings

Green
Composted

Leaves

Loose
Baled

Pine straw

Needles

Evaluation of wood residues as mulches has shown them to be a vital resource that could be used extensively in reclamation of surface-mine spoils. Hardwood tree species used for bark mulches are: ash, basswood, beech, birch, black walnut, cherry, elm, gum-red, hickory, oak (black, chestnut, post, red and white), maple, sycamore, and yellow-poplar. Softwood species used are: red cedar, hemlock, pine (loblolly, long leaf, short leaf, slash, Virginia, and white).

Municipal Wastes

The two types of municipal wastes and their sources are:

Solid waste (composted)

Residential
Institutions
Offices
Industry
Shops
Rural

Sewage sludge

Residential Systems
Septic

Community and Industrial Systems
Solid
Slurry
Liquid

Increased product packaging and urbanization are having their effects on the volume of refuse and sludge produced. Each is directly related to per capita consumption and use with quantities steadily increasing in spite of a reduction in birth rate. By 1990, wastes from these two sources will amount to over 250 million tons annually.

Solid Waste Refuse.--The Council on Environmental Quality estimates that about 200 million tons of municipal refuse are generated each year in the United States. Of this, about 145 million tons are collected. About 30 percent of the total is generated in rural areas and only about 8 percent collected. Trash and garbage production is estimated at 1,100 to 1,700 pounds per person per year, and quantities generated per capita are increasing steadily.

The collectible portion of solid waste generated is, by weight, about 70 percent biodegradable organic material consisting mostly of paper products, food residues, and yard trash, which includes lawn, shrub, and tree clippings and trimmings. The remainder is nonbiodegradable metal, glass, and plastics. The organic component has potential value as a mulch material. The composition of municipal refuse is:

Refuse category	Range of reported values, percent
Paper	28-30
Paperboard	7-24
Garden wastes	7-35
Garbage	2-9
Metal	6-10
Aluminum	0.3-1
Glass	3-10
Cloth	1-3
Plastics	1.5-3
Fats and oils	2-6
Residue (ashes, dirt, etc.)	3-20

Currently most of this refuse is disposed of in sanitary landfills. However, it has become necessary, though increasingly difficult and costly, to locate and obtain public consent for new landfill sites. Application of refuse on the land is a possible alternative to new landfills because it utilizes wastes for a beneficial purpose.

Use of the organic component of municipal refuse as a mulch is practicable only if it is well sorted and shredded. Without such processing, it is neither feasible nor desirable to apply to land. To date, efficient and economical methods for separating nonbiodegradable components from the useable organic fraction have not been developed. Therefore, land application at this time must be considered marginal.

Refuse intended for land application is usually composted to enhance its value as a mulch and to facilitate handling and blending of material with organic wastes such as bark.

Sewage Sludge.--The current annual production of sludge in the United States is 4.3 million dry tons. According to the 1978 USDA special report, "Improving soils with organic wastes", annual production, in thousand dry tons, of sludge by region is:

Northeast	1080.1
Lake States	444.1
Corn Belt	897.0
Northern Plains	76.0
Appalachian	321.5
Southeast	309.0
Delta States	125.3
Southern Plains	295.6
Mountain	192.5
Pacific	536.7
Hawaii, Puerto Rico, Alaska	21.7
Total	4,299.5

Sludge production is expected to increase more than 25 percent by 1990 to about 5.5 million dry tons (assuming a population increase in the United States of 14 percent). An additional 0.69 million dry tons is septage produced from individual on-site residential treatment facilities. This septage is expected to reach 1 million tons by 1990. More than 71 percent of the population producing 60 percent of the sewage is served by municipal sewers. The production equivalent of dry sludge per capita per day is 0.12 pounds. In addition to increased waste due to population increases, mandated improved wastewater treatment will also generate extra sludge.

Various kinds of wastewater and solids have been applied on land for a long time in many areas of the world. In the United States there are three types of sewage waste--solid, slurry, and liquid--that are produced in the three steps of the wastewater treatment process. Solid or sediment from primary treatment is defined as that with total solid content greater than 25 percent (wet weight); slurry or activated sludge from secondary treatment, 8 to 30 percent; and liquid or effluent from tertiary treatment, less than 10 percent (Table 7).

Table 7. Sludge solids content and handling characteristics

Type	Solids content	Handling methods
	Percent	
Liquid (slurry)	1–10	Gravity flow, pump, tank transport
Semisolid ("wet" solids)	8–30	Conveyor, auger, truck transport (watertight box)
Solid ("dry" solids)	25–80	Loader, conveyor, truck transport (box)

There may be some potential problems and constraints associated with sludge disposal on mine spoils. Large-scale application of sludges depends on the resolution of concerns related to public acceptance: objectionable odors, pathogens and parasites, heavy metals uptake by plants, toxic organic compounds, nutrient (nitrogen) content of sludge runoff, pollution of streams and groundwater, and government regulations.

Most of the potential physical, chemical, and biological problems can be minimized or eliminated if waste is composted before use. Problems of a political nature can be alleviated, or at least modified, by appropriate information and education.

The proper use of sewage sludge on surface-mined land makes it possible to grow a wide variety of agronomic and horticultural crops as well as many forages. Where adequate supplies of sewage sludge or effluent exist, they should definitely be considered in view of the documented performance on mine soils.

Municipal sewage sludge could be used in reclaiming many of the 1.1 million acres of abandoned surface-mine land in the United States (Table 8). More than 97 percent of this land is concentrated east of the 100th meridian (Fig. 5). Some of this land has the most hostile of all environments for plant establishment and growth because of spoils that are highly acid and with toxic levels of iron, aluminum, and manganese; droughty; low in fertility; and extremely high in summer surface temperature. The harsh site conditions of some of these abandoned spoils have been ameliorated and productivity improved by irrigation treatments with sewage effluent and liquid digested sludge.

Industrial Wastes

Industrial organic wastes considered suitable for land application come from the following industries: textile finishing, paper and allied products, organic fibers (noncellulosic), pharmaceutical (waste mycelium), leather tanning and finishing (vegetable), petroleum refining, and miscellaneous organic chemicals. Pulp and paper, petroleum refining, and the miscellaneous organic chemical sludge groups are identified as the largest contributors of organic wastes. Although the estimated quantity of industrial sludge considered suitable for land application is more than 9 million dry tons per year, this is only a little more than 3 percent of the total annual production in the United States (Table 9). These organic residues are in addition to those being discharged into and recovered from municipal-waste treatment systems.

Other industrial wastes used or tried as soil amendments are macerated paper, digested paper, pulp-mill chip washings, waste sulphate liquor solids, wood fiber and cellulose, seed refractory screenings, and hulls from crops.

Land application of industrial organic wastes has been practiced on a limited scale usually as means of disposal rather than as an aid to soil and plant growth improvement. It is possible that some industrial wastewater and sludges can be collected, processed, transported, and applied to land using the existing methods applicable to municipal sludges or wastewaters.

Table 8. Acreage of abandoned mine lands in Midwest and East (USDA 1978)

State	Acres
Alabama	72,300
Arkansas	5,600
Georgia	1,700
Illinois	118,700
Indiana	25,900
Iowa	14,000
Kansas	41,300
Kentucky	101,600
Maryland	2,800
Michigan	100
Missouri	70,700
Ohio	196,700
Oklahoma	36,100
Pennsylvania	240,000
Tennessee	29,600
Texas	3,300
Virginia	23,700
West Virginia	84,900
Total	1,069,000

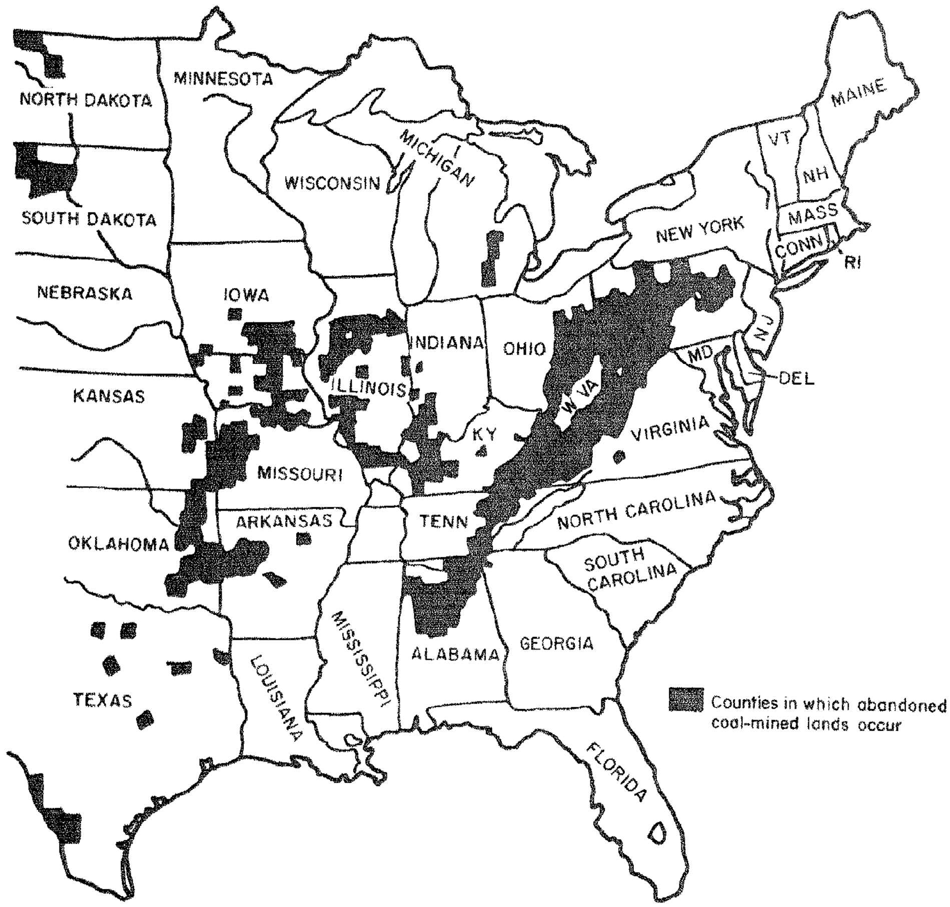


Figure 5.--General location of abandoned coal-mined land east of the 100th meridian (USDA 1978).

Table 9. Estimated annual production of industrial wastes suitable for land application in 1975, 1980, and 1985, by industry (USDA 1978)

Industry	Waste type	1975	1980	1985
		Thousand dry tons		
Textile finishing	Secondary wastewater sludge	42.9	93.5	198.0
Paper and allied products	Primary wastewater treatment sludge	1,870.0	2,090.0	2,310.0
Organic fibers, noncellulosic	Secondary wastewater sludge	5.3	8.0	10.8
Pharmaceutical	Waste mycelium	69.3	89.1	110.0
Leather tanning and finishing (vegetable)	Secondary wastewater treatment sludge	.9	.8	.7
Petroleum refining	Nonleaded product tank bottom	45.1	56.1	68.2
	Waste biosludge	44.0	55.0	68.2
	API separator sludge	37.4	46.2	57.2
	Dissolved air flotation float	31.9	40.7	49.5
	Slop oil emulsion solids	18.7	23.1	28.6
	Crude tank sludge	.4	.5	.7
Miscellaneous organic chemicals	Wastewater treatment sludges	6,050.0	9,983.0	12,251.9
Total		8,215.9	9,983.0	12,251.9

Caution must be exercised in the application of some industrial organic wastes to lands because the original product or the various processing additives may result in materials that are potentially toxic to plants, animals, or humans. Serious constraints that limit their desirability may be associated with specific wastes: high concentrations of one or more heavy metals; hazardous or phytotoxic chemicals; soluble salts, especially sodium; very high carbon to nitrogen (C to N) ratios; and low concentrations of nutrients essential for plant growth. Any particular industrial organic waste considered for land application must be evaluated on its own merits, based on suitable analytical data and site-specific management.

Food Processing Wastes.--Over 3.2 million dry tons of food processing wastes are produced annually from fruit, vegetable, seafood, sugar, fats and oils, and dairy products. Although these liquid wastes are compatible with the environment, it is not likely that they will be available to any appreciable extent for application to disturbed lands. Use of these wastes as an animal feed and for by-product manufacture is expected to increase with developing technology, significantly decreasing the amount of waste available from these sources. Less than 16 percent, or 500,000 tons of the wastes produced, is currently available for land application. Food processing wastes used or tried as soil surface mulches are sugar beet pulp and bagasse.

MULCH SELECTION

In developing a reclamation plan, the first task following the selection of a plant species is to choose a mulch. Correct material selection is difficult because no one mulch material is best for all situations. The physical, chemical, and biological properties of soils, the degree and length of slope, the exposure, and climate are important considerations. Mulches can sometimes cause problems including nutrient and waste immobilization, germination inhibition, potential invasion of weeds, and the attraction of unwanted organisms and plant diseases. A material should be chosen only after consideration of these potential problems.

Not all materials are adapted to all sites; a number of factors affect adaptability. Although these factors are considered separately, it is their combined influences that determine the need for a mulch and the potential of the selected material. The selection of one type of material over another involves not only consideration of the material itself but also a trade off among the many interfacing factors. In choosing a mulch, consider all of the following criteria as a basis for comparing and evaluating materials, and determine which attributes are most important in each particular situation, then choose the material that most nearly satisfies requirements and needs.

Intended Use

When planning a mulch treatment and selecting equipment suitable for its application, one must be familiar with both legal requirements and the revegetation objectives of the project. The type and amount of mulch material selected depends on site conditions, the vegetative cover being sought and approved for the postmining use, and the regulatory requirements for erosion control.

Mulch is used to cover and protect the soil surface and seedbed; to control erosion on steep slopes and in drainage ways; and as a plant mulch to conserve moisture, protect surface roots, and to control unwanted vegetation around tree and shrub seedlings. The advantages of mulching exceed the protection it provides. Mulching also can be used as a decorative ground cover to improve the appearance of an area when landscaping, and in planting beds around mine administrative facilities and other structures frequented by the public. Mulch may be required for one or all of these purposes.

Surface Protection

All mulches provide some protection to the soil surface if applied in sufficient quantities. Application rates that provide 1/4 to 2-inch-thick layers, depending on the mulch used, are generally adequate. The range of effective application rates reflects variability in character of mulch materials used, corresponding percent of surface area covered, site conditions, and seasonal weather patterns.

The most important function of a mulch in surface protection is to provide a protective shield and obstruct water from the soil surface. Mulch will neutralize wind saltation and kinetic energy of raindrop splash, thereby dissipating the transport energy and abrasive action of wind and moving water. A mulch that bonds to the soil surface helps to bind the soil particles together to form a mass that is less easily displaced. The most effective mulch is one (such as bark) that provides bulk and protective cover and good adherence to the soil surface with resistance to blowing or washing away.

Considerable care should be taken to see that mulch material is evenly spread over the area. A partially covered surface is less efficient in protecting the soil surface from falling rain and controlling soil washing. As the percent of cover increases, runoff decreases. The effectiveness of mulch in stabilizing the soil surface is a function of coverage and durability.

Usually, the minimum amount of mulch coverage needed for surface protection is 75 percent. It has been shown that, when compared to a bare site, a mulch coverage of even 50 percent reduced the erosion rate by 35 to 40 percent for a wide range of steepness and length of slopes. For example, on a simulated 15 percent slope, one-quarter ton per acre of straw mulch with only 34-percent surface coverage reduced erosion to about one-half that from an unmulched treatment. One-half ton per acre, or 49-percent coverage, reduced erosion to one-third or less. Four tons per acre, or 100 percent coverage, reduced it by more than 95 percent.

It has been shown that 1-1/2 tons per acre of crop residue on the surface reduced soil erosion on cropland to half that of conventional tillage without residues. If crop residue is used for surface protection against erosion, coverage should equal 2 tons per acre or more.

Seed Cover

Good soil and water control is attained by establishing sods quickly, thus the most desirable mulches should encourage rapid germination, augment seedling population, and stimulate seedling growth. Mulch should be applied at the optimum rate and depth that will provide the necessary protection for the soil surface and encourage seed germination.

Mulches used as cover on new plantings reduce evaporation of moisture from the layer of soil in which young germinating seedlings are becoming established. However, at no time should mulch replace the soil as a seed cover. Seed covered with soil to the proper depth is essential, especially during dry periods. Soil coverage assures that an organic mulch will not take moisture away from seed and cause poor germination.

In establishing vegetation, a 100-percent coverage of mulch is more important than weight or volume needed for erosion control. Uniform application is required to effect complete and even revegetation.

In the germination and establishment of grasses, legumes, and direct seeding of woody vegetation on exposed soil surfaces, the important factors of a cover mulch are depth, type, and particle size of material. Mulch depth must be thin enough to avoid smothering emerging seedlings. Particle size must be large enough to keep the cover sufficiently loose and open and free from compaction.

Erosion Control

A vital function of a mulch is to reduce or prevent surface erosion by shielding, absorbing, and dissipating energy. Steep, bare, unvegetated minesoils are subject to high rates of erosion. Therefore, special efforts to prevent surface erosion are warranted, especially because repair of erosion damage is one of the most expensive recurring costs on mined sites.

Vegetating disturbed areas as quickly as possible is one of the most important and practical means of preventing excessive erosion. However, when site conditions are such that vegetation alone cannot withstand microclimate and imposed stresses of erosion, mulch can be used to reinforce vegetation measures. A properly selected mulch used with other good management practices is the most popular means of providing slope stabilization until a vegetative cover is established.

The objective of mulching is to make the soil surface rough, to minimize soil detachment, and to impede overland water flow thus reducing its volume and velocity and aiding water infiltration.

To prevent erosion, mulch must adhere to the soil. A mulch that makes a good contact with the ground reduces the potential for detachment and transport of soil. The various type of mulch can either physically block or check the overland movement of soil particles. Many solids (chunks) or fiber to the square foot decrease erosion because each particle of mulch becomes a tiny dam and acts as an obstruction to flowing water or wind detachment. The longer the fiber length the greater is the effectiveness of mulch in erosion control. Straw placed across a slope creates a dam and reservoir or ditch check in which sediment collects and develops into a miniature step or bench. This not only reduces the erosive power of the water, but also provides time for more of the water to seep gently into the soil. In torrential storms, mulch must be anchored to be effective.

Natural erosion proceeds at a very slow rate. Approximately 0.1 to 1.0 ton per acre of sediment is lost per year from protected watersheds. Agricultural erosion occurs at the rate of 0.3 to 6 tons per acre per year. The rate of erosion from construction activities ranges from 3 to 200 tons per acre per year. Mine operations that will continue for more than 2 years should try to maintain a sediment yield of not more than 5 tons per acre per year.

Wind erosion occurs primarily when the moisture content is lowered during drought periods. Low moisture content enables the wind to detach and transport light clay particles. When the wind becomes laden with soil particles, its abrasive action is increased. Particles eroded by wind are less than 0.02 inch in diameter. More than 93 percent of the total soil movement by wind takes place below a height of 1 foot, and 50 percent or more probably occurs within 2 inches of the ground. Properly anchored mulches may reduce surface wind velocity and lessen particle movement and dust.

Plant Mulch

The harsh microclimate of minesoils is often detrimental to the establishment of vegetation, especially shrubs and trees. Where soils are droughty or the effective rooting zone is shallow, heavy applications of mulch help to: conserve moisture, insulate shallow rooted plants from heat or freezing, and inhibit competition from unwanted weeds and other herbaceous vegetation. A good mulch for individual shrub and tree plantings, groups, and row plantings should hold water, be coarse, porous and nontoxic.

In addition to protecting the delicate plant roots and soil organisms from the direct influence of excessive heat and drought in summer, the effects of alternate freezing and thawing must also be considered. Frost action along with water thawing is responsible for some of the physical weathering which takes place in minesoils. As ice forms in rock crevices, it causes the rock to disintegrate. Similarly, alternate freezing and thawing subjects spoil aggregates and clumps to pressures and, thus, alters the physical set up in the minesoil. Freezing and thawing of the upper layers of soil can also result in so-called heaving of perennial plants. Herbaceous as well as woody-plant crowns can be exposed as a result of this type of action during the winter and early spring months. This action, which is most severe on bare, imperfectly drained soils, can drastically reduce vegetative stands. It has been found that application of a mulch reduces frost heaving of young seedlings.

Site Characteristics

A mulch should be tailored to the characteristics of the site on which it is to be used. Evaluation of topographic and geologic factors requires information on slope gradient and length, aspect (micro and macro slope), soil type, roughness, and erosion potential because they influence the ability of the mulch material to adhere to the site and its ability to withstand the stresses of erosion and traffic. This involves a review of information from the premining investigation of existing site features and conditions and, if necessary, a thorough field investigation of the site and surrounding areas. Consultation and advice on runoff, soil transport, and ground-water pollution potential may be obtained from USDA Soil Conservation Service.

Slope

Topographic considerations for erosion control, vegetation establishment, and land use include the allowable length and steepness of slope. Slope steepness and length each significantly affect the erosion rate and runoff velocity. As the steepness and length of slope increase, there is a corresponding rise in the velocity, turbulence, and the volume of surface runoff, resulting in greater erosion unless control measures are taken.

The carrying capacity of moving water increases as its velocity increases. Increased velocity associated with steep slopes causes more sediment to remain in suspension than that on lesser slopes. If the flow velocity is doubled due to increasing the degree and length of slope, the water will be able to transport soil particles 64 times larger and carry 32 times more material in suspension.

Long and steep slopes usually erode more rapidly and are more difficult to vegetate and to maintain than gentle short slopes and level areas. Long unbroken slopes of moderate steepness on gently rolling terrain suffer more erosion than steep but very short slopes. For equal areas, doubling the length of a slope increases the soil loss by a factor of 1.5. Long slopes allow surface runoff to concentrate creating rill and gully erosion channels (Fig. 6) that cause inconvenience and loss of efficiency with post-mine land use equipment.

Mining often results in steep slopes that are difficult to stabilize with vegetation. Mulch and vegetation techniques are usually limited to slopes of 2:1 (50 percent or 26-1/2 degrees) or flatter, and a slope of about 4:1 (25 percent or 14 degrees)is the maximum for contour operation of reclamation machinery.

We used the following classifications for slopes.

Slope	Steepness			Length	
	Ratio	Percent	Degree	Slope	Feet
Flat	10:1	10	5.75 or less	Short	33 or less
Rolling	3:1	33.33	18.5	Medium	66
Steep	2:1	50	26.5	Long	100 or over

On a 4 percent 40- to 70-foot slope, the erosion rate is relatively low even without mulch. Sediment was reduced to below 5 tons per acre on a 20 percent 150 foot slope where 25 tons per acre of mixed hardwood chips with 100-percent ground cover were subjected to 2-1/2 inches of intense rainfall.

Most mulches lose effectiveness as slope increases. For example, a 20 percent 150-foot slope with 95-percent cover of 2-1/2 tons per acre of straw eroded at a rate of nearly 70 tons per acre. Straw mulch was unsatisfactory on this slope because of rilling underneath. The same rate of straw effectively controlled erosion on slopes less than 20 percent.

Figure 6.--Rill and gully erosion.

On a 33-1/3 percent slope, 20 cubic yards per acre of shredded hardwood bark did not satisfactorily control erosion under a simulated 6- to 9-inch rainfall per hour, but 25 to 30 cubic yards per acre did reduce erosion markedly. A rate of 40 to 50 cubic yards per acre loose measure was even better and is the minimum rate of bark recommended.

If soil movement on steep slopes is to be controlled or minimized in the short term, it is absolutely essential that mulch material be anchored to the surface or partially incorporated into the minesoil. In relatively level areas, the application of a mulch should be optional if adequate water or moisture is available and the potential for erosion is minimal.

Aspect

Aspect (exposure) is the direction that a slope faces. Depending on the site conditions, aspect affects solar radiation loads, growing season length, and the establishment of vegetation, thus affecting the selection of mulch for mined areas. Contrasts in exposure to sunlight, degree of slope, color of soil and mulch, temperature, time of year, and the direction of prevailing winds create different microclimates on each aspect of a given landscape. Therefore, aspect may influence the choice of color and depth of mulch material to absorb or reflect heat, insulate, or determine the amount needed to resist blowing.

Slopes with southern and western exposures are considerably hotter and drier and have more variation in temperature than slopes with northern and eastern exposures. Temperatures are about 10 to 12 degrees higher on bare slopes with southern or western exposures than on slopes with northern or eastern exposure. Bottoms of north-facing slopes are cool and moist, whereas the top of south-facing slopes are warm and dry and are usually 5 to 10 degrees warmer than base.

During the period of highest temperature, soil temperatures on a southern exposure have been found to be 7 to 10 degrees lower under mulch than on a bare slope.

The slope direction affects the ease of vegetation establishment and stand survival. Some plant species are better adapted than others to specific aspects. For example, pine trees usually thrive better than most hardwoods on south slopes. Mulching provides a more favorable microclimate to help establish vegetation. It is usually more beneficial to seedling establishment on south and west aspects than on north and east ones.

Surface color of a minesoil and exposure is often a limiting factor for vegetation. Dark material on the surface absorbs large amounts of solar energy resulting in elevated surface temperatures lethal to seedlings. This may occur, especially during summer periods, on south and west exposures where high temperatures may cause soil to dry out more rapidly. In such instances, a light-colored mulch should be used to reflect radiation. Due to varying effects of mulches on temperature, it may be desirable to use different mulches at different times of year and on different slope aspects (see Mulch Application).

Roughness

Roughness of the surface has an effect on erosion by wind and water. A rough surface is better than a smooth one for controlling erosion and aids in adhering a mulch to a site. Certain mulch materials spread over a smooth, hard minesoil surface may be subject to slippage, washing, or blowing. Maintaining a rough surface will ameliorate this situation (see Mulch Application).

Soil Properties

Knowledge of soil properties is especially useful for identifying and treating those minesoils with properties that limit or prevent establishment and growth of vegetation. Such knowledge can be helpful in selecting organic mulch materials and plant species that are best suited or adapted to specific sites or conditions.

The most important problems threatening the physical integrity and ability of minesoil to support plant growth are erosion and overcompaction. Poor nutrient status and upward migration of toxic elements or salts present problems in some areas. An analysis and knowledge of the characteristics of the minesoil and overburden from the premine planning phase of the operation and of the regraded and topsoiled areas are necessary to indicate what conditions must be ameliorated on the site.

The type of spoil and soil materials on the site will affect the amount of erosion. Steep, bare, unvegetated minesoils are subject to high rates of erosion and soil losses can be significant. A vital objective of minesoil surfacing activity is reducing or preventing this erosion.

The inherent erodibility of soil is a complex property dependent upon its surface condition, structural stability, texture, organic matter content, moisture content, and infiltration capacity. Runoff and erosion vary from mine site to mine site depending upon these characteristics.

Minesoil

Surface mining disturbs the original soil profile creating spoil that is often called "minesoil". These materials are characterized by a wide spectrum of physical and chemical properties. In southern Appalachia, for example, the parent rock materials are generally sandstone, shale, and slate. Nonhomogeneity of spoil is the rule and must be contended with in any mulching operation. Moisture and temperature variances occur as a result of the heterogeneous nature of the spoil aggregate created during surface mining. On sandstone minesoil surfaces, crusting and moisture stress have resulted in poor germination and seedling development. Mulch applied at seeding has greatly increased germination and survival of herbaceous plants.

Minesoil is among the most hostile of environments for the establishment and growth of plants. It is usually low in nutrients, both the primary ones, such as nitrogen and phosphorus, and the minor ones. It may exhibit extreme droughtiness due to a lack of fine material and a predominance of rock fragments. Physical characteristics may be very poor because the soil is stony, has too much clay, is impermeable, or drains rapidly. The amounts of the different geologic materials and the manner in which they are handled and mixed during mining and grading directly affect the physical, chemical, biological, and mineralogical properties of minesoils. These properties and their relationships to each other determine, to a large extent, the success of plant growth and the benefits of mulches.

Physical Properties

Soil physical properties are important in determining the productivity of a soil. They influence the amount, distribution, and movement of water and air in the soil, temperature relationships, as well as soil chemical and microbiological properties.

Physical problems include extremes in texture, lack of favorable structure, lack of organic matter, and low inherent fertility and high erodibility potential. Treatment of physical problems can include mulching. Countering the adverse effects of poor texture, depth and structure, color, surface, roughness, and stability by mixing spoils and adding organic matter will improve soil aggregation. This influences the degree of compaction and crusting, plasticity, ease of root penetration, moisture infiltration, permeability, drainage, moisture holding capacity, temperature, evaporation, aeration, retention of plant nutrients, efficiency of tillage,and anchorage of plants.

The best solution to physical problems is to prevent them. A premining analysis of the overburden could be beneficial in determining how to separate or mix different rock materials during mining and grading so that the materials left on and near the surface will have acceptable physical properties. On some areas, replacing topsoil may improve the physical qualities of the reclaimed surface for plant growth. But in other situations, improper placement of topsoil may result in adverse qualities such as high bulk density.

Structure.--Soil structure is the aggregation of the primary soil particles into compound parts or clusters. Aggregation affects the extent of runoff and the movement and intake of water and air into and through the soil-surface zone. A highly granular soil ensures a more stable system of pores for absorbing moisture and air. A structureless soil becomes puddled and crusted, therefore compacted, and increases the danger of runoff and erosion. In mining, after backfilling and regrading, unless sufficient topsoil has been stockpiled and respread, the heterogeneous spoils possess little desirable physical structure.

Typically, fresh minesoils in Appalachia have low concentrations of organic matter and high percentages of coarse fragments with weakly developed structure. The surface horizon contains the greatest amount of fine material. Fine clay particles often create an almost air-tight crust and dry out rapidly after a rain and sometimes become very droughty during summer months.

Many organic compounds in mulches are capable of aiding in the formation of aggregates. As the mulch decomposes or is washed into the soil, the structure of the soil is gradually improved. The decomposing mulch materially increases granulation. This effect may be due to both the presence of rotting organic matter and to substances produced by soil organisms. During decomposition of the organic material, soil microorganisms produce or secrete gums, waxes, and other insoluble substances that coat and bond together the individual soil particles. Concentrations of these binders should be maintained. Higher concentrations of nonerodible soil aggregates and bonding substances are present in soil where organic mulches are present than in soil with no mulch. Humus has a high cation exchange capacity and as a result, a high ability to bond ions at exchange sites.

Organic mulch improves and stabilizes soil structure and tilth without cultivation. The mulch layer helps to prevent the surface soil from "running together" and crusting over. A friable crust is found under mulch, whereas a hard crust is dominant where no mulch exists. As the decaying organic matter works downward the soil becomes more friable and is better penetrated by water, and its aeration is improved, thus stimulating root and biological activity.

Texture.--Soil texture refers to the relative properties, of a particular soil, by weight of various sizes of sand, silt, and clay particles. These three factors combined form roughly 45 percent of an "ideal" soil. Sand particles are the largest, silts are intermediate, and clays are the finest.

The relative proportion and distribution of the various size particles and rock fragments affect water relations, soil structure, bulk density, erodibility, cation exchange capacity, and workability of the minesoil. Sand, when dominant, forms a coarse texture or "light" soil that allows water to infiltrate more rapidly but the soil dries out quickly. Silts and clays make up fine textured or "heavy" soils and can be plastic when wet and very hard when dry.

In minesoils with no adverse chemical characteristics, plant growth usually is most favored where about equal proportions of fine and coarse materials are present. Generally, minesoils that are high in silt, low in clay, and low in organic matter are the most erodible. The absence of a mulch or too low a mulch rate can have a negative effect on particle-size distribution. With little or no mulch or organic matter, contents of fine particles will decrease in the surface 0- to 1-1/4-inch layer due to raindrop impact and runoff.

Maintenance of a soil in a granular friable state is helped by the addition of an organic mulch, which can counteract the adverse effect of poor texture by improving drainage of heavy clay soils and water-holding capacity of sandy soils by enriching them with natural humus.

Bulk Density.--Bulk density is the weight of a unit volume of dry soil, ordinarily expressed as grams per cubic centimeter. Soils that are loose and porous have low bulk density; those that are densely structured or compacted, or high in clay content have high bulk density. The size and volume of pores are important to plant growth because they influence the movement of water and air in the soil. The bulk density of minesoils is related mostly to the types and amounts of the geologic and soil constituents and the proportions of different particle sizes. Excessive movement and compaction by grading and soil-moving equipment can also affect bulk density. Bulk densities of minesoils are usually greater than those of undisturbed soils because of their compacted state, lack of structure, immature pedogenetic nature, and high coarse-fragment content.

Surface mulches effectively decrease bulk density. The nature and extent of the physical effects vary somewhat with the amount and size of mulch particles. Coarse particles tend to decrease the water-holding capacity if incorporated into the soil. Very fine particles tend to puddle and exclude water and air from the soil. Bulk density decreases with increased mulch rate due to more organic matter and higher biological activity on properly mulched areas than on areas with little or no mulch.

Color.--The color of a soil is important in terms of the heat budget at the soil surface. Soils high in organic content and dark in color will absorb more energy than those light in color. Whether the higher heat absorption will result in a warmer soil depends on the amount of moisture. A dark-colored soil that is somewhat poorly drained may not warm up in the spring as quickly as a well-drained, light-colored soil.

Color can be a clue to chemical characteristics. For example, sandstone with a brown interior color is weathered and will not be toxic to plants. Sandstone with a gray interior is unweathered and may be toxic to plants because it may contain unoxidized pyrite. Black shales often are acid and toxic-forming and should be buried under nontoxic material. Occasionally, dark-colored materials are not acid and chemically are the best overburden material available for plant growth. In such instances the material should be left on the surface and mulched, or if possible, lightly covered or blended with topsoil or light-colored spoil material.

Soil Replacement.--Replacement of native soils on surface-mined areas may benefit or harm the establishment of vegetation. Few of the benefits and disadvantages are universal to all surface mines because native soils, as with minesoils, vary greatly from one region to another and among areas within regions. In some areas, such as northern Illinois, the native prairie soils are thick and relatively fertile. Where surface mined, many of these areas are regulated as prime farmlands under special provisions of the Federal Surface Mining Control and Reclamation Act of 1977. In other areas, such as in much of the Appalachian Region, native soils are thin, highly leached, and relatively infertile. Replacement of these soils may not always enhance the establishment and productivity of vegetation on mined areas.

The primary goal of replacing soil is the improvement of the quality of plant-growth medium on areas where the spoils or minesoils are chemically and physically less desirable than the native soils. Usually, soil replacement will create a fairly uniform surface condition over the entire area with few or no rocks to interfere with tillage, planting, and seeding. Perhaps the most universal benefit of soil replacement, especially of the surface or A horizon, is the potential source of soil fauna, microorganisms such as endomycorrhizal fungi, and seed, rhizomes, or other plant parts that will help reestablish the native vegetation. Immediate replacement of the soil is most beneficial because populations of many of the biological organisms are reduced by long-term storage or stockpiling of soil.

Detrimental effects of soil replacement can occur on areas where covering soils have chemical and physical properties that are less desirable than those of the spoils that will be covered. Often, the replaced soil will be compacted and physically degraded by repeated travel of the earth-moving equipment. Replacement soils often erode more easily than spoil materials. The interface between the replaced soil and the covered spoils sometimes creates a barrier to root penetration. Some replacement soils may contain seed of unwanted plant species that could produce competition with the desired planted species.

Chemical Properties

Chemical composition of the minesoil is strongly related to the geologic origin of the parent material. A soil developed in limestone will be characterized by high levels of calcium and perhaps magnesium. In Appalachia, the parent rock materials are predominantly sandstone, which contains various amounts of sulphur bearing pyritic shales that may cause high acidity in soils. The geologic materials that are exposed are often extremely infertile and may be highly toxic with accompanying high concentrations of salts, acids, and metals such as iron, aluminum, and manganese in mine-water drainage.

Plant growth is closely correlated with the chemical composition of the minesoil. The condition and inherently low nutritional levels of the minesoil may inhibit or completely prohibit plant life. A chemical laboratory analysis of the spoil will establish pH and toxic elements that have to be neutralized, and the nutrients needed for plant growth. After the composition of the spoil material has been determined, then amendments are selected to modify the spoil medium so that plants may prosper.

The chemical properties of minesoils most relevant to mulches and revegetation are chemical reaction (pH), acid and mulch induced toxicities, and nutrient availability.

Reaction.--Soil reaction is the degree or intensity of soil acidity or soil alkalinity expressed as pH. The pH scale ranges from 0 to 14. A pH of 7 is neutral: figures below this are increasingly acid and values above it are increasingly alkaline. The pH scale is logarithmic, that is, the intensity of acidity or alkalinity changes tenfold with each unit pH. For example, a pH of 4.0 is 10 times more acidic than a pH of 5.0, and a pH of 3.0 is 100 times more acidic than a pH of 5.0. The chemical elements in the soil eventually may be dissolved in or mixed with water to create soil conditions that are acid, neutral, or alkaline in reaction.

Soil reaction (pH) may be considered a symptom of the particular chemical condition that caused it, and hence, it may be used to indicate the possible effect of these conditions on plant growth. It is probably the most useful criteria for predicting the capacity of minesoil to support vegetation. A knowledge of the conditions that cause different soil reaction, therefore, is valuable in reclaiming and revegetating minesoils. Not only is plant growth affected by pH, but also inferences can be made about other qualities. For example, the availability of some plant nutrients is limited in both extremely acid and strongly alkaline soils, but these nutrients are available to plants in soils that are moderately acid to slightly alkaline.

There is a natural tendency for soils to become increasingly acid in humid climates because rainfall tends to leach away bases liberated by ionic exchange and mineral decomposition. In the humid section of the Eastern United States, minesoils are usually in the acid range (pH below 7.0), though some are mildly to moderately alkaline (pH 7.0 to 8.5). Most agricultural soils have a pH range of 5.0 to 8.5. Problems with revegetating the alkaline minesoils are few. Problems with revegetating acid minesoils are more common, especially those that are extremely acid (pH 4.0 and lower). Oxidation of iron sulfides found in the coal and overburden strata is the primary cause of extremely acid and toxic minesoils.

A pH reading also can indicate where an amendment is needed for neutralizing acidity. A recommended practice for treating acid minesoil is to raise the pH to 5.5 or higher by applying lime. At pH 5.5, most of the toxic elements will be precipitated from the soil solution and will no longer have harmful effects on plants. The application of certain fertilizers tends to increase soil acidity through the development of mineral acids.

Soil reaction generally follows the normal seasonal fluctuation with increased acidity in the summer months. This phenomenon may obscure soil reaction changes brought about by decomposition of mulch. Concentrations of various cations can be directly or indirectly affected by organic mulches. Soils mulched with large quantities of organic matter may release iron and manganese in concentrations that increase with ease of biodegradability, suggesting a biologically induced reaction. Mulch materials are usually basic and thus favorably increase pH in the soil surface.

The accepted method of salinity control is to provide sufficient and effective leaching and drainage. Salt concentrations in plant rooting zones can be decreased by surface applied mulches. Mulches help to reduce the amount of capillary movement of the soil solution to the surface (evaporation) and thereby prevent the concentration of soluble salts at the spoil surface. In addition, mulch usually results in improved infiltration and percolation, thus, enhancing the leaching of salts.

The pH values that sometimes result from the addition of organic material may be a factor to be considered. If plants are known to be sensitive to soil reaction, the effect of organic material on the pH value of the soil should be ascertained before they are used. When acid material is applied to a plant that requires lime, it may be harmful if the soil is already near the lower limit of acidity tolerated by the plant.

Nutrients.--Chemical properties affect the amount and availability of plant nutrients in the soil. The sixteen elements needed for the growth of higher plants are commonly referred to as plant nutrients or essential elements.

Nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur are required in large quantities and are referred to as the macro or major elements. Nutrients required in considerably smaller quantities are called the micro or trace elements and include manganese, iron, boron, zinc, copper, molybdenum, and chlorine.

The carbon, hydrogen, and oxygen combined in the photosynthetic process are obtained from air and water; the remaining 13 elements are obtained from the soil. Most of these nutrients exist in organic matter and in mineral form and as such are unavailable to plants. Nutrients become available through organic matter decomposition and mineral weathering. The nutrients are absorbed from the soil solution or from colloid surfaces as cations (+) and anions (-).

Through its decomposition, organic matter is a potential source of nitrogen, phosphorus, and sulfur. Usually, in the absence of fertilizers and mulches, the soil organic matter would supply the nitrogen and only a part of the phosphorus and sulfur that plants need. The balance of the nutrients is supplied through decomposition of inorganic or mineral particles of the soil. Mineral decomposition is extremely slow in comparison to the rate of decomposition of organic matter. A marked increase in soluble nitrogen, phosphorus, calcium, potassium, magnesium, and boron has been found under an organic mulch. Very few soils contain all of the necessary ingredients to support desirable vigorous plant growth, therefore, an initial and continuous supply of nutrients and organic materials must be provided.

Nutrient Deficiencies.--The minesoils of Appalachia are usually deficient in nitrogen, phosphorus, calcium, magnesium, and to a lesser extent, potassium.

In most instances nitrogen is deficient, especially where original topsoil and associated organic materials are of little or no consequence or were destroyed during clearing operations. Applications of supplementary nitrogen are necessary if successful herbaceous vegetation is to be established. With few exceptions, minesoils also need applications of phosphorus. However, potash is not usually needed. For most minesoils, it is recommended that 50 to 100 pounds of nitrogen and 50 to 100 pounds of phosphorus per acre or 150 to 300 pounds of ammonium nitrate (33 percent N) and 100 to 200 pounds of triple super phosphate (45 percent P) be added.

Plant-available potassium is adequate for plant establishment in most coal minesoils because clay, minerals, micas, and some feldspars that constitute a source of potassium usually are present in the overburden materials. Thus, use of potassium fertilizer usually is not needed for establishing vegetation. However, occasionally some spoils need potassium as part of the fertility program.

Deficiencies of other nutrients undoubtedly occur on some minesoils, but most of these have not yet been defined. It is known that on some minesoils, imbalances between calcium and magnesium occur that can hinder the establishment and vigorous growth of vegetation.

Chemical analyses of the spoil material or plant deficiency symptoms can indicate when elemental deficiencies exist. A nitrogen deficiency is shown by symptoms generalized over the whole plant; plant light green in color, lower leaves yellow. Likewise, a phosphorus deficiency is shown by dark green plant developing red and purple colors; lower leaves sometimes yellow, drying to greenish brown or black. A potassium deficiency is shown by localized symptoms; mottling or chlorosis on lower leaves; small spots of dead tissue usually at tip of leaf and between veins.

Generally, plant nutrient deficiencies become a major problem on most spoils, but instances occur in which certain nutrients from weathering rock are abundant.

Carbon-Nitrogen.--Applications of fresh organic materials that are high in cellulose often result in nitrogen deficiency due to microbial immobilization of soil nitrogen during decomposition. Nitrogen is tied up by cellulose decomposing organisms, especially during the early stages of the decomposition process. When the microorganisms cannot obtain enough nitrogen from the mulch itself, they turn to the soil for their nitrogen supply. If too much of the available nitrogen is immobilized by the microorganisms, plants will show typical signs of nitrogen deficiency. It has been found that nitrogen immobilization usually peaks at about 40 days, and can usually be overcome by applications of additional nitrogen along with other nutrients (chemical fertilizer) necessary to assure microbial activity and plant growth.

From the nutritional standpoint, the major shortcomings of various organic mulches are their high carbon to nitrogen (C to N) ratios and subsequent fixation of the inorganic nutrients. Carbon to nitrogen ratio is the relative proportion, by weight, of organic carbon to nitrogen. Most plant materials contain between 40 and 45 percent carbon, so the C to N ratio can be estimated if the nitrogen content of each material is known. The C to N ratios of plant materials vary widely. For example, wood wastes commonly have a ratio of 400 to 1, cereal straw 80 to 1, animal manures less than 30 to 1, and young clover 10 to 1.

Plant materials with small C to N ratios (25:1) are relatively rich in nitrogen, whereas those with higher values (200:1) are relatively low in nitrogen. Organic residues with ratio less than 15 to 1 or 20 to 1 usually contain enough nitrogen to satisfy the requirements of the decomposing organisms. The ideal ratios for C to N is from 20 to 1 to 25 to 1. Organic residues do not begin to release nitrogen until their C to N ratio has been narrowed to 15 to 1 or their total nitrogen content is 1.7 percent. Carbon to nitrogen ratios greater than 25 to 1 can cause nitrogen deficiency because the microorganisms that attack the organic mulch are more efficient than plants in using what organic nitrogen there is in the soil.

Because of their high C to N ratio, most organic mulches need additional fertilizer to compensate for the microbial tie-up of nitrogen during the decomposition process. The quantity of nitrogen required is a function of mulch particle size and the soil surface area that is in direct contact with the mulch material. The microbial immobilization rates of a variety of organic materials range from 0.2 to 1.7 percent of material weight. A minimum amount of nitrogen is needed to sustain microorganisms that are active along the mulch and soil interface. Sufficient nitrogen should be added to the material to bring the nitrogen concentration of the mass up to 1.2 to 1.5 percent. This corresponds to about 115 pounds of ammonium sulphate or 72 pounds of ammonium nitrate per ton of dry mulch. Nitrogen reserves will not be overtaxed if the preceding fertilization practices are followed.

Composting organic materials decreases the C to N ratio and increases the base exchange capacity of the material, while also increasing the content of essential nitrogen, phosphorus, potassium, calcium, and manganese. The chemically treated material can be inoculated with _Corprinus ephenerus_, an organism that is efficient in decomposition of cellulose. Chemical treatment includes addition of anhydrous ammonia, neutralization with phosphoric acid, and enrichment with other essential nutrients.

Toxic Substances.--Substances toxic to plants and to certain microorganisms accumulate in some soils as a result of the incomplete decomposition of organic matter. Methane, hydrogen sulfide, phosphine, skatole, indole, and numerous organic acids are toxic compounds produced, but they are generally considered merely products of improper soil management. If good drainage and tillage are provided with the proper use of fertilizer and lime, these toxins should not be a problem.

The phytotoxic compounds isolated from fresh and decomposing organic mulches include organic acids, lactones, tanins, phenols, alkaloids, and turpenoid compounds. Presumably, for a compound to affect vegetative growth, it must be adequately water soluble or have a vapor pressure high enough to diffuse the plant. Phytotoxins may be present in certain crop residues or may be produced by microbiological degradation of the residues.

Occasionally, some wood or bark contains small amounts of toxic compounds that may be harmful to germination of some seeds and early growth of certain plants. Growth inhibiting compounds found in wood are phenols and phenolic compounds, turpenes, steroids, alkaloids, cyanids, organic acids, and bark extract. Certain phenolic compounds may retard or inhibit enzyme activity. Bark tannin in particular concentrations may kill certain plant pathogenic fungi.

Certain wood constituents especially turpentine, resins, oils, and tannins, when present in large amounts, may exert a toxic action on plants either directly or through their decomposition products. In some instances, the temporary growth-depressing effect of C to N ratio may be amplified by tannin and other organic-solubles present in certain types of wood.

Concern that wood residues contain toxic components harmful to vegetation may be over emphasized. Most woods and barks are not appreciably toxic to plants and can be used safely as mulches if adequate nutrients are supplied and the soil is not too acid.

Soil Organisms

Although soil organisms comprise only a small fraction of the soil mass, they play a vital role in the development and maintenance of vegetation and in the establishment of natural ecosystems. A teaspoon of soil may contain billions of living organisms that depend on plant and animal residues (organic materials) and soil oxygen to carry on their life processes during which important chemical elements are released and are made available for plant growth. The vast number of soil organisms are grouped into flora (plants) and fauna (animals).

Soil Flora.--The more important groups of plant organisms found in minesoils are bacteria, fungi, actinomycetes, and algae. All of the groups aid in the decomposition of organic matter and plant residues and the nitrification or accumulation of nitrates in the soil as a result of the decomposition process. Bacteria are the most numerous and are important in organic matter breakdown, nitrogen and sulphur transformation, and nitrogen fixation.

The biological processes involving decomposition, nitrogen fixation, and nitrification are favored by pH values in the neutral range. The activity of bacteria and actinomycetes is significantly reduced at a pH of 5, while fungi dominate under these conditions due to their tolerance to acidity. The kinds and numbers of organisms in recently mined and unvegetated minesoils are very few or completely lacking as compared to agricultural and forest soils. However, when an area is mulched and as the vegetation becomes established the populations of some of these organisms will increase by natural processes. Other types may need to be artificially introduced. Some plant organisms are symbiotic, which means that they give to and derive benefit from the plants on which they live. For example, Rhizobium bacteria live on the roots of legumes and take nitrogen from the air and fix it in nodules for use by the host plant. Similarly, most species of plants have mycorrhizal associations that involve root-inhabiting fungi that tend to increase the plant's ability to take up nutrients, especially phosphorus. Mycorrhizal associations are beneficial to survival and growth of most plants.

Mulching benefits the "life" of the soil. Generally, higher moisture conditions and lower temperatures under a mulch favor soil organisms. Woody mulches promote higher populations of organisms, especially molds. Wood mulches are strongly acid (4.5) which in part accounts for the high mold count.

Soil Fauna.--The animal organisms are the worms, beetles, bugs, and similar creatures that are primarily responsible for consuming and altering organic materials and burying or mixing them in the soil. Many new minesoils normally are devoid of soil fauna. Natural establishment of soil fauna populations is relatively slow because most soil fauna are not highly mobile. Thus, several years may be required for a mined area to be repopulated by the natural movement of organisms from adjacent undisturbed lands. Artificial introduction of animal organisms is possible and has proven beneficial in small experimental plots, but its practicality has not been demonstrated on large areas. Immediate replacement of topsoil is probably the most promising means of establishing soil fauna on mined sites.

Pathogen.--There has been some concern about using trimmings of trees that are diseased or infected with insects. If the trimmings are composted for 2 to 3 months, any problem is usually eliminated.

Organic Matter

Organic matter is plant and animal residue in various stages of decomposition. The organic matter is important in the surface environment of the soil because it affects soil physical, chemical, and biological properties. The organic matter in soil is one of the most important and, also, one of the most easily exhausted resources.

The relative amount of organic matter in soils is generally recognized through color. Dark soils are usually considered superior in organic matter content to lighter soils. The base exchange capacity and erodibility of soil are largely dependent upon organic-matter. As the amount of organic matter increases, the ability of the soil to absorb water increases and runoff is reduced, thus, minimizing erosion. The ideal amount of organic matter in soil is about 5 percent. Most minesoils are inadequately supplied averaging less than 1 percent.

Amending minesoils with organic matter may not be practical; however, normal applications of organic mulches contribute to the establishment of an initial supply of organic matter to the soil. The gains in organic matter in the surface inch are directly related to the use of mulch and the nature and abundance of vegetation. The bulk of the organic matter added to the minesoil comes through topsoil replacement and use of a mulch. Organic matter is important to the rooting zone because it supplies nitrogen (soil organic matter is about 5 percent N), helps develop a more stable soil structure, and holds water and nutrients.

The composition of organic residues is important to the nature and rapidity of the liberation of the nutrient elements in forms available for plant growth, and to the formation and nature of the residual organic matter. Lignin, which occurs in older stems and other woody tissue, occupies an important place in the formation of humus making up 40 to 45 percent of the total. Because lignin content of wood by-products is higher than that of crop residues (4 to 12 percent), it generally results in greater increase in stable soil organic-matter content and is very resistant to decomposition.

Major components of wood as percentages of total dry weight are:

Component	Softwood	Hardwood
	Percent	
Cellulose	10 - 42	42 - 51
Lignin	27 - 33	19 - 24
Hemicellulose	23 - 31	23 - 38

Oat straw decomposes fairly rapidly. More than 50 percent of the hemicellulose and 10 percent of the cellulose will be decomposed within 10 days after application.

Because the decomposition of organic matter is a biochemical process, any factor that affects the activities of the soil organisms will affect the rate of organic-matter decay. The C to N ratio of the waste material often dictates the rate and extent of decomposition.

In general, the younger the plant from which organic material was obtained the more rapid will be its rate of decomposition. This occurs because of the higher content of water-soluble constituents, a higher nitrogen content, a more narrow C to N ratio, and a smaller percentage of lignin. Of the various plant residues, those having the higher nitrogen content usually decompose most rapidly. Maintenance of organic matter is a problem in soils of a sandy nature in warm humid regions.

Organic matter is particularly important in clay, sandy, saline, and alkaline soils. The bacterial decomposition of organic matter in such soils increases the ability of the soil to buffer rapid changes in alkalinity and acidity and to neutralize some potentially toxic substances.

Moisture Relationships

Moisture is a major factor in reclamation and vegetative establishment. Soils that are able to hold large quantities of water are desirable.

The water-holding capacity of a minesoil depends on its texture, permeability, depth, and organic-matter content. Moisture is lost by runoff, plant transpiration, soil-surface evaporation, and percolation through the soil.

Infiltration is the process whereby water enters the soil surface. Under most conditions, the movement of water through a soil is a relatively slow process. As a result, many storms supply water at a faster rate than most soils can absorb it. When the rainfall rate exceeds the infiltration rate, water runs over the surface and erosion may occur.

A mulch cover can be used to protect the surface from forceful contact of raindrops and to slow the movement of surface water allowing additional time for infiltration. A desirable soil profile acts as a sponge that retains water near the surface. When mulch is added, the soil surface becomes porous and remains loose and friable. The soil surface is protected from sealing and "running together" or crusting over due to raindrop impact, and, as a result, higher infiltration rates are maintained.

The effectiveness of mulch in maintaining high infiltration is correlated with the type and percent of surface cover. Coarse textural materials will decrease surface runoff. Large particles usually absorb less moisture than fine materials. However, coarse materials with a high percentage of fines can have a wicking action that draws moisture out of the soil and later loses it through evaporation. Some fine-textured materials have been known to crust over and shed water and may be of little value in soil-plant-moisture relations.

Mulched surfaces generally have a high rate of water intake compared to bare surfaces for all periods of rainfall. The nature of the rainfall pattern and time lapse between rains has considerable bearing on the effectiveness of mulch in conserving water.

Mulches have been shown to conserve substantial moisture to a depth of about 12 inches. Any thickness of organic mulch will increase soil moisture. However, optimal application depth for moisture modification has not yet been determined.

Evapotranspiration causes most of the water removal from soils under normal field conditions. It can account for the loss of 30 to 40 inches of water during the growing season for a stand such as alfalfa.

After water enters the soil, some of it is normally drawn back to the surface through capillarity and is lost by evaporation. Evaporation from soil surfaces can be modified and influenced by using organic mulches. In situations where the soil surface is exposed to the sun, a 2-inch layer of mulch can cut water loss due to evaporation by as much as 50 percent.

Mulch acts as a one-way valve, allowing water to enter the soil but reducing evaporation later. When the air becomes dry and has the capacity to absorb water from a wet surface, then mulches generally dry quickly. When dry, they no longer act as capillary conduction and further drying of the soil profile is slowed.

Relative humidity and temperature play a major role in determining how quickly water is lost and consequently in determining the amount of water that plants need. In certain areas, it is believed that warm moist air invades the interior of the porous mulch and moisture condenses when the air comes in contact with cooler soil surface.

A mulch should not have a high absorptive capacity itself because during periods of light rain or long intervals between rain very little water may actually reach the soil. Certain kinds of mulches (peat, sawdust) intercept and absorb a large share of the rainfall, resulting in less water available for plant growth.

Climatic Variables

An understanding of how climate influences the interaction of physical, chemical, and biological processes is essential to the successful reclamation of mined lands. Climatic conditions in a given area are governed by such factors as latitude, elevation, prevailing winds, moisture source, and terrain. Local climatic information may be obtained from the Soil Conservation Service or the U.S. Department of Commerce.

Knowledge of the effects various mulch materials have on climatic conditions is helpful in determining how and when each type of mulch can be used to best advantage in land reclamation. Mulch materials should be selected for their adaptability in meeting the macroclimatic and microclimatic conditions found at the site.

Seasonal Characteristics

Elevation affects length of growing season. Generally, as elevation increases length of growing season decreases. In high-elevation areas, mulches can reduce the problem of frost heaving and its adverse effect on young seedlings.

Mulch color can help raise spring temperature and speed up the germination rate, or can help lower summer temperatures, thus aiding areas where the soil surface is affected by solar radiation (see Mulch Application).

Precipitation

Precipitation and its associated potential runoff are important elements that affect the ability of a mulch to remain in place and to control erosion. Mulch must be adapted to expected rates and kinds, seasonal distribution, frequency, duration, volume, and intensity of precipitation.

Regions with a large annual rainfall are subject to severe erosion. The coal regions of the humid East have an annual precipitation of about 33 inches or more (Fig. 7).

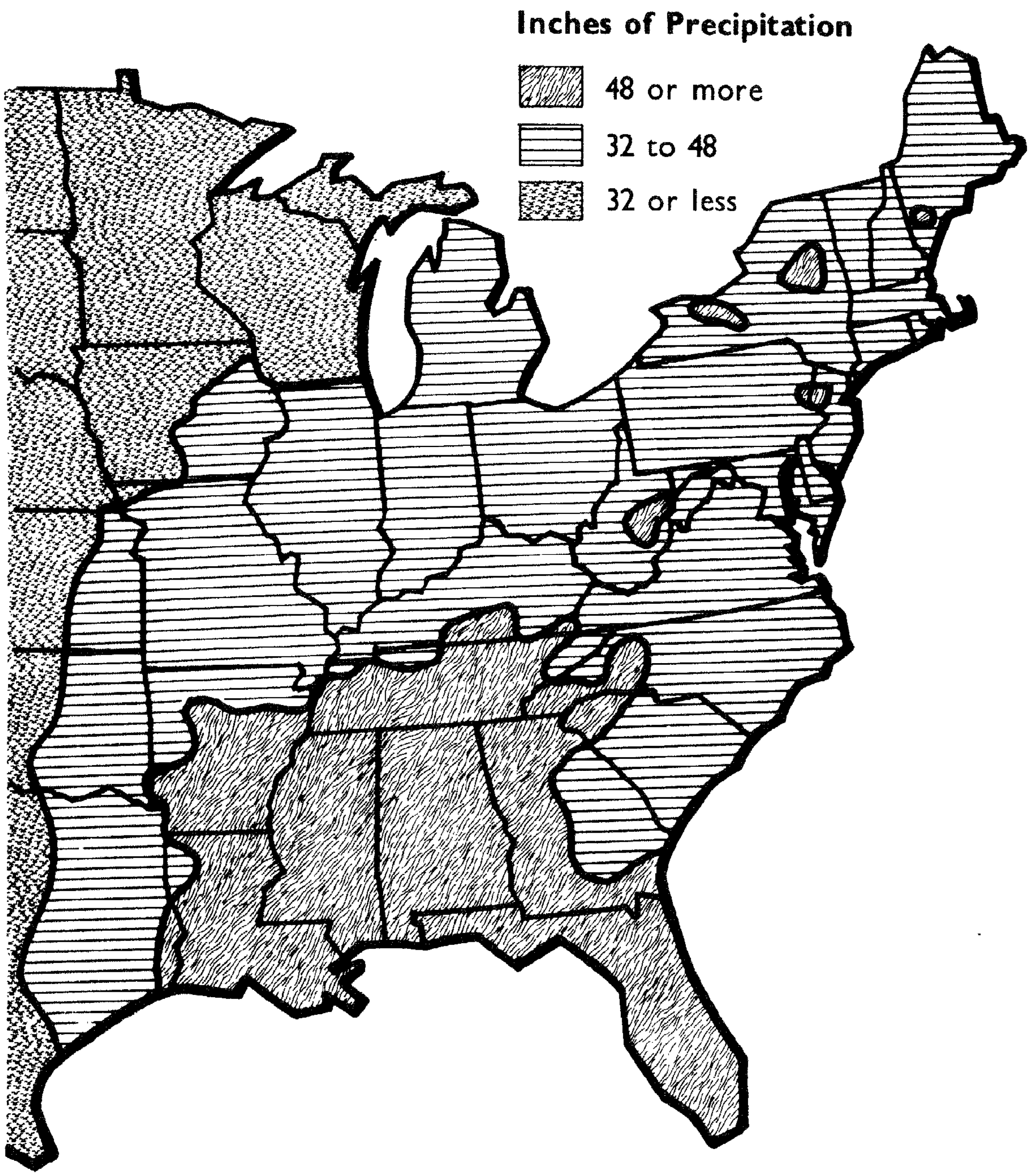


Figure 7.--Precipitation zones of the Eastern United States.

Rainfall energy is a better prediction of erosion than rainfall amount. The erosiveness of flowing water depends on its velocity, turbulence, the amount and type of abrasive material it transports, and concentration of runoff in rills and channels.

Mulching is particularly valuable in protecting areas from high-intensity short-duration storms by dissipating kinetic energy of raindrops, lessening splash erosion and surface sealing, lessening rill and channel erosion, and allowing more infiltration. Mulch can cut water losses by two-thirds and soil losses by as much as 80 percent.

Temperature

The temperature regime and the microclimate at and near the soil surface have a significant effect on the reclamation process. Plant growth and microbial action are influenced by soil temperature. As temperatures decrease, the life processes of both plants and animals are slowed down. There is relatively little biological activity below 32°F or above 122 to 140°F for active shoot tissues. Leaf functions are impaired at temperatures over 107°F. Growth processes of most plants are sluggish at temperatures below 40°F. The most favorable limits are 70 to 90°F with 86°F the optimum temperature for absorption by roots. When soil temperature is high, roots stop growing and plants suffer even if moisture is plentiful. Temperatures in the root zone (3 to 12 inches) of drastically disturbed soils frequently exceed the lethal plant-tissue temperature of 120°F. The chemical processes and activities of soil organisms, which convert organic matter into available nutrients, are also materially influenced by temperature.

At any particular latitude the slope of the surface and its aspect will determine the amount of solar radiation reaching the soil surface. The angle at which radiation hits the surface influences the intensity of radiation. In the northern hemisphere soils located on southern slopes warm up more rapidly than those located on the level or on northern slopes. Maximum radiation intensity occurs on flatter slopes in summer when the sun is high and on steeper slopes facing the sun in winter when the sun is low.

Soil temperature is controlled or modified by regulating the incoming or outgoing energy or altering the thermal properties of the ground. One way of doing this is to place an insulating layer, such as an organic mulch, on the ground surface. The thermal properties of the ground can be modified by regulating evaporation, soil moisture content, and by mulch on the ground surface.

Organic mulches have a complex influence on soil temperature which varies with the mulch color, season of the year, and prevailing weather conditions. Mulch is used to mitigate the effect of solar radiation and drying winds and to provide proper soil temperature by decreasing evaporation and moderating extremes of diurnal and seasonal fluctuation. The color and type of material affect temperatures by absorbing or reflecting energy and by insulating the soil.

The daily air temperature in temperate regions reaches a maximum at about 2 p.m. The surface soil, however, does not reach its maximum until later in the afternoon. This lag is greater and the temperature change is less as depth increases. Clear weather accounts for rapid changes in surface soil temperature, and rapid movement of air above the soil accounts for a great loss of energy.

Usually, temperature changes lag in soils under a mulch because of the insulating effect. On a 24-hour basis, a mulch will result in greater soil-surface temperature variation but less variation within the minesoil body proper. Compared to bare soil, mulched areas have lower and more uniform soil-surface temperatures. In the summer, the average soil temperature of a mulched area will usually be cooler by day and warmer at night than bare soil. However, when temperature of bare soil approaches or falls below 32°F, the temperature effect is reversed.

In general, mulches applied at depths of 1/2 to 1 inch will decrease the range of surface temperatures. However, as the applications are increased to 2 to 4 inches the decrease becomes less significant.

Soil temperature of 108°F at a 2 inch depth and 100°F at a 4 inch depth are root-killing temperatures. In general, 3 inches of mulch will reduce the temperature by 8 to 10°F. This means that when the soil surface on bare ground is 108°F the temperature of soil under 3 inches of mulch would be 98°F at 2 inches deep and 90°F at 4 inches. Temperature drops an average of about 4°F per inch of soil depth.

Mulch Characteristics

In selecting an effective mulch for a specific reclamation job, consider: availability; physical, chemical, and biological properties of both mulch and minesoil; application procedures; overall application and maintenance costs; effects on vegetative response; and personal bias. To select the best material the basic characteristics of all available materials must be evaluated.

Availability

Once the type of mulch material has been selected, determine where it can be obtained, how it will be transported and applied, and how or where it can be temporarily stored until applied. These decisions should be made as early as possible because some materials may be difficult to obtain and others may be available only in a particular season.

Sources of materials should generally be available in all eastern states. Supplies should be locally available on or near the reclamation site in sufficient quantities, and preferably obtainable all year. Products should be nonhazardous; economical; and easy to handle, transport, and store.

Some residue materials such as bark often can be obtained at little or no cost, but handling, transportation, or application may require costly or specialized equipment. Sometimes an alternative mulching material is available but is not used because of lack of knowledge and uncertainty of its value. For example, some people believe that wood chips are acid-producing and toxic to vegetation.

Physical Properties

The physical properties most relevant to the selection of organic materials are: form, size, weight, color, and durability. Form, particle size, and weight determine whether the material will blow or wash away. In general, mulches with the longest fiber are the best for adhering to a slope. Large, coarse-textured, solid particles increase the size of pore spaces, while small, fine-textured particles tend to pack and bind which restricts air and water movement into and through the soil. A mixture with a range of particle sizes is desirable. The color and type of material can affect temperatures by absorbing or reflecting radiant energy. A durable material has tenacity and stringiness (like fiber), and should stay in place by becoming attached to the soil. Consider the potential for fire hazard when choosing materials.

Chemical Properties

Chemical properties to consider are: reaction, C to N ratio, toxicity, nutrient content, and durability. Reaction of minesoils should not be adversely affected by the mulch. Materials should be nontoxic to plants and microorganisms. Depletion of available plant nutrients during decomposition should be minimal.

Biological Properties

Where possible, the material should inoculate microorganisms into the minesoils. The decomposition rate should be slow enough to allow vegetation to become suitably established. Decomposition is usually more rapid in fine-textured materials such as sawdust or hydromulch, than in high-cellulose materials, such as straw and wood chips. Leguminous fiber mulches decompose at a faster rate than cereal fibers.

Measurement

The units of measure used for mulch applications are expressed as weight or volume per acre depending upon the type of mulch selected. Application rates relating to weight must be based on air-dry weight to assure uniformity.

Application rates of crop residues and solid animal wastes are generally given in tons per acre. For example, for unweathered straw and hay, the average is 1-1/2 to 2 tons per acre and for manure, 10 tons per acre.

Logging and wood manufacturing wastes are applied by the cubic yard because of the extreme variability in moisture content, which affects a weight basis. Municipal, industrial, and animal waste-water slurries or liquids and hydromulch are applied by the gallon.

Maintenance

Of paramount importance, is that the material selected has a low-maintenance character because periodic post-mining treatments after application can be costly. The ideal low-maintenance material would be resistant to washing, blowing, decomposition, and require no refertilization.

Vegetation Establishment

Basically, the growth of plants depends on the minesoil for the prime source of water, oxygen, and nutrients. Beyond this, the minesoil must provide mechanical support for the plant and an environment in which roots can function. Oxygen must be available for root respiration, and the carbon dioxide produced must diffuse out of the soil. Inhibiting factors such as acid and toxic forming materials, high concentrations of soluble salts, and high C to N ratios should not be present.

The growth of plants is the manifestation of many chemical and physical processes. Water plays a major role as a medium for these processes. Plant growth depends on temperature and proceeds properly if there is adequate heat in the environment. The amount of heat and water needed for optimum plant development covers a fairly wide range, but excesses or shortages of either can have a limiting effect on growth.

Harsh microclimates are often detrimental to the establishment of vegetative cover on surface-mined lands. Extreme diurnal surface temperatures and low moisture contents are the factors most detrimental to seed and seedlings. These problems make it difficult to establish and maintain a diverse vegetative cover that will meet the little or no maintenance requirements for reclaimed areas as set forth by PL 95-87.

Successful first-effort establishment of vegetation is economically important. Careful adherence to recommended seeding and planting techniques, procedures, and use of appropriate amendments and mulches greatly improve the chances for success.

The plant-growth environment is nearly always improved with mulch. Organic mulch provides microorganisms, organic matter, and some nutrients to the soil. Mulch holds seeds in place and provides maximum protection from erosion, predation, rapid temperature changes, direct sunlight, and loss of moisture during and after the germination period and until the new seedlings are sufficiently established. Woody seedlings that are heavily mulched benefit by root protection and reduced competition from excessive growth of unwanted vegetation.

Mulch selection and application rate need to be coordinated with vegetation species to be used. For example, Kentucky-31 tall fescue is suited for areas in which fertility is low and moisture is limited periodically during the growing season. The application rate of mulch could be reduced for these species whereas with others it may need to be increased. Mulch must encourage both a prompt vegetative cover and recovery of productivity levels that are compatible with the approved post-mining land use. The long-term purpose for mulching is to enhance and promote the establishment and development of a permanent vegetative cover.

Mulching nearly always shortens the time needed to establish a plant cover. It permits the use of lower seeding rates and improves environmental conditions for better germination, emergence, root growth, more efficient uptake of water and nutrients, uniform vigorous stands, higher yields, better survival, and better growth. Mulch reduces soil crusting and produces a more favorable seedbed for seedling emergence and conserves water in the rooting zone. Some mulches contain essential elements to aid plant growth. Mulch temporarily stabilizes disturbed soil while vegetation is being established.

Grasses, legumes, and woody plants respond to different soil mulching agents with native species having the highest potential for success. Because mulches greatly modify microclimates, species best suited to such modification should perform best. For example, greater total ground cover responses are often observed in legumes than grasses following mulch application of bark or wood chips. Also, some grass species may perform better under fiber mulches, such as hay, than under other types of mulch.

Wood residues may not be as good as crop residues for establishing Ky-31 fescue or orchardgrass. Very favorable germination and seedling growth of legumes is achieved under wood residue mulch. Seedlings of legumes such as crownvetch normally grow more slowly during the seedling year than vigorous grasses such as Ky-31 fescue and lovegrass. Also, seedlings of species such as crownvetch have been more successful where a mulch was used. Greater response may be noted in plant species that have a relatively low salt tolerance following mulch application, because increased moisture conditions under mulches may enhance leaching of salts from the plant rooting zone.

Germination

Microclimatic conditions are extremely important during the period of germination and seedling development on newly planted areas. At this time, plants must be supplied with adequate water and oxygen, and the temperature must be within the range necessary for germination and growth. During the several weeks following germination, the seedling produces rudimentary root systems and a primary leaf. The newly formed seedling cannot tolerate a dry environment for long.

Mulches are effective in protecting the newly seeded area from erosion and in enhancing seedling success. They have greatly increased germination and survival resulting in quick sod establishment in areas of high soil temperature and moisture stress. The effectiveness and suitability of mulch treatments are evaluated by the protection it provides from time of seeding until a stable size and density of vegetative cover is established.

Because of size and weight and depth of application, some mulches inhibit seedling emergence. Mulch depths of 2 or more inches will retard the establishment of most grasses and legumes (see Mulch Application).

Favorable vegetative response following addition of surface mulches is primarily related to regulation of soil temperature and conservation of soil moisture. However, mulches can cause slow germination and plant growth by lowering soil temperature. Increased mulch rates in the spring may delay the time that soil would reach favorable temperatures for seed germination. Also, light-colored mulches can be a disadvantage because they keep soils cool. Application of dark mulch can advance growth of plants by a month or more by increasing the temperature. Dark-colored mulches might have an advantage for fall seedings because elevated temperatures during suboptimum temperature periods might augment germination and growth.

Although reduced soil temperature, as well as reduced fluctuation of temperatures, beneath mulch is a possible benefit to growth, the most important benefits of mulching are reduced evaporation, increased infiltration rates, and greater retention of soil moisture.

In the humid region, mulched and fertilized vegetation is more drought resistant due to increased top and root growth and root penetration. The total water consumed may be greater, but it is used more efficiently.

Mulch on dry sites may be detrimental because seed can be fooled into germinating with the first light rainfall. This can encourage plant suicide because organic mulch can take moisture away from seed resulting in some dieback from lack of sufficient moisture for continued growth.

Undesirable Plant Growth

Presence of undesirable seed in some crop-residue mulches can affect reclamation. When straw contains seed heads, a volunteer start of grain may result. This may be advantageous as a nurse crop if the start is not too thick. However, seed that has been threshed from grain straw can produce vegetation that inhibits establishment of the seeded plant species. Aggressive plants of volunteer weeds or cereal grain in the straw crowd out the slow growing perennial grasses and legumes.

Oats straw contains many viable seeds that germinate and provide competition for the grass and legume seeding. Straw can be expected to contain 0.5 to 5 percent cereal seed by weight. This may result in considerable plant cover in the first year. One-fifth (20 percent) of the plants found on straw-mulched areas were nonseeded annuals that do not contribute toward long-term erosion control. Thirteen percent were weed species and 6 to 7 percent were volunteer oats.

Annual plants will develop early and provide additional erosion protection for the short term but offer little protection for the long term. They are prohibitively competitive with the planted mixture. Rice straw, if available, is better because neither the rice nor associated weeds are expected to grow on most unirrigated disturbed lands.

Manure that is high in bedding material may contain undigested seeds that could infest the land with weeds. Grain and hay seedlings generally emerge easily through the mantle of manure.

The use of hay as mulch may sometimes be restricted due to contamination with noxious weed seeds or with organisms that cause diseases in agricultural crops. Aggressive weeds may crowd the desired plants.

Hay is sometimes preferred as a mulch where vegetation is for land uses, such as wildlife habitat, because it may contain seed of species favorable to wildlife. Because of the seeds contained in hay, it may promote better grass cover than that of straw. Some hay may contain sufficient grass seed so that the hay serves both as a mulch and a seed source.

Wood residues, and municipal and industrial wastes usually eliminate introduction of undesirable species. Weed species, including the noxious varieties, are far less prevalent on bark-mulched areas than on straw- and hay-mulched areas. Coarse-textured mulch may trap airborne seed that will germinate and grow, but this is not a serious problem. Weed seeds do not germinate readily under a heavy mulch.

Herbicides, when incorporated with organic mulches, provide a synergistic effect. Herbicide and mulch combinations provide more effective control than when either is applied alone. The organic mulch holds the herbicide and provides a long residual life and reduces the chance of herbicide runoff and phytotoxicity to the treated plants. A secondary benefit is that small quantities of herbicide can be premixed and applied with mulch. Potentially, bark should be an excellent carrier for herbicide compounds.

Dichlobenil, diphenomil, and simazine products have been tested. The addition of herbicide to 2-inch oak bark mulch enhanced its weed-control properties. The herbicide killed the germinating weeds at time of mulch application. This virtually eliminated weeds at the start. Further weed germination and growth is reduced by the residual action of the herbicide.

Some plant species can be troublesome where planted in association with plants for other land uses. For example, Japanese honeysuckle is a valuable plant for wildlife cover and food. Yet, this plant can become a pest because it will rapidly spread and smother or suppress other plants growing near it. Planting of Japanese honeysuckle and other plants such as Kudzu and multiflora rose in conjunction with forestry or agricultural uses is not recommended. Authorities have classified some of the plants as noxious weeds and made it unlawful to plant them in certain areas.

Considerations When Selecting a Mulch

The following items should be considered when selecting a mulch to facilitate reclamation:

A. General Information

1. Distance of land application site from mulch source
2. Distance of land application site from waterways, urban areas, or residences
3. Proposed land use
4. Proposed vegetative species
5. Regional land use planning requirements
6. Expansion potential (additional land)

B. Environmental Interactions

1. Climate
    a. Seasonal characteristics
    b. Precipitation
    c. Temperature
    d. Prevailing wind direction
    e. Evapotranspiration

2. Topographic and geologic features

    a. Slope steepness
    b. Slope length
    c. Slope aspect
    d. Erosion potential
    e. Flood potential

f. Infiltration and percolation characteristics
g. Minesoil characteristics
h. Ground water pollution potential

C. Land Use History

1. Crop
2. Pastureland
3. Forestry
4. Wildlife
5. Conservation practices
6. Irrigation potential

D. Application

1. Intended Use
2. Mulch depth
3. Mulch rate
4. Method of Application
5. Anchoring

Mulch Descriptions

Detailed information has been prepared for materials that are most frequently used and recommended and for some that have been successful on experimental plots but otherwise have been little used. The material descriptions are arranged by residue type:

Agricultural Residues

Straw
Hay
Manure

Silvicultural Residues

Bark
- Hardwood
- Softwood

Wood Chips
- Hardwood
- Softwood

Sawdust
Leaves

Municipal Wastes

Solid Wastes
Wastewater Sludge

Industrial Wastes

Wood Cellulose Fiber

Straw

Type of material: Long fiber cellulose

Sources: Cereal crop residue (wheat, oats, barley, etc.)

Packaging: Loose or baled (rectangular or round)

Availability: Local farms, farm stores (grain and feed), prior reclaimed land

Measurement: Tons, pounds

Properties:

Form: Fiber

Size: Minimum length, 6 inches; average, 10 inches

Color: Light yellow

Durability: One growing season

pH: 5.6 to 7.1

C to N ratio: Wheat 128:1 to 150:1; oats 48:1

Nutrients: lb/ton, dry matter

	N	P	K
Oats	12	4	30
Wheat	14	3	23

Application:

Intended use: Tons needed per acre - Seed cover: 1.5 to 2, Erosion control: 3, Plant mulch: 4

Methods:

Application: Manual, spreader, or blower

Anchoring: Crimper or asphalt tackifier

Vegetative response: Weeds or grain seeds that are usually present can restrict desirable plant species. There is no long-term effect due to nitrogen deficiency.

Comments: Straw is one of the most economical mulches. However, cost is influenced by weather and demand. Supply can be undependable due to short-stem small grains and increased demand. Grain crops raised on previously reclaimed mine sites are a potential source. Usually 100 pounds of straw are produced for each bushel of wheat harvested. A grain yield of 40 bushels per acre would result in a straw residue of about 2 tons per acre.

Straw is available in 70 to 90 pound rectangular bales with 25 to 30 bales per 1 ton. Generally, unweathered, unchopped small-grain wheat, oat, or barley straw is best. Wheat straw is preferred because it does not decompose as rapidly as oat straw. Barley straw has a dusty character but is highly efficient. Compared to wheat straw, barley straw has a thinner stem shell, which makes it lighter in weight, and provides more coverage when applied by weight.

Dry straw usually contains about 15 percent moisture, 5 percent ash, and 80 percent organic matter. It will absorb considerable liquid (twice its weight) and can "wick out" moisture from soils. Rapid decomposition reduces its efficiency in retarding surface runoff. Straw improves soil aggregation and has no measurable effect upon soil reaction. Fats, waxes, and oils serve as soil aggregate binders and make up 1.5 percent of average wheat straw.

Straw obstructs solar radiation. One ton per acre can reduce soil-surface temperature by 10 to 15°F. In the spring, it can be a disadvantage due to its light color and reflective qualities, which slows warming of the ground and delays seed germination and early crop growth.

Straw materially reduces the formation of nitrates because of the soluble organic derivatives leached into the soil during decomposition. Microbial immobilization of nitrogen during decomposition averages about 1.5 percent of the original straw weight. Therefore, 1.25 to 1.5 percent nitrogen (50 to 60 pounds per acre) is needed with optimum mulch application (1 1/2 to 2 tons per acre). The anaerobic decomposition of wheat straw by a suspension of soil microorganisms has led to production of substances inhibitory to plant growth. Acetic acid was the phytotoxin present in greatest amount.

Straw is superior to manufactured short-fibered wood cellulose for soil protection. For optimum protection, it should be applied at the rate of at least 1-1/2 tons per acre or about 1 inch in depth. It should be spread 3 to 5 intermeshed straws deep. A 1- to 2-inch matt equals 125 pounds per 1,000 square feet or 2.7 tons per acre. Where straw makes extensive contact with the soil surface, its long fiber tends to block the path of the runoff flow and physically blocks the movement of soil particles. Much of this effectiveness is lost if the straw becomes perched or bridged above the surface. On 1:1 slopes subject to heavy rainfall, straw is difficult to hold in place and tends to flow down the slope. On a 3:1 slope, 2 tons per acre anchored with 400 gallons of asphalt emulsion can be effective in controlling erosion.

Application of 1,500 pounds per acre is about the least amount of straw that controls evaporation from the soil. When compared to bare soil, a mat 1-1/2 inches thick (about 2.25 tons per acre) reduced moisture loss by 73 percent. One-half ton per acre reduced soil loss by 66 percent; four tons reduced soil loss by 95 percent. A good treatment for erosion is a combination of 3,000 pounds per acre of straw mulch that is oversprayed with 700 pounds of hydromulch. Thick applications can create problems in the summer if the fibers thatch together preventing penetration of water. Also, thick applications can be a fire hazard when dry.

A fine-stemmed baled mulch is preferable to a loose mulch for mechanical spreading. Wheat, barley, and oat straws work well in blowers that shred, cut, and evenly scatter mulch. Rice straw does not scatter easily, it does not work well in a blower. Straw that is excessively brittle or is in an advanced stage of decomposition smothers or retards plant growth and should not be used.

Baled straw is long or short depending on agricultural practice used in baling. For anchoring mechanically, stems should not be less than 6 inches. In crimping, 50 percent of the fibers should average 10 inches or longer for incorporation into the soil to a depth of 2 to 2-1/2 inches and still leave tufts or whisker dams. On an equal-weight basis, standing residues are more effective than residues lying flat for wind erosion control. As a general rule, to hold wind erosion to a tolerable level of 5 tons per acre, about twice as much flattened residue than standing residue is needed.

Undesirable seeds harvested with straw may conflict with establishment of desired plant species.

Hay

Type of material: Long-fiber cellulose

Sources: Grass and legume hay crops

Packaging: Loose or baled (round, rectangular)

Availability: Local farms, farm stores (grain & feed), prior reclaimed land

Measurement: Tons, Pounds

Properties:

Form: Fiber

Size: Minimum length, 6 inches; average, 10 inches

Color: Brown to Gray Green

Durability: One growing season

pH: 5.5

C to N ratio: Legume 19:1; grass 19:1 or less

Nutrients: lb/per ton, dry matter - N: 48, P: 10, K: 28

Application:

Intended use: Tons needed per acre - Seed cover: 2, Erosion control: 3, Plant mulch: 4

Methods:

Application: Manual, spreader, or blower

Anchoring: Crimper or asphalt tackifier

Vegetative response: Weed seeds are usually present.

Comments: Hay requirements are much the same as straw. Source of supply may be undependable and prices are influenced by weather and demand. Cuttings of forage crops raised on previously reclaimed sites can be used for mulching on new reclamation projects.

Hay is available in 40- to 90-pound rectangular bales or 1,200- to 1,500-pound round bales depending on the kind of hay being baled and its moisture content. Hay comprised primarily of grass is as effective as straw. Fescue hay or other good grass hays are better because they last longer due to more stem and less leaves per volume than legumes.

On spring seedlings, hay decomposes rapidly reducing its efficiency in retarding surface runoff. It is more effective for fall seedings because decomposition is not as rapid.

Alfalfa hay contains 43 percent carbon, 2.34 pounds of nitrogen with a C to N ratio of 18:1. Where used as a mulch, applications have significantly reduced pH in the surface 2 inches of minesoil. Very definite increases have occurred in the total quantity of exchangeable bases in soils. Nitric and carbonic acids produced during decomposition reduce the concentration of exchangeable calcium. Legumes should aid nitrification because soil nitrates tend to be slightly higher under them than under cereal straws. Areas receiving legume residues considerably out yield those mulched with cereal straws.

Hay is not as slippery as straw because long fibers lock together and restrict movement. The recommended minimum application rate is 3,000 pounds per acre crimped into the surface, a minimum depth of 1-1/2 inches and a maximum of 3 inches. Excessive rates can be a fire hazard in dry weather.

Application of hay is usually accomplished with a blower. However, processed hay containing maximum fiber length is capable of being hydraulically applied.

Mature hay and late season cuttings often are contaminated with seeds that conflict with establishment of desired plant species. Seed of grass and legume components may be beneficial on sites where a pasture is the post-mining land use. Native grass hay can add desirable native species on potential wildlife areas.

Solid materials are applied by spreader or blower and should not be deposited in piles or windrows. Slurry and liquids are applied by irrigation systems or tank wagons. Wastes should not be spread on frozen soil or on actively melting snow because substantial nutrient losses can occur with surface runoff. Local precipitation records should be evaluated to avoid spreading wastes when runoff or leaching potential is high. Excessive manure application rates may lead to nitrate pollution of both runoff and ground water or may increase soil salinity through accumulation of sodium and potassium salts.

Annual crops are best adapted to manure applications because of the annual working of soil surface. Slight discing of manure into the surface greatly reduces odor.

Solids that are high in bedding material may depress plant growth unless supplemented with nitrogen fertilizer. High rates of manure application may cause high ammonia levels that may inhibit germination and plant growth. Accumulation of nitrate nitrogen can be toxic. Nitrates should leach from the soil but could accumulate in ground water. Grasses respond favorably to poultry wastes with seedling emergence triple that of untreated areas.

Another component of animal manures is weed seeds, necessitating careful vegetation selection and management practices. Manure storage may or may not decrease weed-seed viability.

Hardwood Bark

Type of material: Long fiber (shredded)

Sources: Deciduous woody vegetation

Packaging: Bulk--raw as it comes from debarker or processed from shredder

Availability: Residue from primary forest products industries or timber harvest on or off mine site.

Measurement: Ton, pounds, cubic yard (volume is preferred measure)

Properties:

Form: Fiber (shredded), ground, chunk

Size: 1/8 inch to 3 inches

Color: Light (straw color), reddish to gray brown

Durability: 3 to 4 years

pH: Fresh 4.2 to 6.4, composted 6.5 to 8.5

C to N ratio: 115:1 to 435:1, Average = 223:1

Nutrients: Percent - N: 0.1 to 0.2, P: 0.02 to 0.06, K: 0.05 to 0.32

Application:

Intended use:

	Seed cover	Erosion control	Plant mulch
Depth (inches)	3/8	2	4
Cubic yard per acre	45	240	480

Methods:

Application: Manual, spreader, blower, blower/impactor

Anchoring: Not required

Vegetative response: Hardwood bark produces a temporary nitrogen deficiency with no long-term effects. Inoculated legumes suffer no reduction in growth. Hardwood bark traps airborne seed.

Comments: Hardwood bark is readily available throughout the year in large quantities in localized areas in western, eastern, and northern Appalachian coal regions. It may be used raw as it comes from the debarker, or processed (hogged) to reduce to a more uniform size.

Bark is marketed on either a volume or weight basis. However, the relationship is important because weight is influenced by its moisture content.

Bark conserves moisture and is successful on the harshest of sites and during extended droughts when other mulches fail. It is superior to straw or hydromulch. Bark with high percentages of fines may act as a wick on droughty sites. However, when the particle size is larger than one-eighth of an inch, water retention is markedly reduced. Oak bark has a porous structure and requires one-third more depth than softwood bark to achieve similar moisture conservation results.

Bark has good insulating properties. Composted bark 1-1/2 inches deep may reduce temperatures by 40 to 50°F at 2-1/2 inches below the soil surface. Bark is 97 percent organic matter, containing 42 percent lignin and 55 percent carbon. It has a great variety of organic and inorganic compounds and elements. It may contain chelating agents that retain mineral plant nutrients. Organic acids may protect plant-available phosphorus against precipitation by calcium. Nutritional aspects of calcium, magnesium, and potassium may increase but with little difference in nitrogen or phosphorus. Bark has a high-cation exchange capacity, and the pH of leachate has a tendency to increase.

Bark contains little nitrogen and causes a nitrogen deficiency during decomposition. However, it is not as serious as problems with other wood mulches because the large individual particles decompose slowly due to the absence of cellulose. About 2 pounds of nitrogen per cubic yard can be added to bring the nitrogen concentration of the mass to 1 percent. Nitrogen requirements are usually higher for hardwoods than softwoods. An increase in plant-available phosphorus can result from the addition of shredded hardwood bark.

Bark is 11 to 15 percent of a tree's volume. Twelve hundred pounds of green bark by-product is generated with each thousand board feet of lumber produced. Conversion factor of weight to volume is 2.7 to 3.0 cubic yards per ton of mixed hardwood bark based on 50 percent moisture content, green weight basis. Moisture can vary with the time of year that logs are debarked and with the method used. For estimating, bark averages over 18 pounds per cubic foot or approximately 500 pounds per cubic yard.

Bark of shredded hardwood species has high density and is usually long, rough, and fibrous. Mulch should be graded to pass a 2-inch screen. The ratio of small, medium, and large particles determines the percentage of pore space and the effectiveness of the mulch to alter soil-moisture characteristics. Large particles assure high-porosity while fines raise the cation-exchange and moisture-holding capacities. Particle size should range between 3/16 inch to 1-1/8 inches for optimum soil stabilization.

Differences in properties of bark from various tree species are considerable. Barks from maple, poplar, and alder are typically high in cellulose (readily degradable carbon) and have a relatively high decomposition rate--40 to 50 percent in 60 days--and a nitrogen requirement of 1.0 percent by weight. Bark from all of these trees require 5 to 10 pounds of nitrogen per ton of bark to counteract C to N ratio during decomposition. Wood residues decay at a slower rate if used as a surface mulch; therefore, they demand less nitrogen for decomposition. When nitrate nitrogen depression is used as a measure of decomposition, hardwood residues may decompose 3 to 10 times more rapidly than residues from softwood. Rate of decomposition tends to increase with decreasing particle size. Very finely ground wood fiber or bark material will decompose at a very rapid rate because it increases the surface area for microbial attack. The absorption of water, nutrients, gas, and the attraction of particles for each other are all surface phenomena that influence decomposition. Thus, decomposition rates for these finely ground materials will be substantially higher and faster than that for coarse materials. Therefore, effective life of wood residues can in part be governed by selection based on particle size.

The older the tree, the smaller the ratio of cellulose to lignin. The lower the content of cellulose, the smaller the amount of nitrogen required when bark is used for mulch. Hickory, oak, and black walnut are resistant to microbial attack because there is less cellulose in the bark.

Composting removes some toxins and improves the bark as a mulch by forming humic acid. Optimum temperature for composting hardwood bark is 140 to 150°F. Optimum moisture is 50 to 60 percent on a wet-weight basis. Four weeks usually are required for composting plus 1 month stabilization.

Composting is not to be confused with stockpiling. Composting requires turning and other practices that induce a dark brown color.

When bark is stored in large stockpiles, decomposition takes place. If the piles are over 8 feet tall and 8 feet wide, anaerobic respiration takes place and organic acids that can be harmful to plants are formed. Bark should be kept in small piles so aerobic respiration continues and no harmful materials are produced. If acids are formed, the bark can be leached to wash out these organic acids or buffered with 10 pounds of lime per cubic yard. With proper methods, bark can be stored outside a year or more with little adverse effect. Bark is preferable if it has been weathered.

Hardwood bark mulch is a probable source of beneficial soil microorganisms, such as endomycorrhizal fungi. Damping-off fungi found on some bark mulch may affect success of direct seeding of conifers. Great numbers of mites may be found in bark compost, and these mites can initiate great populations of fungus gnats (Sciaridae sp.). Under field conditions, these organisms invade the partly fermented material in immense numbers and in a rather mysterious way. This invasion is one illustration of the symbiotic association of fungi and insects. A fungus (Fudigo septica) may develop large amounts of custard-like tissue on the bark surface, but it is not harmful and does not last for more than 1 to 2 weeks.

Ground bark is 1/50 to 1/8 inch in size. Excessive amounts of small particles can lead to compaction and anaerobic conditions. Loose bark aerates better. Under normal conditions coarse bark will not crust, blow, or wash away and particles 1 to 1-1/4 inches exert a favorable effect on the physical and chemical qualities of the minesoil.

Compared to wood chips, bark mulch is less subject to movement by wind and water because of the weight of the material and the long strands of rough-surface fiber that interlock. Long splintering particles stick well to the soil. They create a terrace effect as they lodge crosswise contributing to the effectiveness for erosion control.

The recommended optimum rate for good herbaceous cover is 30 to 50 cubic yards per acre, green weight. Thirty cubic yards (loose measure) of bark mulch per acre is recommended for application on north- and east-facing slopes that are 2:1 or less. Fifty cubic yards (loose measure) per acre is needed on slopes greater than 2:1, on slopes that face south and west, and for overwinter protection of disturbed sites. This provides a depth of 3/8 to 1/2 inch. Rates of 50 to 100 cubic yards per acre have little adverse effect on the emergence of most grass and legume species.

Where bark and straw have been tested side by side, leguminous vegetation with bark was more prompt and heavier and the distribution of plants was more uniform. High moisture content of bark material enhances rapid germination and growth of legumes in the early stages of development. Also, germination and growth may be hastened by the organic compounds in the bark leachate.

The effect of toxic components of bark on the establishment and growth of plants appears to have been overemphasized. Bark contains no weed seeds that would compete with desired species but will catch windborne natural seeds. The beneficial effects of using bark as mulch and soil conditioners for ornamental plants have been demonstrated by the continued and successful use of these materials by horticulturists and nurserymen. Considerably less is known about the use of these materials on woody vegetation on minesoils.

Surfaces that have been mulched with bark for surface protection before seeding do not have to be reworked for seeding to establish permanent cover. Broadcast seedings can be made on the surface of the mulch because seeds are "planted" in the voids between the mulch particles. A 2-inch layer of bark has supported a growth of grass that was sown directly on top.

Softwood Bark

Type of material: Solid to granular, shredded fiber

Sources: Coniferous woody vegetation

Packaging: Bulk--raw as it comes from debarker or processed

Availability: Residue from primary forest products industries or timber harvest on or off mine site.

Measurement: Ton, pounds; cubic yard (volume is preferred measure)

Properties:

Form: Ground, minichips, nuggets, chunk, shredded

Size: 0.25 inch, 0.25 to 0.75, 0.75 to 1.5 inches, 1.5 to 3.25 inches

Color: Reddish to dark brown to grays with aging

Durability: 5 to 10 years

pH: Fresh 3.5 to 5.5; composted 6.5 to 8.5

C to N ratio: Highly variable, 131:1 to 930:1

Nutrients: Percent - N: 0.76, P: 0.04, K: 0.25

Application:

Intended use:

	Seed cover	Erosion control	Plant mulch
Depth (inches)	3/8	2	4
Cubic yard per acre	45	240	480

Methods:

Application: Manual, spreader, blower, blower/impactor

Anchoring: Not required

Vegetative response: Softwood bark produces nitrogen deficiency with no long-term effects.

Comments: Softwood bark is readily available throughout the year in large quantities in the southern part of the Appalachian coal region.

Bark is measured in bulk form by the cubic yard. It is 8 to 24 percent of a tree's volume. Nine hundred forty pounds of green bark by-product is generated with each thousand board feet of lumber produced. Bulk density is 14 pounds per cubic foot, dry basis noncompacted or 17 pounds compacted.

Softwood bark contains approximately 98 percent organic matter with 55 percent lignin, 30 percent cellulose, 13 percent carbon sugars, and 2 percent inorganic matter. Eastern red cedar and various spruces are high in cellulose. Softwood bark needs 1 pound of additional nitrogen per cubic yard for decomposition to avoid nitrogen deficiency in plants. Since softwood decomposes more slowly, it requires about half the nitrogen of other wood residues for denitrification. Fresh pine bark requires 6 weeks of composting. Water-insoluble resins in softwood are largely responsible for slow decomposition. Cypress and white, shortleaf, longleaf, slash, and loblolly pines contain little cellulose. Therefore, little additional nitrogen is required. Because of a high content of acid compounds such as polyphenols, bark readily absorbs 2 percent nitrogen as ammonia. This is more than required for complete microbial decomposition. Cork bark rhytidome of older pine is resistant to decomposition due to suberin content. Thin bark of young pine has negligible amounts of rhytidome and has a pH about 5.4. Polymeric phenolic acids in softwood bark render it susceptible to many chemical reactions that might inhibit the growth of certain microorganisms.

Softwood barks (except cypress and cedars) are usually granular rather than fibrous and are not as porous as hardwood bark. Mulch should not contain a large proportion of fine particles, which may cause disagreeable dust and compaction of the mulch layer. Too many fines may result in poor drainage and root sloughing. A certain amount of fines is necessary because of the moisture-holding capacity. An optimum mulch contains the following size-class distribution.

Percent of weight	Size class (inches)
20	1 and over
10	1/2 to 1
20	1/4 to 1/2
20	1/8 to 1/4
10	1/16 to 1/8
10	1/50 to 1/16
10	greater than 1/50

Ground bark 1/8 to 1/4 inch is used primarily as a soil conditioner. Particles less than three-sixteenths of an inch do not give optimum performance for soil stabilization. Minichips, 1/4 to 3/4 inch, provide a good seed cover. Nugget size, 3/4 to 1-1/2 inches, is optimum for erosion control. Chunk size, 1-1/2 to 3-1/4 inches is right for mulching shrubs and trees. A 4 inch depth is most effective in smothering weeds.

Conversion factors for softwood bark: pine bark nuggets, 15 pounds per cubic foot, or 404 pounds per cubic yard, or approximately 5 cubic yards per ton. Pine bark minichips, 17 pounds per cubic foot, or 459 pounds per cubic yard, or 4.4 cubic yards per ton. Pine bark ground, 22 pounds per cubic foot, or 594 pounds per cubic yard, or 3.4 cubic yards per ton.

Softwood is less desirable than hardwood for erosion control because particles are granular, lighter in weight, and have a tendency to flow or move more easily in runoff water during heavy rains. Surface should be rough where softwood bark is used so that mulch particles can lodge in soil. The fibrous softwood barks (cedar and cypress) are recommended for erosion control when slope is a factor.

When the lignin fraction of pine bark begins to decompose, it releases a chemical similar to gibberellic acid, which has unusual plant growth stimulation.

Hardwood Chips

Type of material: Solid to granular and platy

Sources: Deciduous vegetation

Packaging: Bulk--raw as it comes from chipper

Availability: Pulp chips: product from sawmills, veneer and chipping plants. Whole-tree chips: mobile chip harvesting on or off mine site.

Measurement: Ton, pounds; cubic yard

Properties:

Form: Solid chips

Size: 1/4 inch to 4 inches; average length, 3/4 to 7/8 inch

Color: White to yellow, weathers tan to gray

Durability: 5 to 15 years depending on species

pH: Oak 4.1 to 6.0, average 5.3

C to N ratio: 615:1

Nutrients: Pounds per ton, dry matter - N: 4.0, P: 0.87, K: 3.32

Application:

Intended use:

	Seed cover	Erosion control	Plant mulch
Depth (inches)	1/4	2	4
Cubic yard per acre	50	268	536

Methods:

Application: Manual, spreader, blower, blower/compactor

Anchoring: Not required

Vegetative Response: Hardwood chips produce temporary nitrogen deficiency with no long-term effects; inoculated legumes suffer no reduction in growth. Hardwood chips trap airborne seeds.

Comments: Hardwood chips are readily available from mills or whole-tree chipping operations throughout the year in western, eastern, and northern Appalachian coal regions. Supply seems to be more than adequate to satisfy mulching needs. There are 50 to 150 tons per acre of woody vegetation on typical Appalachian hardwood sites depending on age, quality, and past management practices. There are 70 to 120 tons per acre in eastern Kentucky even after sawlogs are removed.

Salvage and conversion of woody vegetation that is usually wasted on a mine site during clearing operations can be a source of wood chips. If the mine area has 100-ton-per-acre vegetation, only 1/4 to 1/3 of the wood chips potential would be needed for mulch. Initial cost may be more than other mulches, but performance is better and cost may be less in the long run if no maintenance is required. Costs can be reduced by on-site chipping, which would be part of clearing and grubbing costs rather than reclamation costs. They are produced from the entire aboveground portion of trunk, limbs, and branches and are usually used without further processing. They are marketed on either a volume or weight basis. However, rates of application are expressed in cubic yards because chips show extreme variation in moisture content. Rates relating to weight must be based on air-dry weights to assure uniformity. Conversion factors from weight to volume are influenced by the species composition of the chips. A ton of green oak chips contains about 4 cubic yards while a ton of red maple has nearly 5 cubic yards. A weighted average used by paper companies in estimating green chips is 18 pounds per cubic foot or 500 pounds per cubic yard or 4.0 cubic yards per ton. Fine chips average about 17 pounds per cubic foot and coarse, 24 pounds per cubic foot.

Chippers can be adjusted to produce chips 1/4 inch to 4 inches in length. Chips should not be larger than three-eights of an inch thick or more than 6 square inches (2" x 3") in area and should be graded through various size sieves to blend particle sizes. Small particles retain more moisture but can interfere with drainage. Large chips absorb less moisture and provide good drainage.

Chips are 98 percent organic matter, with an average of 26 percent lignin and 72 percent carbon. Forty-five percent of green weight is water. Fourteen to eighteen percent of dry weight of whole-tree chips is bark. In summer, an additional 1 to 2 percent is leaves.

Denitrification is not a serious problem with wood chips because the particles are larger and usually decompose more slowly than crop residues or wood fibers. Chips decompose faster than bark because of a higher cellulose content. They settle naturally, needing no compaction and remain in place for 8 to 15 years, depending on species of wood and depth of coverage.

Nitrogen is utilized during chip decomposition. Fifty pounds of nitrogen per ton of wood chips can be applied in stockpile so decomposition starts before application. Composting wood residues aerobically for 3 months or more also helps. Application of 45 to 50 cubic yards per acre under normal seeding and fertilization practices normally does not cause a nitrogen deficiency. One pound of nitrogen per 100 pounds of chips or 20 pounds per ton is a rule-of-thumb for adding nitrogen to chips to prevent soil denitrification.

The amount and causes of microbiological deterioration of wood mulches during storage are important. For example, if wood chips are to be stored for any length of time, a full assessment of the destructive capabilities of organisms, particularly those known to be prevalent in chip storage piles and capable of causing substantial weight losses in wood, is desirable. Fungi grow prolifically within a wood-chip pile creating heat. This warmer environment encourages growth of "heat-loving" fungi, which replace some of the earlier fungi that are restricted as the temperature rises above 104°F. Temperatures rise to 122 to 140° F and higher in chip piles. Temperatures above 150°F kill virtually all fungi in a pile. Ideally, storage should not exceed 2 to 3 months for hardwood chips and 4 to 5 months for softwood chips piled in above-freezing weather. Hardwood chips stored outside average a loss in weight of 5.5 to 7.5 percent. An average weight loss of 1 percent per month can be expected, and losses up to 2 percent per month have occurred in some hardwood chips.

Any soil acidity increase caused by wood product decomposition is negligible. Wood mulches are strongly acid and pH values range from 3.5 to 7.0 with an average of 4.5. The effects that decomposition of the products may have on soil reaction are of greater importance than the initial pH. The end product is alkaline-like wood ashes. Since the ash of these products contains more basic than acidic constituents, the pH should increase with the ultimate effect toward a less acidic condition.

Application rate of chips must be at least 6 times that of straw to obtain the same surface protection as straw. The recommendation is 10 to 20 tons per acre or 40 to 60 cubic yards. This provides a depth of 3/8 to 1/2 inch, which is adequate for protecting the soil surface and enhancing germination and establishment of most seedlings. A 2-inch layer of mulch is an effective erosion deterrent on steep denuded slopes up to 150 feet in length. A 1-inch cover of chips is not sufficient to provide erosion control on slopes steeper than 3:1. However, a 1-inch layer of chips controls erosion better than 2 to 3 tons of straw per acre. Four-inch layer of chips is effective on slopes between 4:1 and 1:1 when used purely for erosion control and will remain in place 8 to 15 years.

Partially decomposed wood products are preferred because they tend to be less susceptible to movement. The ragged edges of chips mesh and hold each other in place. However, when dry, chips are more subject to movement by wind and water than hardwood bark. Chips are more effective than standard wood-fiber mulch in preventing soil erosion.

Chips invariably will affect vegetative growth unless supplemental nitrogen is added or they are composted before application. Because of their size and weight, chips can inhibit seed emergence. Depths of 3 to 4 inches retard the establishment of grasses. Layers less than 2 inches are preferred when used for establishing herbaceous cover.

Chips do not contain weed seeds but do trap airborne seeds. They do not create a fire hazard and do not favor insects or rodents.

Softwood Chips

Type of material: Solid to granular and platy

Sources: Coniferous vegetation

Availability: Pulp chips: product from sawmills, veneer plants, and chipping plants. Whole-tree chips: mobile chip harvesting on or off mine site.

Measurement: Ton; cubic yard

Properties:

Form: Solid chips

Size: 1/4 inch to 4 inches; average length, 3/4 to 7/8 inch

Color: White to yellow, weathers tan to gray

Durability: 5 to 15 years depending on species.

pH: 3.9 to 5.1

C to N ratio: 615:1

Nutrients: Percent - N: 0.138, P: 0.020, K: 0.102

Application:

Intended use:

	Seed cover	Erosion control	Plant mulch
Depth (inches)	1/4	2	4
Cubic yard per acre	50	268	536

Methods:

Application: Manual, spreader, blower, blower/compactor

Anchoring: Not required

Vegetative Response: Softwood chips produce temporary nitrogen deficiency with no long-term effects; trap airborne seeds.

Comments: Softwood chips are available throughout the year in the southern part of the Appalachian coal region. Chips are usually used without further processing. They are produced from entire aboveground portion of the trunk, limbs, branches, and needles. Whole-tree chips are about 83 percent wood, 13 percent bark, and 4 percent needles.

Chips contain 98 percent total organic matter with an average of 28 percent lignin and 69 percent carbon. Softwoods usually contain more lignin than hardwood. Carbohydrate fraction is 70 percent of the weight of wood.

Chips are marketed on either a volume or weight basis. Rates relating to weight must be based on air-dry weight to assure uniformity. White pine chips average 13 pounds per cubic foot or 5.7 cubic yards per ton. In general, pine is more effective than oak hardwood in improving the soil. Pine decomposition is much slower and usually more acid than hardwood. High lignin content, greater concentration of resinous compounds, and the less porous structure in softwood are probably the major factors contributing to slower initial decomposition of softwood. Cedar contains toxic materials that, under certain conditions, adversely affect the growth of some plants.

Softwoods require about 15 pounds of nitrogen per ton for decomposition. Maximum nitrogen immobilization is reached in 80 to 160 days.

Sawdust

Type of material: Solid to granular

Sources: Deciduous and coniferous vegetation

Packaging: Bulk

Availability: Local sawmill, forest products industry

Measurement: Ton; cubic yard

Properties:

Form: Granular to green air dried, kiln dried, composted

Size: 8 to 40 mesh

Color: Light yellow darkening with weathering

Durability: 3 to 5 years

pH: 3.5 to 7.0, average 5.2

C to N: 200:1 to 500:1

Nutrients: Pounds per ton, dry matter - N: 4, P: 2, K: 4

Application:

Intended use:

	Seed cover	Erosion control	Plant mulch
Depth (inches)	1/2	2	4
Cubic yards per acre	65	260	520

Methods:

Application: Manual, spreader, lime/fertilizer

Anchoring: Chemical, asphalt tackifier

Comments: Sawdust is readily available throughout the year in large quantities in western, eastern, and Appalachian coal regions. It may be used raw, weathered, or composted. It is available as green, air dried, kiln dried, or composted. Well weathered sawdust, leached for at least 1 year, is the most desirable. Some objectionable features in handling sawdust are slivers and dust.

Sawdust is often graded for size and in some instances by species. Hardwood sawdust is sifted in 8 to 40 mesh, while softwood is not.

In the production of a thousand board feet of lumber, pine produces 1 ton of sawdust; soft hardwood, 0.95 ton; and hardwood, 1.10 ton. There are 775 to 800 pounds per cubic yard or about 2.5 cubic yards per ton.

Sawdust is capable of absorbing water at 2 to 6 times its own weight. It can have a wick effect under certain conditions. Because of its small particle size, sawdust tends to pack tightly, and thus retard aeration and infiltration.

Decomposition of sawdust is more rapid than that of other wood residues because of the more finely divided materials and high cellulose content. However, decomposition rate is slower than that for an equal weight of straw.

Sawdust includes tannins and phenolic compounds injurious to plants and soil microbes, and its high cellulose content results in a high C to N ratio. This leads to the impoverishment of soil in nitrates and ammonia consumed by carbohydrate-decomposing organisms. Toxicity may be avoided by the application of 25 pounds of nitrogen per ton of dry sawdust. This corresponds to 115 pounds of ammonium sulphate or 72 pounds of ammonium nitrate.

The lignin in sawdust is valuable in the maintenance of soil fertility. The carboxyl groups of this high-molecular aromatic compound have an ability to part with hydrogen and retain adsorbed ions of ammonia, calcium, magnesium, potassium, and other bases. In this manner, lignin acts as a storehouse of nutrients that are preserved from leaching and yet are available to plants through the exchange reactions.

Most sawdusts are slightly acid: changes in the pH of the mixture depend on the wood species. If sawdust is strongly fermented, pH may decrease. Yellow pine, spruce, white, and black oak sawdusts have a pH of 4.1 to 5.0; red pine, maple, red, and pin oak 5.1 to 6.0. Sawdust has little effect on soil acidity, but if it is applied to areas requiring lime, any acid in it may be slightly harmful. Any acidity in sawdust can normally be neutralized with the application of 100 pounds or so of finely ground limestone per ton of dry material.

Sawdust can be used at high rates, but its nitrogen requirement may be the factor determining practical limits to the rate of applications. Small, granular particle sizes that are light in weight make sawdust subject to floating or blowing away. Sawdust performs less favorably than most other mulches on slopes. Sawdust applied at the rate of 30 cubic yards per acre on a 3:1 slope was severely eroded after a simulated 6-inch-per-hour rainfall that lasted 30 minutes.

Sometimes sawdust has a depressive effect on plants but that can be overcome by the addition of nitrogen. No weed seeds are found in the mixtures.

Leaves

Type of material: Short fiber

Sources: Deciduous trees

Packaging: Whole leaves--bulk or compacted bales, composted--bulk

Availability: Local municipalities

Measurement: Ton, whole leaves or shredded; cubic yard, composted

Properties:

Form: Whole leaves, shredded, compost

Size: Variable

Color: Yellow to dark brown

Durability: One growing season

pH: Composted, 6.5

C to N ratio: 40:1

Nutrients: Percent N: 1.28

Application:

Intended use: Tons needed per acre - Seed cover: 3, Erosion control: 4, Plant Mulch: 5

Methods:

Application: Manual, spreader, blower

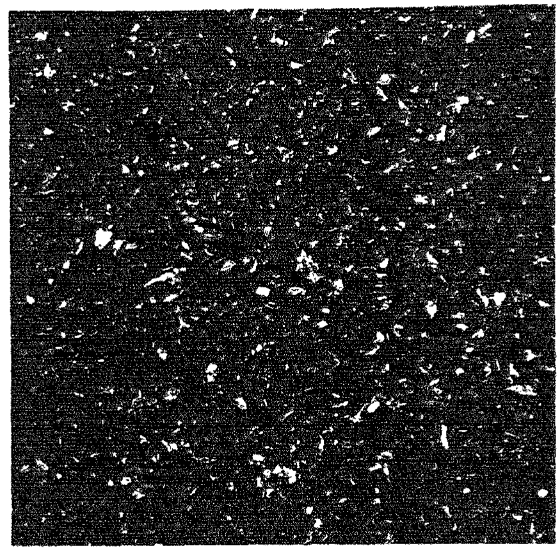
Anchoring: Whole or shredded leaves crimped lightly

Comments: Leaves are available in the fall from communities in the western and eastern Interior and the northern Appalachian coal regions. Ordinances banning or prohibiting open burning have created a surplus of leaves. They may be used whole (unrotted), shredded, or composted.

Availability of whole leaves does not coincide with the time when they are needed. Usually, fall seeding is accomplished before leaves are available. If they are baled and covered, they can be held until spring.

Little data exists on the use of leaves as a surface mulch on large disturbed areas. Leaves are an important source of organic matter (leaf mold). They contain 53 percent carbon and 26 percent cellulose, dry weight. Application rates are similar to straw and hay. Excessive rates could be a fire hazard. Bales of whole leaves may contain foreign debris such as twigs, rocks, sand, and plastic bags that should be removed before mechanical application.

Leaves are usually composted and screened. Composting requires about 200 days. Every 4 cubic yards of whole leaves yield approximately 1 cubic yard of compost. Use of leaves is limited to level areas and slopes less than 3:1 because light discing to a 2-inch depth is necessary to hold leaves in place. A 2- to 3-inch layer of partly rotted leaves will break down fast enough to add plant food and humus to soil.



Type of material: Short fiber

Sources: Processed or composted garbage

Packaging: Bulk--shredded or composted

Availability: Municipalities or commercial waste-recovery plants

Measurement: Ton; cubic yard

Properties:

Form: Fiber

Size: 1 to 2 inches shredded, 1/2 inch after composting

Color: Grayish green to grayish black

pH: Compost 7.5 to 8.5

C to N ratio: Unprocessed, 45:1 to 55:1

Nutrients: Percent

	N	P	K
Compost	1.0	.25	.25

Application:

Intended use: Tons needed per acre - Seed cover: 20

Methods:

Application: Manual, spreader, blower/impactor

Anchoring: Light discing

Vegetative response: Solid waste has beneficial effects on plant growth

Comments: Solid waste is available shredded or as a compost from communities and as commercial products. Shredded municipal refuse contains a considerable amount of solid fragments (glass, plastic, metal) that are not readily biodegradable and may detract esthetically when applied to land. Waste material that has been sorted to remove these fragments and other inorganic material is most desirable.

There has been increased use of the organic/compost fractions of refuse. Composting is an ancient practice. It is a microbiological process that depends on the growth and action of mixed populations of bacteria and fungi that are indigenous to various organic wastes. One of the major advantages of composting solid wastes is that it helps to abate problems of objectionable odor, human pathogens, and undesirable physical properties associated with utilization of organic wastes.

Composting results in a 40 to 50 percent reduction in volume and weight. C to N ratio of refuse can be lowered by the addition of sewage sludge during composting. Garbage should be shredded to 1 or 2 inch lengths and woody material to 1/2 inch for composting.

Solid waste compost is most valuable as a soil conditioner. It promotes soil aggregation which enhances the air-water relationship of soil. Compost usually possesses a full complement of trace elements.

Composted municipal waste reduces acidity. It provides increased buffering capacity due to the rapid change in soil acidity and alkalinity and neutralization of certain toxic substances. Constraints on solid waste can be excessive C to N ratio or high concentrations of elements and metals if excessively applied. Up to 20 dry tons per acre can be applied without overfertilizing. Twenty-five to seventy-five tons per acre would provide a more stabilized organic layer. Generally, applications up to 40 to 50 tons per acre are not excessive if added in spring. Dried and ground substances can be applied with blower/impactor and then lightly disced. Solid waste is eroded by heavy rainfall. Light-weight and small particle-size characteristics of solid waste do not hinder surface runoff. So, the solid waste becomes saturated and incorporated with soil particles. It cannot be held effectively on a slope. However, fibers do hold the soil better than no mulch. There are no weed seeds in solid waste.

Wastewater Sludge

Type of material: Solid, liquid

Sources: Municipal and industrial sewage sludge, residential septic sewage

Packaging: Bulk--dewatered sludge, slurry, liquid

Availability: Municipal and industrial treatment plants and septic tank cleaning companies

Measurement: Ton; gallon

Properties:

Form: Solid, slurry, liquid

Color: Dark, gray to black

Durability: 90 days

pH: Solid, 5.7 to 6.8

C to N ratio: 25:1

Nutrients: Percent dry weight basis

	N	P	K
Dry Sludge	3.5 to 6.4	0.8 to 3.9	0.2 to 0.7
Slurry	2.9 to 8.0	3.0 to 7.0	0.3 to 0.6
Liquid	1.7	1.4	0.4
Compost	0.6		

Application:

Intended use: Dry ton per acre for disturbed lands - Seed cover: 23-375

Methods:

Application: Solid--spreader, Slurry--water tight box spreader, liquid--hydraulic sprinkler, tank truck

Anchoring: Light discing

Vegetative response: Wastewater sludge provides significant beneficial effects on plant growth.

Comments: Sludge is a good, inexpensive, and readily available source of organic matter. Pipeline, railroad, truck, or barge is used to transport various forms of sludge from distant communities. Dewatering sludge permits hauling less water to projects and permits prolonged storage. Land application of sludge is not acceptable without further stabilization such as digestion, composting, or lagooning.

Projects receiving sludge should be provided with an analysis before application showing pH, percent of solids, nutrients, and heavy metals. Sludge should be stabilized to yield a product that is equivalent to that obtained by anaerobic digestion for 10 days at 78 to 110°F. Digested or stabilized sludge has minimal odor. Sludge direct from the digester averages 5 percent solids.

Sludge is about 50 percent organic matter, dry weight. Sewage effluent and liquid digested sludge are very low (about 3 percent) in BOD (biological oxygen demand) material. It provides no significant increase in organic material except for organic inputs from increased vegetative growth due to nutrients from sludge.

Many problems associated with the use of sludge can be overcome by composting. A composted stabilized sludge will add organic matter through the introduction of a bulking agent such as wood chips or bark. Wood chips mixed 3:1 with sewage sludge on a volume basis (1:1 weight basis) induce crumbling of sludge producing a rich form of compost. The wood residue provides a structure throughout the mass for air movement and absorption creating a blotter-like effect that lowers moisture content of the biomass to an optimal content of 50 to 60 percent by weight.

One of the advantages of composting is the conversion of sludge into a product that can be handled with a minimum of difficulty and in a manner that is both environmentally and hygienically sound. In the digestion process, a temperature of 95°F or above lowers human and plant pathogen content. Optimal temperatures for composting range from 140 to 160°F. Rapid composting occurs when the C to N ratio is 25:1 to 35:1 and a continuous supply of oxygen is available. It takes about 3 weeks to compost sludge by aeration. Compost is dried, screened, and cured. When chips are used as the bulking agent, about half of them become part of the compost and the balance is reused.

Digested sewage sludge does not hinder microbial activities or restrict their populations. Reduced acidity in the surface spoil layers from alkaline effluent and sludge creates a more favorable environment for autotrophics such as nitrosomones and nitrobacteria. Increased microfungal derivatives are most likely due to the accompanying elevation in pH, resultant higher levels of organic matter, and improved water-holding capacity. The effects of these factors on microfungal activity can show up to a fourfold increase in the density of the fungal population compared to that on untreated minesoil.

In general, effluent and sludge improve the chemical characteristics of minesoils and provide a source of nutrients needed for successful vegetation. Sludge colloids absorb soluble nutrients preserving them from loss through leaching and making them available to plants. Effluents have increased cation-exchange capacity and contain significant quantities of bases, calcium, magnesium, and sodium. Effluents are effective in diluting salt concentrations and can reduce the concentration of toxic elements by leaching them below plant-rooting depth.

Most digested sludges have a greater fertilizer potential than that of composted sludge. Nutrient content is reduced by composting and the dewatering and drying process. Sludge contains only about 5 percent nitrogen, dry weight. Only about 10 percent of nitrogen in compost is available at application, and the remaining 90 percent in organic form is unavailable until mineralization occurs, releasing nutrients slowly over a long period of time.

Phosphorus is present in both organic and inorganic forms. The soluble phosphate is directly used by plant roots and the excess is strongly held to the soil particles. Proportion of phosphorus to nitrogen in sludge is higher by a factor of 5 or more than the proportion needed by a plant.

Sludge and softwood-bark compost with a pH of 6.0 to 7.0 increase pH of minesoils. Alkaline effluent has a flushing action on acid spoil leachate. It effects the greatest pH changes in the plant rooting or surface 6 to 12 inches, resulting in immediate significant increases.

Metals and certain toxic substances in sludge may be phytotoxic to plants. Some organic chemicals endanger the food chain after absorption and accumulation. Elements that are most likely present in concentrations toxic to plants are aluminum and manganese. On acid minesoils, metal concentrations may increase unless enough material is applied to effectively neutralize the acid spoil or raise it above the critical level of 4.0. There is little uptake of heavy metals by plants when pH is greater than 6.5.

Characteristics of sludge vary widely due to the great difference in type and source of wastewater and in the design and operation of wastewater treatment plants. Plumbing in buildings is cause for high concentrations of copper, zinc, and lead; greater amounts of metals are expected in wastewater from heavy machinery, battery, and plating industries. Sludge application rates should not cause heavy metal additions to land.

Excess nitrogen leaching into groundwater, presence of pathogens, and some odor are primary nuisances involved with land application of sewage sludge. Nitrogen in sludge is usually the factor that limits the amount to be applied. Rates should not exceed plant needs. If nitrate-nitrogen is applied or formed at a greater rate than it can be removed by plant uptake, denitrification, and microbial use, the excess nitrates are likely to contaminate ground or surface water.

For reclamation, rates may need to exceed those used on croplands. Two 1-inch applications per week are most commonly used for reclamation and supply about 10 pounds of nitrogen per acre. Two inches of sludge provide about 13 tons per acre, dry matter. An application of 2 dry tons per acre is equivalent to approximately 19,500 gallons or 1/4 inch of liquid. This liquid contains 2 to 45 tons per acre of solids with a pH of about 7.

Solids in dry form are applied much like animal manure. Dewatered sludge, which is 20 to 30 percent solids, is applied with a rear discharge truck or manure spreader. Septic tank wastes are applied to the land with a tank-truck injection system or by tank-truck surface spreader. Application should be in isolated areas at least 500 feet from nearest residence.

Slurries can be hauled directly to the field with a tank wagon or diluted with water and pumped to the area through pipeline irrigation equipment. Slurry eliminates dewatering and eases application by irrigation, but creates more material to transport. Additional energy and transportation costs for slurry need to be weighed against that for dewatering.

Liquid forms are applied by tank trucks, gravity flow, pressurized systems, surface sprayers, subsurface soil injection or sprinkler (spray) irrigation, and flood furrow. Spray irrigation provides the highest uniformity and is the most frequently used type of liquid application. It involves construction of distribution lines, either stationary or movable, pumping equipment, and storage lagoon.

Spray irrigation of treated sewage effluent helps to moderate surface temperature of dry minesoil by direct heat transfer to the water and cooling of the surface as it evaporates. In spraying, one has to be careful not to coat the leaves of plants with so much sludge that it interferes with photosynthesis and respiration. Sludge content of 6 percent solids is the limit for spraying. Sludges with over 10 percent solids do not flow by gravity through a 6-inch pipe.

Sludge should not be spread on slopes greater than 12 percent. If sludge is applied on slopes greater than 5 percent, material runoff should be retained by use of contour strips, terraces, and border areas. Liquid wastes usually are not spread on land where the erosion and runoff potentials are great. Good management implies that liquid wastes on rolling or hilly land should not be applied in excess of the infiltration capacity or in a volume greater than the surface layer can absorb and retain.

Wood-Cellulose Fiber

Type of material: Short fiber

Sources: Natural virgin wood-cellulose fibers produced from wood chips or recycled wood pulp.

Packaging: Bags, 50 to 60 pounds; bales, 800 to 1000 pounds

Availability: Manufacturers of commercial products made from above sources

Measurement: Ton, pounds (Air-dry weight)

Properties:

Form: Shredded

Size: 0.5 inch

Color: Natural or green (temporary dye)

Durability: Effective for 30 days after application

pH: Conwed, 4.8, turfiber, 7.0

Application:

Intended use: Pounds needed per acre - Seed cover: 1,500, Erosion control: 3,000

Methods:

Application: Hydroseeder mulcher

Anchoring: Chemicals used in special situations

Vegetative response: Wood-cellulose fiber contains no germination or growth-inhibiting factors. It is free from chemical additives and foreign matter that inhibit growth.

Comments: Wood-cellulose fiber mulches are usually either wood or paper fibers. Material is readily available and inexpensively produced from reprocessed wood-pulp chips or recycled paper products. It is available in bags or bales, which can be easily handled and conveniently stored for long periods.

Wood-fiber mulch is desirable where rapid mulching of an area is essential. It is considered comparable to straw or hay but does not last as long and is less effective in reducing surface temperature, conserving moisture, and in preventing erosion.

Effectiveness is roughly related to the size and shape of the fiber. Long, narrow fibers are superior to short, finely ground products. Wood fiber is longer and therefore more desirable than paper fiber. Virgin wood fibers of aspen, alder, or hemlock seem to last longer and are consistently superior to all other fibers. Recycled office wastes and newspaper are less effective but could be improved if fiber length was increased. Because it has long fibers, the waste corrugated box can be recycled into a product nearly equal to that of virgin wood.

Wood fibers are cut at a slight angle that allows splintering of fiber when weathering. Even with high application rates, short wood fibers break down very rapidly, and little mulch remains on the surface 8 weeks after application. This rapid decomposition reduces its efficiency in moisture conservation. However, no additional nitrogen is required for decomposition. Another mulch usually must be considered where surface protection is to be maintained more than 30 days.

Wood fiber and wood cellulose have equal value if applied at the same dry weight. They are free from chemical additives and foreign matter that inhibit growth.

The common application rate on slopes flatter than 4:1 is 1,500 pounds of mulch per acre and 1,500 to 2,000 pounds per acre on steeper slopes. This provides only minimal coverage with no consistent beneficial effect observed with less than 1,500 pounds and little or no benefit from 1,000 pounds. During periods of stress, 1,500 pounds of wood fiber is not as effective as 3,000 to 4,000 pounds of straw or hay. It takes 2,000 to 3,000 pounds per acre of wood fiber to produce a true mulch effect.

Wood-fiber mulch is mixed with water, seed, and fertilizer to form a slurry and is applied in a one-step operation with a hydroseeder mulcher. A 2,500-gallon hydroseeder with a 1,500-pound-per-acre rate can cover 0.6 acres per each load of material or about 4.8 acres per day.

The hydromulching process offers a high degree of control in placement. Material can be sprayed into inaccessible areas, notably steep slopes. It can be sprayed with good precision even in a strong wind.

Consistent uniform size and texture of mulch disperses uniformly and evenly on the surface. A nontoxic, water-soluble, green dye is used on the mulch to facilitate uniform distribution and to provide a pleasant finished look to the newly mulched area. Color fades in about 3 to 5 days.

When applied with seed, fiber-mulch applications are restricted to recommended planting dates for the seed mixture. There is evidence that fiber mulches may reduce the percentage of seeds germinating and slow plant growth. Hydromulch has a tendency to keep seed from making direct contact with mineral soil by leaving the seed suspended in the mulch where it is more susceptible to moisture stress during wetting and drying cycles. A high percentage of the seedlings have little or no chance of getting their primary roots into the soil. Higher seeding rates may be used to compensate for these losses, or the seed can be applied in one application and the mulch in a second application.

Slopes should be left rough before hydromulching to facilitate adherence of mulch to the soil surface. The fibrous mat of the mulch provides initial protection and resistance against erosion. However, it breaks down rapidly in heavy rain. Recycled paper-cellulose fiber does not hold seed in place as well as wood fiber and provides less erosion protection. On sandy soils, fiber mulch does not control wind erosion as efficiently as other materials.

In general, wood-fiber mulch does not develop better grass or legume starts than those on unmulched areas. Seedlings of legumes come in more slowly when applied in hydromulch. Cereal grain seeds are subject to germination damage if left in the tank in direct contact with concentrated fertilizer in suspension over 45 minutes before application. However, wood fiber is weed free, nonpolluting, clean, and biodegradable.

MULCH APPLICATION

Adherence to proper mulching rates and application procedures will greatly enhance success in establishing vegetation and in protecting the minesoil from erosion. In this section, information is discussed on surface preparation, application rates, time of application, methods, anchoring techniques, and equipment.

Surface Preparation

The finished minesoil surface must be suitable for vegetation establishment. Practices for preparing the minesoil surface for seeding are applicable to mulching since it is part of or immediately follows the seeding operation.

The landform design and the effects of backfilling, grading, and topsoiling the mined surface for reclamation should be carefully considered. Some design and construction practices produce surface conditions that are not always necessary or appropriate for applying seed or mulch.

Grading practices on some minesoils, especially those with a predominance of clay and silt particles, can actually hinder successful runoff control and vegetation establishment. Disturbing and grading wet or muddy minesoils or tilling and leveling dry material to a fine smooth finish alters the physical properties of the minesoil, creating compaction and other undesirable surface conditions.

Often, there is a tendency to unnecessarily finish, grade, or manicure the prepared surface. The surface should be left as rough as possible without disrupting the approved postmining land use. Contoured furrows, ripped strips, or other rough tillage are preferable to the smoothly graded and harrowed surfaces. A properly roughened, cloddy, and loosened surface will enhance mulch adherence; reduce evaporation; provide numerous depressions that will intercept and slow surface runoff and retain moisture; create ridges that protect against abrasion by windblown soil; and provide pockets that trap and hold sediment, improve water infiltration, and benefit plant growth.

Roughening of the soil surface by mechanical means with a large-particle mulch can, on some soils, completely stay wind and water erosion temporarily. Every stone, clod, unevenness of the ground, particle of mulch, or other obstacle in the path of wind or running water retards their movement and consequently the cutting and transporting capacity of these agents. The optimum variations in the height of the roughened surface for effective wind erosion control are from 2 to 6 inches. Coarse mulch in combination with a rough surface will almost eliminate wind surface creep. Additionally, a 3-inch ridge will trap about 60 percent of the flow in saltation.

Slopes should be designed and constructed as flat as economically possible. As slopes become steeper, erosion-control cost increases rapidly and the effectiveness and performance of control measures decrease. Where possible, slopes should be designed with gradients reduced to a degree that will provide mechanical stability with adequate rounding at both top and bottom and with appropriate transitional grading in between. This will improve appearance, facilitate vegetation establishment, and reduce maintenance costs.

The purpose of grading and shaping the slopes is to reduce the erosive forces of water and retain it on site for use by vegetation. On steep slopes, it is desirable to keep soils loosened, mulched, and if possible, somewhat ridged at right angles to the slope. All final grading and tillage should be performed on the contour; back blading that results in a smooth compacted surface should be avoided.

Application Rates

The selection of the optimum rate and depth of a mulch is influenced by intended use and the effectiveness of the mulch in modifying environmental factors associated with the site conditions. Soil and seed protection, erosion control, and growth enhancement are the main purposes for use of mulch and are the most logical components on which to base application rates (Table 10).

An important consideration in the efficient use of mulch is that of mulch depth in relation to application rate (Table 11). Also, the particle size and correct amount of mulch is directly related to the proper depth at which to apply the mulch. For example, 135 cubic yards of bark minichips will cover 1 acre 1 inch deep whereas it takes 160 cubic yards of chunk bark for the same coverage. Coverage with straw at 1-1/2 tons per acre provides about a 1-inch layer. The rate and depth of application varies due to the type of material and particle size.

Coarse and more bulky materials may be applied in greater depths than those of small materials that will compact. The selected material should be sufficiently loose and open for free circulation of air to favor development of vegetation.

Seed Bed Cover

The quantity of mulch needed at a specific site varies with soil surface and seeding conditions; species of plants to be seeded; and their requirements for germination, seedling emergence, and establishment. Therefore, mulch should be applied at a rate that will provide the necessary protection for the soil surface yet not prevent seed germination and emergence.

Cover mulches are usually applied at depths from 1/4 inch up to a maximum of 2 inches depending on the type and size of material (Fig. 8). Depths greater than 2 inches will begin to significantly affect germination and emergence of seedlings. The optimum depth of mulch for seed cover is related to seed size. If the mulch is too thick or tightly matted, the seedlings may not have sufficient energy to penetrate the layer. The smaller the seed, the less energy available to emerge. For small seeded species, such as lovegrass or timothy, emergence is likely to be reduced where they are covered with more than 1/2 inch of solid mulches such as bark. In situations where higher rates of mulch are needed or required, increase the seeding rates of species with small seeds to compensate for the reduced emergence, or select vegetation species with larger seeds that would be compatible with the higher rates.

Table 10. Common application rates per acre

Mulch	Intended Use		
	Seed cover	Erosion control	Plant mulch
Straw (ton)	1.5-2	3	4
Hay (ton)	2	3	4
Manure (ton)	10-15	30-40	40-60
Hardwood bark (cubic yard)	45	240	480
Softwood bark (cubic yard)	45	240	480
Hardwood chips (cubic yard)	50	268	536
Softwood chips (cubic yard)	50	268	536
Sawdust (cubic yard)	275	550	825
Leaves (ton)	3	4	5
Solid waste (ton)	20	---	---
Sewage sludge (ton)	75	---	---
Wood-cellulose fiber (pound)	1,500	3,000	---

Table 11. Coverage of mulch by depth and intended use

Depth (inches)	Intended use	Coverage per cubic yard[a] (square feet)
1/4-2	Seed bed cover	1,728-162
2-4	Erosion control	162-81
4-6	Plant mulch	81-54

[a] Coverage varies depending on particle size.

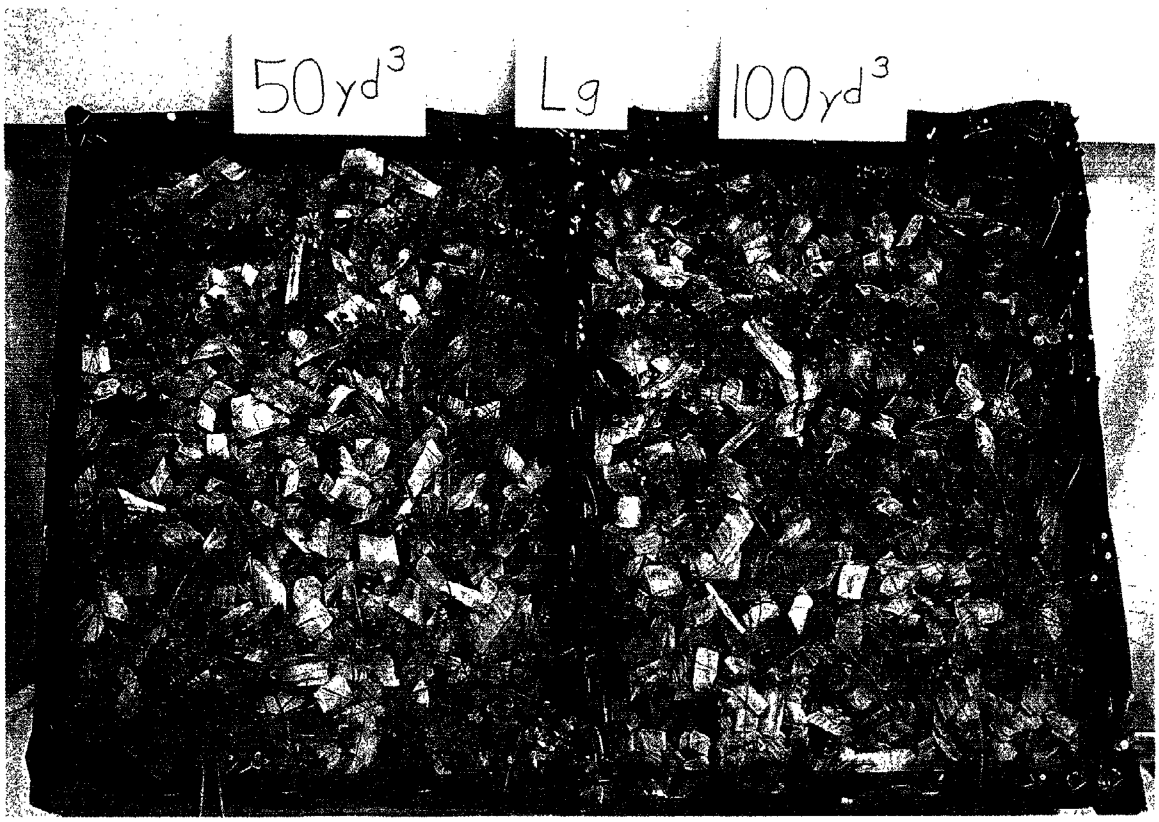


Figure 8.--Grass and legume emergence through large wood-chip mulch.

Compared to most of the grasses and legumes with smaller seeds, large-seeded species such as winter rye or sorghum will emerge through a greater thickness of mulch. Mulch depths of 1 inch or more have been used to cover large seeds. In a greenhouse study, it was found that bark mulch at rates of 50 to 100 cubic yards per acre (3/8 to 3/4 inch in depth) will have little adverse effect on the emergence of most grasses and legume species. At rates greater than 100 cubic yards per acre, emergence of most species will be reduced (Fig. 9).

In general, light applications of cover mulch are more desirable than heavy applications. However, if application is too light, the result is little or no improvement in soil protection, seed germination, and ground cover. Too much mulch may smother seedlings by intercepting all light or by forming a physical barrier that seedlings cannot penetrate. Heavy applications may prevent full circulation of the air which can lead to composting. The heat generated from composting kills the seed and prevents seedling growth.

Erosion Control

When mulch is to be used alone as a temporary erosion control measure, the quantity of mulch needed at a specific site varies with the shape, slope, aspect, and roughness of the minesoil surface. Thicker applications are usually needed on bare soils, in drainage ways, on topsoil stockpiles, or during the dormant season when seeding is not practical.

The mulch should be deep enough to protect and hold the soil surface. Increasing rate usually gives increased protection. So, on steep slopes, mulch is usually applied to a depth of 2 to 4 inches to satisfy stabilization needs. High rates of mulch provide little additional reduction in runoff flow but give greater surface protection from raindrop impact.

Crop residues applied at rates of 1.5 to 4 tons per acre on agricultural soils reduce erosion. Wheat straw applied at 2 tons per acre on a 20 percent slope decreased runoff velocity by approximately two-thirds or from 0.08 foot per second to 0.03 foot per second. Runoff velocity for a 1/2 ton per acre application is about half that for no mulch. Lower mulch rates effectively reduce erosion of fine sand but not silt-size particles. Although smaller rates provide lesser surface protection, they still help.

Plant Mulch

Heavier mulch application rates are required for plants than for seed cover to keep soils cooler for better woody plant growth and to control weed growth. For example, mulches for individual shrub or tree plantings and group or row plantings are usually applied from 4 to 6 inches deep.

The depth or thickness of the mulch to be applied will depend on the kind of mulch and the type of soil. Fine materials have better insulation properties than coarse materials, but when applied in a heavy layer, can affect aeration. When this happens, plants suffer. Thus, a mulch of sawdust should not be applied as thick as hay or bark. Additionally, a thicker layer of mulch can be applied to a light sandy soil than to a heavy clay soil. It is always necessary for air to reach the roots in the soil.

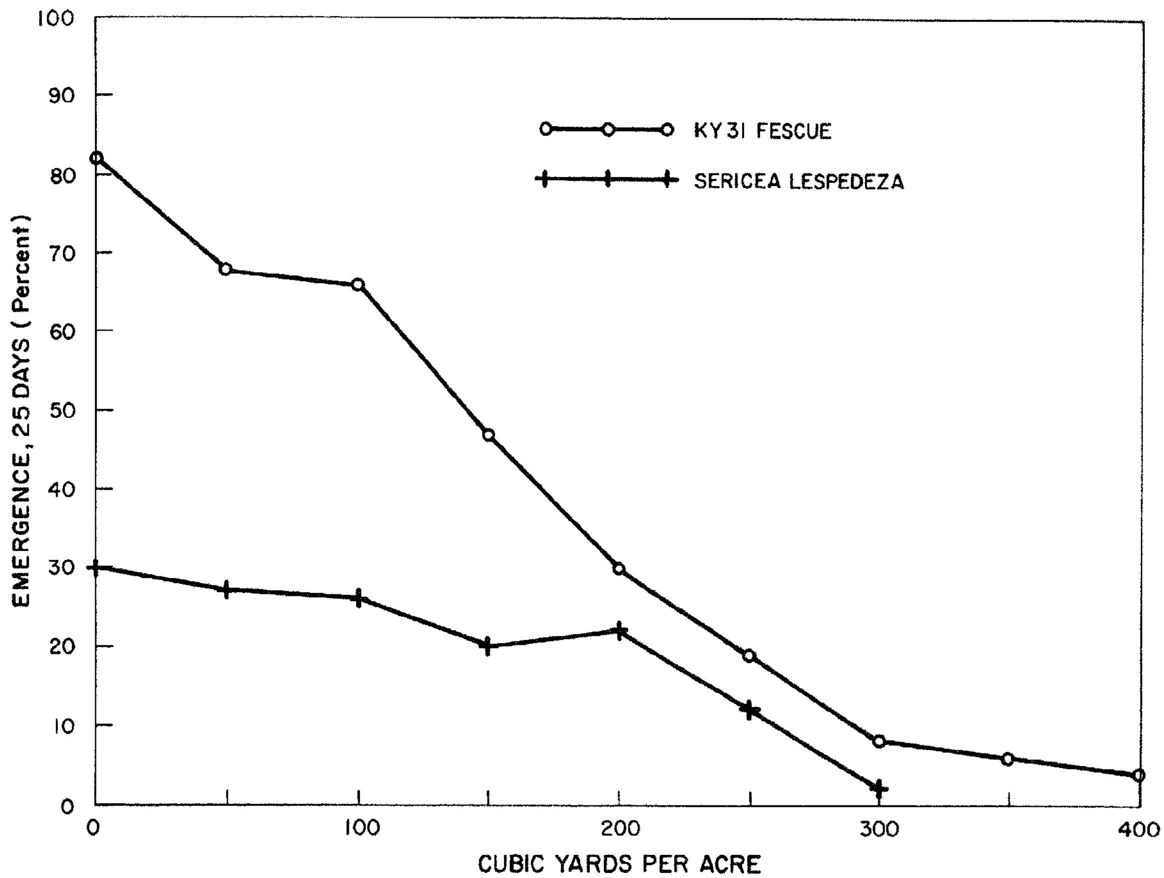


Figure 9.--Effects of rate of hardwood bark mulch on emergence of KY-31 fescue and *Sericea lespedeza*.

Site Conditions

Differences in site conditions, such as aspect, slope, weather patterns, and seasonal climatic variations, have an influence in determining a range of effective mulches and application rates. Aspect affects the choice of mulch color and dictates depth of application. The color and uniformity of mulch depth are critical because they have varying effects on establishment and growth of vegetation.

Adverse effects are usually related to seasonal variations in moisture and temperature. Because of this, mulch rates must vary. A site with a north-facing slope usually requires less mulch for a particular purpose than a south-facing slope. In the spring on gentle north- and east-facing slopes, thin, light applications of a dark-colored material may be necessary to raise surface temperatures to speed up germination, but at the same time must be heavy enough to protect the soil surface and slope from seasonal precipitation.

If conditions are severe, such as those frequently encountered on harsh sites, steep slopes, or south- and west-facing slopes, mulching rates are usually increased. In summer seeding on south and west slopes, heavy rates of light-colored material may be necessary to reflect solar radiation, to reduce evaporation, and to lower midafternoon temperatures that affect seed mortality and optimum plant growth. In the fall and winter, heavy applications of dark-colored material may be necessary to insulate soils and plants subject to frost heaving. Different mulch colors and rates are usually associated with north and south slopes, long and short slopes, and steep and moderate to level areas. For example, 30 cubic yards per acre of bark mulch would be used on a gentle, cool slope, while 50 cubic yards per acre might be necessary on steep, hot slopes.

Time of Application

Mulching materials can be applied at any season of the year depending on conditions of minesoil and weather at time of treatment and the intended purpose for which mulch is being applied. Usually mulch is spread immediately after seed and fertilizer have been applied, unless it is part of a hydroseeding operation.

Under most circumstances, it is essential that seeding and mulching take place shortly after the earth-moving and grading process so that both the actual disturbed area and the length of time it is exposed are kept to a minimum. If reclamation takes place at a time when seeding is least desirable (summer, late fall, and winter), mulches may be used to temporarily stabilize the soil until seeding can be done at a more favorable time.

Climate and Soil Conditions

The temperature and amount of rainfall at time of application will affect site conditions and influence the efficiency of the mulch material. Thus, sensitive field operations must be scheduled according to local weather patterns and conditions before, during, and after application.

In some areas, adverse weather and soil conditions may hinder access and on-site travel. To spread solid or liquid mulches, soils must be dry enough to support machinery and avoid soil compaction. In early spring, the ground is often too wet; mud can impede the operations of both seeding and mulching. Mulching can be done in the spring after the immediate surface soil has dried out.

Spreading of animal, municipal, and industrial sewage wastes should be avoided when runoff or leaching potential is high. Even though wet ground does not interfere with liquid application, the extra water could result in greater nutrient leaching and runoff losses.

Caution should be used when applying mulches to steep frozen or snow-covered ground. When applied under conditions leading to maximum spring snowmelt runoff, large amounts of organic materials or potential pollution can be transported from the land.

Wind direction and velocity can be limiting factors in sprinkler or spray and blower applications. They can cause uneven surface coverage and carry dust, mist, or unpleasant odors from material into areas of habitation.

Mulch Use and Seasons

Moisture and temperature regimes dictate the proper planting and mulching season and strongly influence results of mulching. Mulching for soil protection and seed cover should be scheduled so that moisture and temperature conditions are sufficient to germinate the seed and maintain seedling growth before adverse conditions occur. In addition, the application of mulch can extend the seeding season and make more effective use of existing and future moisture. To do the most good, mulches should be applied well in advance of spring rains, active weed growth, and summer drought.

If the intended use of the mulch is primarily for erosion control, proper timing of mulch application depends on the potential for loss of soil. Logically, then it will be timed to most benefit soil surface protection.

Materials used as plant mulches should be applied before active weed growth starts. If allowed to gain a strong foothold, weeds rob the plants of needed light, moisture, and nutrients. In summer applications, modifying the environment is most important because of the need to provide weed control, insulation, and shading. Applications in conjunction with fall planting of tree seedlings should be done well before the ground freezes. This will avoid alternate freezing and thawing that often results in seedlings being heaved out of the ground.

The proper time for seeding, planting, and mulching will vary from one region to another in the East and with the species to be planted. In some areas, there are several appropriate times for seeding and planting. The advantages and disadvantages of these planting periods should be known.

From a moisture and temperature standpoint, April, May, June, and late August, September, and October are the best times to seed and mulch. In most regions, weather patterns favor early spring seeding for cool-season species; fall seeding may produce the greatest success in other areas. For example, in western Kentucky, fall seedings are more successful than spring seedings because spring sown plants sometimes drought out during late spring and early summer. Early to midspring is normally the best time to sow perennial and some annual warm season species. Midspring to early summer is the best time for seeding most summer annuals. For example, spring seeding period in Illinois may extend from about March 15 to May 1 but in Alabama it may be February 1 to March 15. Similarly, recommended dates for late-summer and fall seeding are July 15 to August 20 in Pennsylvania, whereas August 15 to October 15 is suggested in Kentucky. Recommendation for best seeding and mulching dates in a given region can be obtained from local farmers and agricultural service agencies.

In areas with hot, dry summers, seeding in late spring and summer can be risky and is not recommended unless the area is mulched. In these areas, materials and rates superior for conserving moisture and moderating high air and soil temperatures are used to enhance germination and the establishment of seedlings.

In some regions, summer rainfall is usually sufficient to establish warm season annuals in late spring to midsummer without the benefit of mulch. Occasionally, summer precipitation is adequate for establishment of cool and warm season perennial species as well. Thus, where mining is completed in late spring and summer and the site is ready for reclamation, it should be seeded and mulched as soon as possible after grading is completed.

In late summer, it is desirable to mulch and establish sound vegetative cover before the fall rainy season or before winter to avoid soil and seed losses. In the fall, applications provide cold-weather protection with major influence on temperature and erosion control in winter and spring. Prolonged soil stabilization during winter is imperative since protective vegetative cover is not likely to be attained until spring. Winter mulches must be resistant to hard freezing and thawing conditions. Winter seeding is not required or recommended, though mulching areas that are ready for seeding may help control erosion during the winter. Adverse weather and spoil conditions, however, may hinder access and travel on mined areas.

Application Method

Uniform application of the mulch is critical to effect complete and even vegetation. Incorrect rates and distribution of the mulch material can impair the soil surface, delay seed germination and development, degrade the quality of surface and ground water, and evoke nuisance complaints from neighboring property owners.

Organic materials should be placed on soils in accordance with sound locally approved soil and water conservation practices. Such practices minimize the extent to which components of the material enter surface and ground water. They also minimize odors and provide for application to soils that will benefit the most.

Methods of mulch application vary depending on form of mulch material and type of equipment and labor available. The method of application chosen depends on whether the mulch is fibrous, solid, or liquid as well as on its particle size, weight, and composition.

Uniform distribution at the desired rate and depth is essential. Poor distribution may impair seedling growth or leave part of the surface inadequately protected. Depth is somewhat difficult to control because of uneven surfaces. However, an absolute even depth of mulch is not necessary as long as an average depth is obtained over the site. Mulching rates should be determined before the mulching operation and the equipment carefully calibrated to achieve the desired results. Commercial fiber mulches are often dyed with nontoxic fugitive green dye so that they are plainly visible when applied, aiding the operator in obtaining uniform coverage.

Currently, mulches are spread manually and mechanically with either of three spreading mechanisms: rotary, pneumatic, and hydraulic. All three mechanical application systems can be used in spreading various fibers, though solids are usually applied with a rotary spreader or pneumatic blower and some fibers and liquids with hydraulic spray. All types of mulch can be spread by hand.

Manual Application

Spreading or broadcasting mulch by hand is generally used in hard-to-reach, small (1 to 2 acre) areas, on harsh sites or steep slopes beyond the reach of a blower or hydraulic spray; and around trees and shrubs. The method is difficult, tedious, time-consuming, and costly even on small areas.

It is difficult to spread fiber evenly by hand, though leaves may be spread easily. Unchopped fiber spread by hand remains in place and is more effective than chopped, yet the manual labor required for such spreading is costly.

Mechanical Application

Many types of mulch material are applied uniformly by mechanical means. Physical characteristics of the mulch may be such that specialized equipment must be used if it is to be spread efficiently and economically. Rotary pneumatic or hydraulic application requires products that are uniform in size and preferably free of trash, dirt, and dust.

Rotary Spreaders.--Mulching with rotary spreaders is common and involves the application of dry, fibrous and heavy, solid mulch by using a combination of conveyors, augers, rotary beaters, paddles, flails or centrifugal bladed disks, or spinners to broadcast the mulch to the rear or to one side of the machine. Lime/fertilizer spreaders, municipal spreaders, manure spreaders, modified stack processors, and tub grinders are conventional and modified equipment available in this category. Rotary spreaders are driven or pulled and work well on benches, terraces, and level or moderately rolling terrain adaptable to typical agricultural implements. Usually only two people are required on a rotary spreader operation. A third may be necessary if the mulch has to be tacked.

Pneumatic Spreaders.--This method uses an airstream to dispense mulch. Dry fibers or solid mulch materials are blown out of a discharge chute onto an area using air pressure generated by a motor-driven, high-pressure, paddle-wheel fan. An impactor is provided on some machines as an additional force to more efficiently propel heavier material. Some machines are equipped to spray a chemical adhesive (tackifier) on the mulch as it leaves the discharge spout.

Fiber is spread more easily by blower than by hand. A blower shreds, cuts, and evenly spreads or scatters fibrous material. The mulch lies down in closer contact with the soil than does hand-spread fiber. A fine-stemmed, baled, fiber mulch is preferable to a loose mulch for pneumatic spreading.

Wood fiber or cellulose can be applied with a blower but application in this manner leaves much to be desired. Leaves even when damp can be spread with a pneumatic spreader. Power mulchers and the Estes spreader are conventional and modified equipment available in this category.

Pneumatic spreaders provide the ability to cover inaccessible or steep slopes. They are drawn or driven along a road, terrace, or bench above or below the slope to be treated. They enable mulching of steep slopes without the water required for hydromulching.

Four people are usually required to operate pneumatic spreaders efficiently with a possible fifth person needed when it is necessary to tack the mulch.

Hydraulic Spreader.--Hydraulic spreaders are used to apply wood fiber and cellulose. Tank trucks with gravity or pumped discharge and various forms of sprinkler/irrigation are used to apply slurry and liquid sewage wastes.

Spray applications are used most successfully with wood fiber or cellulose mulches applied with a hydraulic seeder, more commonly called a hydroseeder or hydromulcher. The main advantage of the hydraulic spray method is that mulch can be applied to areas that cannot be easily reached by other methods. The spreading distance is as much as 200 feet from the machine depending on efficiency of the machine and wind conditions.

The system is popular because of ease of application and because all materials needed for revegetation can be applied in one pass over the area.

Disadvantages of the hydraulic spray equipment are that only a relatively small area can be treated with each load of material and a source of water must be readily available near the mulching job. A considerable amount of time may be required in transporting or pumping water.

Liquid and slurry sewage waste are applied by self-propelled sprinkler irrigation equipment, such as a center pivot or a portable or traveling gun, which has a single large nozzle (3/4 inch to 2 inch orifice) with 80 to 100 psi pressure. With the traveling gun system, a large single sprinkler on a carriage is winched across the area, pulling a flexible hose through which sludge is pumped. An aerosol drift problem may occur with high pressure sprinkler systems. Spray irrigation may involve the construction of distribution pipe lines (either stationary or movable), the installation of pumping equipment, and time-cycle devices.

Mulch Anchoring

It is essential that some mulches, such as cereal crop straws, hay, leaves, wood fiber and cellulose, and other lightweight fiber materials, be anchored to the soil surface to assure protection of the soil. Some can be anchored as they are being applied. Where this is not possible, they should be anchored with a tackifier, such as asphalt, immediately after placement to minimize loss or movement. Coarser aggregates such as shredded bark have interlocking pieces that have a tendency to stay in place even on steep slopes.

Size of area, mulch material, cost, and effective life of required treatment should determine the anchoring method to be used. Whatever method is selected, it should effectively hold the mulch in place until vegetation takes over. The basic methods of anchoring mulches are manual, mechanical, and chemical.

Manual Anchoring

Manual anchoring is most applicable on small or critically sloping areas. It involves manually tying the mulch down with stakes or pegs, twine, string netting, or wire mesh. If stakes are used, they are driven usually on five foot centers with twine strung between stakes to form square, diamond, or cross patterns over the surface of the mulch. A variety of nets and mesh have been used including jute, baling wire, wire poultry netting, concrete reinforcing wire, chain link fencing, plastic fabrics, and twisted woven kraft paper (Fig. 10). Nets and mesh should be anchored at enough points to prevent material from curling or whipping in a wind.

Mechanical Anchoring

Mechanical anchoring is the pressing of a fiber mulch into the soil by crimping, discing, or rolling. The average length of blown mulch fiber should be 6 inches and incorporated to a depth of 1-1/2 to 3 inches, which is sufficient to anchor but not bury it. Properly placed fibers should create a stubble effect that provides an excellent obstruction for wind saltation and surface flow (Fig. 11). Straw, unless crimped, tends to perch rather than bind with the soil, allowing rilling even on gentle slopes. Fiber crop residue used for mulch should be new and pliable because excessively dry or rotten mulch is easily broken or cut in two.

Machines for anchoring operate most efficiently on relatively level or moderately rolling land with slopes less than 3:1. On steep slopes, where machines are not suitable, mulch should be anchored with nets, mesh, or a chemical tackifier.

Crimping is accomplished with a specially designed crimper or with a conventional farm disc. These machines work best if the soil has been scarified to a depth of 4 to 6 inches during seedbed preparation because the blunt notched disks will not penetrate hard soil.

Rolling or punching is done with a specially designed pronged roller. A conventional sheeps-foot roller may be used on light soils. Punching may not be as effective as crimping because of the staggered arrangement of punched mulch compared to the "whisker dams" made by crimping.

Figure 10.--Plastic netting.

Figure 11.--Straw mulch anchored by crimping.

Chemical Tackifier

Tackifiers are organic and inorganic chemical products applied in water solutions to lightweight mulches to hold them in place. Chemical tackifiers can be added to the mulch as it is being applied. Adhesive injectors can be mounted at the mouth of the discharge chute to coat the mulch as it is ejected. Alternately, hydraulic sprayers can be used in a separate operation to cover the mulch after it is on the ground.

Numerous chemical stabilizers are available. However, there is insufficient knowledge about the comparative value of different products and about the most effective application rates for specific materials. Two broad classes of chemical stabilizers are recommended as tackifiers: polyvinyl acetate emulsions and acrylic copolymer emulsions. Recommended application rates are 25 to 50 gallons per acre. A dilution rate of 1:10 to 1:20 (1 part stabilizer to 9 or 19 parts water) is suggested.

The most commonly used chemical tackifier in the Eastern United States is asphalt emulsion at a rate of 600 to 1,200 gallons per acre. Caution must be exercised in using asphalt because it may retard germination and lower seedling start. Some plants react negatively to asphalt, while others react positively. Asphalt softens in hot weather and can be a sticky nuisance if allowed to drift onto traffic areas. Its black color helps increase soil temperature which may help to encourage growth in cool weather. Asphalt adhesives for application with mulch are usually liquid asphalt conforming to American Society for Testing and Materials (ASTM) Specifications D2028, designation RC-70 or emulsified asphalt conforming to ASTM Specifications D-77, grade SS-1. The specifications used by the Soil Conservation Service are:

1. Liquid asphalt rapid curing (RC-70, RC-250, or RC-800) or medium curing (MC-250 or MC-800). Apply 0.1 gallons per square yard.

2. Emulsified asphalt (SS-1, SSk, SM-K, MS-2, RS-1, RS-2, RS-2K, or RS-3K). Apply 0.04 gallons per square yard.

Rapid setting (RS) is formulated for curing in approximately 24 hours. Slow setting (SS) is formulated to allow adequate working time during dry hot weather. A higher number in the formula indicates a heavier residue. Emulsion can be applied either as a separate spray over the mulch or simultaneously with the mulch using the injection method. Some materials are applied from the top of a slope down with blowers equipped to spray a chemical tack on the mulch as it is being discharged. Application from the toe of a slope upward can create small dams that pond water on the surface of the mulch, causing some slumping, especially where the mulch helped maintain moisture at field capacity. Asphalt is nonporous, causing surface water to run off, but conserves moisture underneath it.

Chemical stabilizers also are used in combination with wood fiber and wood cellulose mulches more frequently than stabilizer alone. Assuredly, site protection obtained with low rates of the combined material is comparable to that obtained with high rates of either product used alone. A combination recommended and used in some eastern states is: 50 gallons per acre of stabilizer mixed with a minimum of 500 pounds per acre of wood fiber or wood cellulose.

Because they can be applied with a hydroseeder, chemical stabilizers have an advantage for tacking mulches on long steep slopes and other hard-to-reach places.

It is not feasible here to list all of the chemical tackifier products presumably available or to rate their comparative values. They are costly and usually require more precise preparation and procedural placement control than mulches. For those interested in using chemical tackifiers, advice should be sought from research reports on their use or from reclamation companies, highway departments, and conservation agencies that have had experience with their use. Sales promotions are not always reliable sources of information.

Fiber.--Wood fiber or wood cellulose alone or premixed with chemical tackifier can be used as a short-term adhesive. The strength of the bond and the effective life of the treatment depend on the amount of the tackifier applied; the higher the rate, the greater the effectiveness.

In experiments, a straw mulch tacked with 700 pounds per acre of wood-fiber mulch by the hydro method served as a good mulching combination with better results than many of the binder or tacking agents (Fig. 12). Additionally, a very fibrous type of shredded hardwood bark mulch applied and held in place with emulsified asphalt may produce a mulch equal in effectiveness to sodding or jute matting for controlling erosion.

Application Equipment

A variety of equipment has been developed or adapted to aid mulching and anchoring. Conventional implements are used in normal operations, and specialized equipment is required on large areas and steep slopes. Usually, heavy-duty implements will be more useful and require less maintenance than light- and medium-duty machinery.

In selecting equipment, consideration must be given to the type of terrain to be covered, the size of the area, the cost of labor, and support equipment needed to service and operate conventional application equipment efficiently. For example, wheel-type equipment cannot be used on very steep slopes (3:1 or less). Therefore, the equipment selected must be adaptable to a travelway, a bench, or have the spray capability and range to cover hard-to-reach areas. Good mulching and revegetation jobs are achieved through use of the right equipment and not by attempting to economize with makeshift equipment. The increased success obtained will more than offset equipment costs.

Equipment companies continually are redesigning and modifying standard equipment or developing new equipment. Researchers, as well as mining and reclamation companies, continue to develop equipment designed to meet specific reclamation needs.

As an aid in planning mulching treatments and selecting suitable equipment, the most recent information on the following equipment designed or adapted for preparing and applying mulch has been assembled:

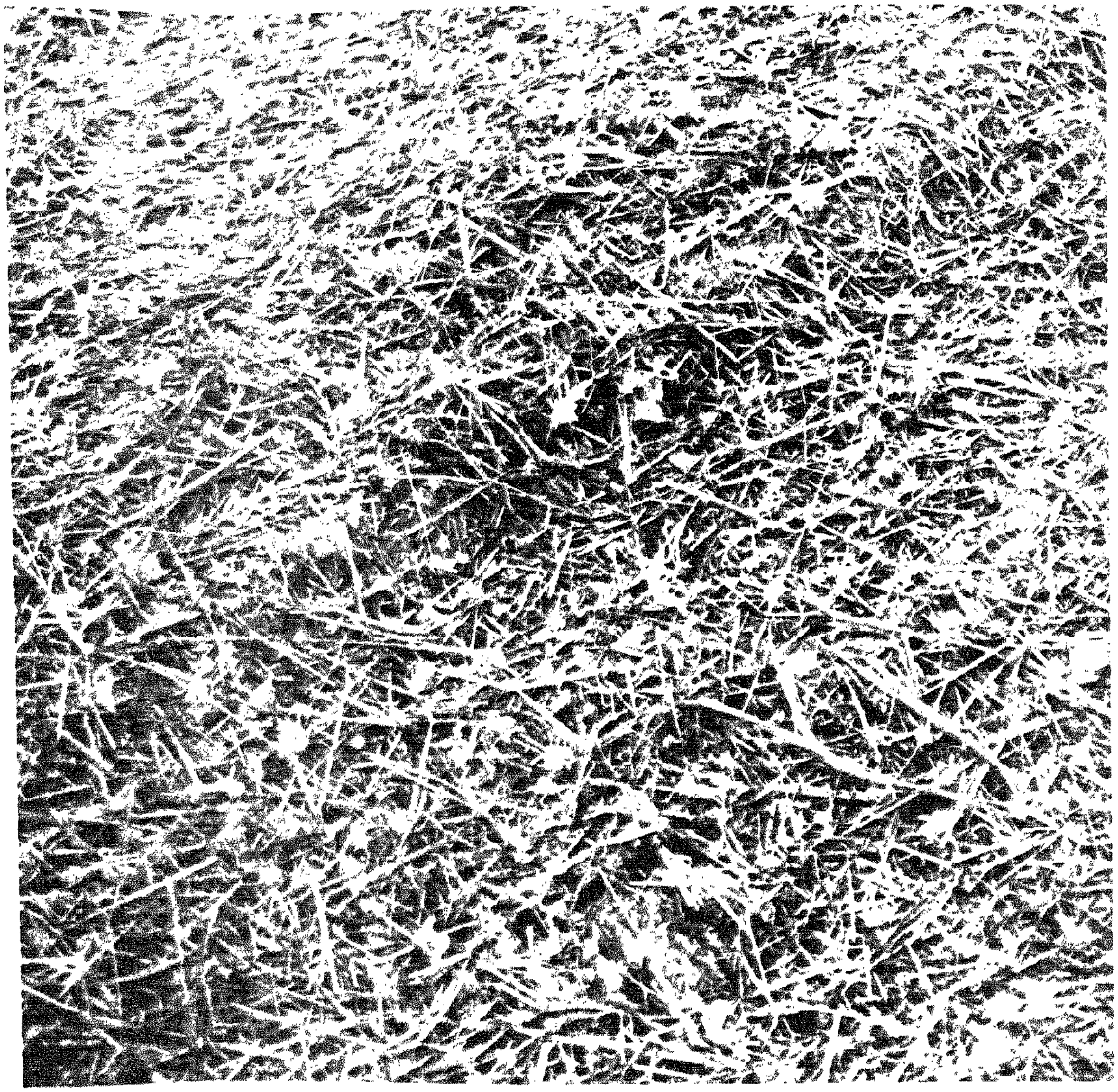


Figure 12.--Hydromulch fibers over straw mulch.

Spreaders

Rotary

Lime/fertilizer/sludge
Manure spreader
Modified stack processor
Roto-grind mulcher

Pneumatic

Power mulcher
Estes blower/impactor

Hydraulic

Seeder/mulcher
Tank truck
Irrigation sprinkler systems

Anchoring

Manual

Stakes
Twine
Netting
Wire mesh

Mechanical

Disc
Krimper-Finn
Roller

Chemical

Power mulcher
Hydraulic sprayer

Essential facts are provided on the structure and operation of equipment, including its function, description, techniques for use, capabilities and limitations, general specifications, labor and equipment requirements, and sources of supply. Most of the equipment described and illustrated is commercially available. In some areas, various equipment may be available on a rental basis.

Fertilizer Spreader

Function.--Fertilizer spreaders distribute dry solid material over large, level, or moderately rolling terrain. They have large capacities and adjust for a variety of application rates. Materials that can be spread with this equipment are lime, fertilizer, shredded or chunk bark, sawdust, wood chips, corncobs, composted municipal wastes, or dewatered sludge.

Description.--Fertilizer spreaders are usually mounted on trailers, trucks, or high flotation equipment. They have large hoppers with sloped sides. The sides converge on a steel mesh or rubber conveyor belt that moves the material to the rear of the hopper and drops it onto one or two rotating, bladed disks or spinners. The spinners and conveyor belt are usually powered hydraulically or with power-take-off (PTO) from a tractor. The conveyor belt is sometimes wheel-driven. Agitators placed above the conveyor belt ensure a continuous flow of material (Fig. 13).

Techniques.--The fertilizer spreaders are driven or pulled over the area to be treated. The application rate is controlled by the size of the rear hopper opening or the speed of the conveyor belt. The spinner is kept constant for even distribution over the swath.

Capabilities.--Fertilizer spreaders have large capacities and are adjustable over a variety of spreading rates. Most types of dry amendments can be spread with them.

Limitations.--Fertilizer spreaders are not suited to rough or very steep land. They are most useful where amendments are spread rapidly over large areas.

Specifications.--High flotation or truck mounted

Pattern width: 24 to 60 feet

Hopper capacity: 5 to 14 cubic yards; 5 to 17 tons

Labor and Equipment.--This machine requires one person to operate the prime mover, a second to operate front-end loader for loading material on site, and a third when mulch requires tacking.

Availability.--High flotation or truck-mounted:

Ag chem Equipment Co.
4900 Viking Dr.
Minneapolis, MN 55435
(612)835-2476

Big Wheels, Inc.
Box 113
Paxton, IL 60957
(217)379-2369

Dempster Industries, Inc.
Box 848
Beatrice, NE 68310
(402)223-4026

Henderson Manufacturing Co.
Box 40
Manchester, IA 52057
(319)927-2828

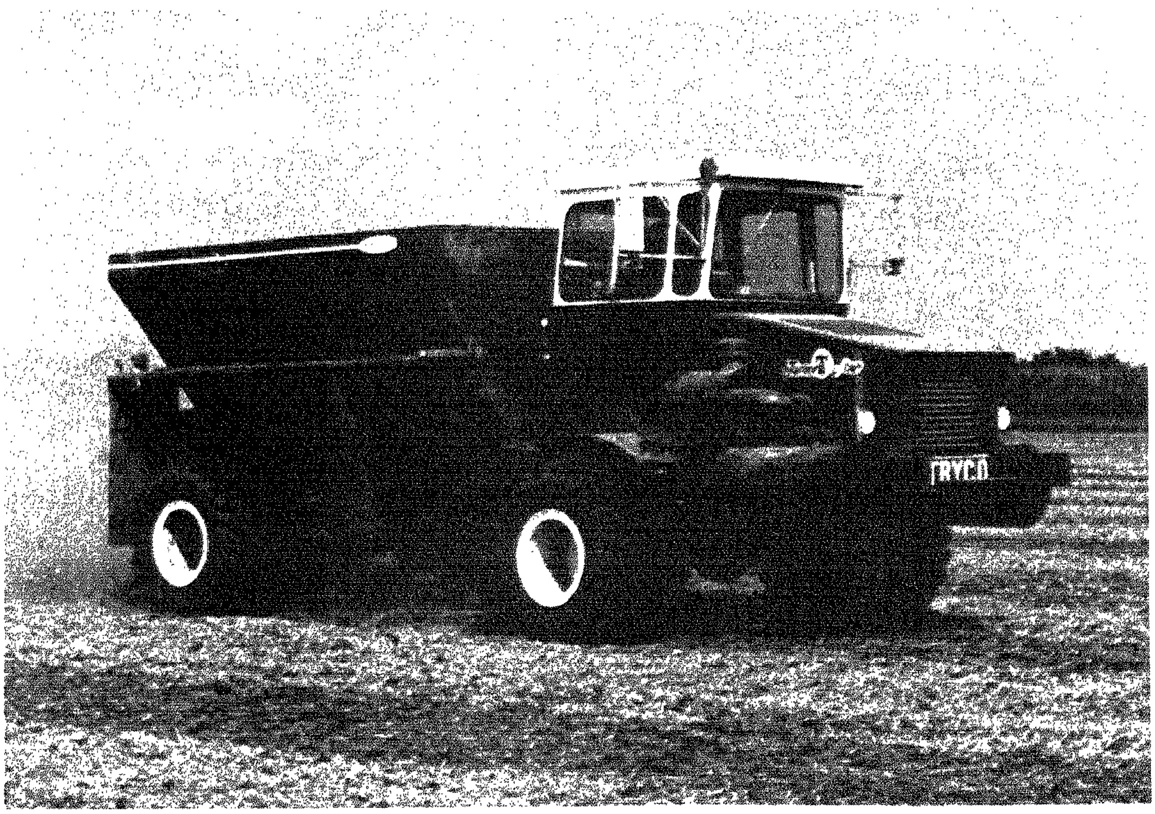


Figure 13.--Truck-mounted fertilizer spreader.

Highway Equipment Co.
616 D Avenue NW
Cedar Rapids, IA 52405
(319)363-8281

John Blue Co.
Box 1607
Huntsville, AL 35807
(205)536-5581

Lakeside Truck Body Co.
Box 1104
Turlock, CA 95380
(209)632-7501

Rickel Manufacturing Co.
Box 626
Salina, KS 67401
(913)825-1631

Tryco Manufacturing Co.
Box 1277
Decatur, IL 62525
(217)428-0901

Tyler Division
TCI, Inc.
Benson, MN 56215
(612)843-3333

Wilmar Manufacturing Co.
Box 957
Wilmar, MN 56201
(612)235-0767

Manure Spreader

Function.--Manure spreaders are used to distribute heavy solids over an area.

Description.--Manure spreaders are large, open trailers or trucks with conveyor beds. The spreading mechanisms located at the rear of the spreaders consist of beaters, paddles, or flails which rotate at moderate speeds forcibly ejecting the material. The spreading mechanisms and conveyor beds are usually powered through PTO attachments. Auxiliary beaters are often located above the spreading mechanisms to aid the flow of material through the spreaders. A modified manure spreader has been specially developed to distribute mulch over surface-mined land. Blueprints for modifying the spreader are available from the Equipment Development Center, U.S. Forest Service, Missoula, Montana (Figs. 14 and 15).

Techniques.--The spreaders are towed or driven over the areas to be treated. The conveyor moves the material to the rear of the spreaders where it is ejected by the rotating beaters, paddles, or flails. Discharge rates can be varied by adjusting the speed of the conveyor bed.

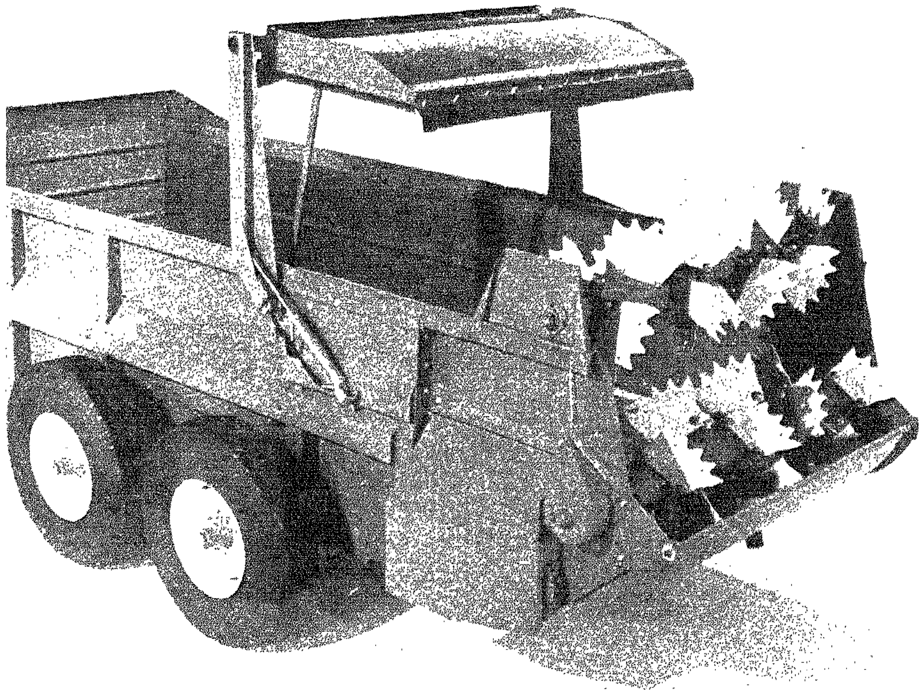


Figure 14.--Standard manure spreader.

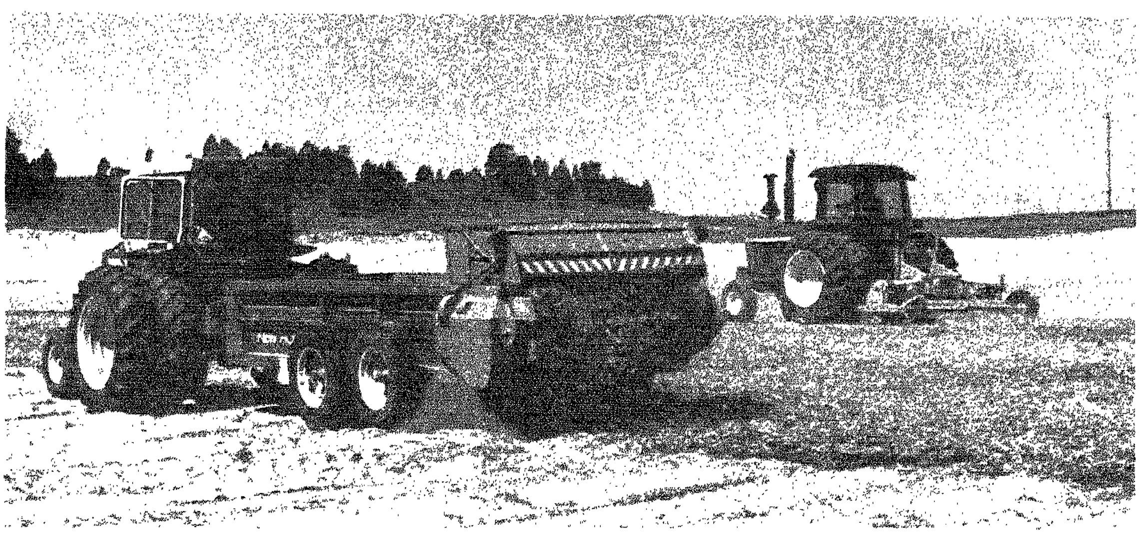


Figure 15.--Manure spreader modified to apply straw mulch.

Capabilities.--Manure spreaders can handle and distribute almost any type of mulch, including animal wastes, straw, hay, caked sewage sludge, leaves, sawdust, bark, and wood chips.

Limitations.--The operation of manure spreaders is limited to gently to moderately sloping terrain. Uncomposted manure is difficult to distribute evenly. Baled fiber tends to fall in bunches unless it is cut or shredded for scattering.

Specifications.

Capacity: 64 to 360 cubic feet (2.8 to 18 tons) level full

Overall width: 6.5 to 11 feet

Power requirements (drawbar): 30 horse power, minimum

Labor and Equipment.--This machine requires one person to operate the prime mover. A supply truck and driver can be used to deliver material to the machine in the field.

Availability.

AVCO
New Idea Farm Equipment
420 South First Street
Coldwater, OH 45828
(419)678-5311

Big Wheels, Inc.
Box 113
Paxton, IL 60957
(217)379-2369

Blair Manufacturing Co.
929 East Washington
Blair, NB 68008
(402)426-2151

Deere and Co.
John Deere Road
Moline, IL 61265
(309)752-8000

Du-Al Manufacturing Co.
1000 West Cherokee Street
Sioux Falls, S D 57104
(605)336-3869

Farm Hand, Inc.
525 15th Avenue South
Hopkins, MN 55343
(613)938-7651

Ford Tractor Operations
2500 East Maple Road
Troy, MI 48084
(313)643-2000

Gehl Company
143 East Water Street
West Bend, WI 53095
(414)334-9461

Hawk Bilt Company
402 East 6th Street
Vinton, IA 52349
(319)472-2313

International Harvester Co.
Agricultural Equipment Division
401 North Michigan Avenue
Chicago, IL 60611
(312)836-3874

Schultz Manufacturing Co.
Box 388
Waterloo, IA 50704

Schwartz Manufacturing Co.
Box 248
Lester Prairie, MN 55354

Sperry New Holland
500 Diller Avenue
New Holland, PA 17557
(717)354-1121

United Farm Tools, Inc.
Box 9175
South Charleston, W V 25309
(304)768-8221

Modified Mulch Spreader:

Drawings (No. 611) and information can be obtained from:

USDA
Equipment Development Center
Bldg. 1, Fort Missoula
Missoula, MT 59801
(406)329-3157
FTS 585-3157

Modified Stak Processor

Function.--A Hesston Stak Processor modified with a flail device is used to distribute straw or hay mulch from 1,500-pound round bales.

Description.--The Stak Processor was designed to lift, transport, and shred large round bales of hay and to distribute it in windrows for cattle feed. The implement consists of a four-tine, hydraulic bale-pickup and a shredder and auger powered by PTO.

The modification or MacFarland flail consists of a standard hydraulic motor with four reinforced rubber-belt flails and a stabilizer mounting bracket attached underneath the side opening of the Stak Processor. The flail hydraulics are independent of the bale pickup and allow the flail speed and direction of rotation to be controlled from the tractor (Figs. 16 and 17).

Techniques.--The pickup tines slide under the bale and are tilted up, forcing the bale into the shredders. The shredders break apart the compacted straw or hay and deliver it to the auger. The auger forces the material out the side of the machine into the MacFarland flail.

The flails intercept the mulch material from the Stak Processor discharge and distribute it over a wide area. Flail speed should vary inversely to the tractor speed for uniform distribution. Flail direction is clockwise, except when strong winds are blowing from the rear of the unit or into the discharge chute.

Capabilities.--Picking up and distributing large round bales becomes a simple, one person task with the modified Stak Processor. The speed and direction control of the flail unit allows uniform distribution of mulch under most conditions.

Limitations.--The modified Stak Processor is not suited for steep or rough terrain.

Specifications.

Capacity: 3,000 pounds

Flail speed: 100 to 1,000 revolutions per minute

Power-take-off (PTO) speed: 540 revolutions per minute

Power requirements (drawbar): 40 horse power minimum

Labor and Equipment.--One person is required to operate the prime mover for the machine.

Availability.

Stak Processor:

Hesston Corporation
Box 788
Hesston, KS 67062
(316)327-4000

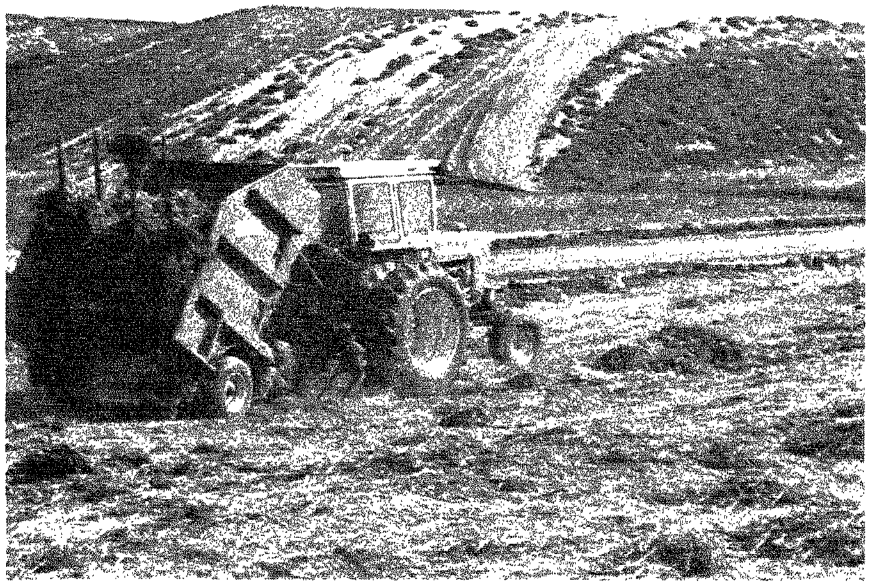


Figure 16.--Hesston Stak Processor with MacFarland flail to distribute straw mulch from round bales.

Figure 17.--MacFarland flail.

MacFarland Flail:

Western Energy Co.
Box 67
Colstrip, MT 59232
(406)748-2366

Tub Grinder--Mulchmaster

Function.--The Roto Grind Mulchmaster spreader applies wet or dry fiber and solid mulch, such as large (1,500 pounds) round or standard square hay or straw bales, and other types of crop residue, shredded or chunk bark, wood chips, or most any other organic material.

Description.--The Mulchmaster is a modified rotary tub grinder. A large tub-shaped hopper is mounted at the top of the machine over four sets of hammers mounted on a flywheel-type rotor. The hopper revolves, using prime mover hydraulics, and shoves the mulch material into the rotating hammers that tear the material apart and blow it out the discharge located on the left side of the machine. An adjustable riser works in conjunction with the hammers to control the amount of material that is discharged per revolution of the hopper. The direction of flow of material can be controlled upward or downward by two adjustable plates on the discharge (Figs. 18 and 19).

Techniques.--The Mulchmaster is towed over the area to be treated. Loose material or bales of mulch are dumped into the hopper with a front-end loader. The rotary tub feeds the material into the mulching rotor where it is ejected by the rotating hammers. Ground speed of the unit, plus rotational speed of the tub and rate of flow, determine the amount of mulch applied per acre.

Capabilities.--The Mulchmaster spreader is useful for highway roadside stabilization and surface-mine reclamation. The spreader is designed to efficiently distribute almost any type of wet or dry organic material.

Limitations.--The Mulchmaster spreader is limited to accessible areas and to moderate slopes. Wet material can be spread but uses more horse power and tends to bunch slightly. A safety problem is presented when small foreign objects or chunks of hard material are ejected from the discharge at high velocity.

Specifications.

Capacity: Ranges from 5 to 20 tons per hour, depending on type of material, moisture content of material, horse power used, and speed of loading.

Hammer speed: 1,000 revolutions per minute

Tub speed: 0 to 9 revolutions per minute

Power requirements: 80 horse power or more; PTO speed 1,000 revolutions per minute

Spread rates: 5 to 20 tons per hour or 20 to 40 acres per day

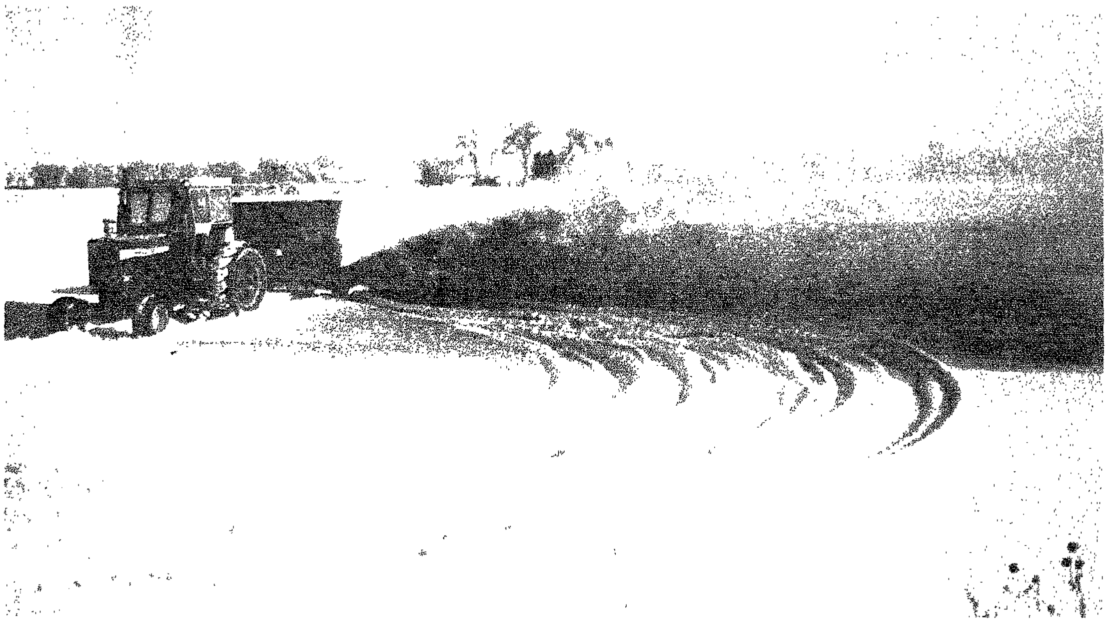


Figure 18.--Mulchmaster spreading mulch on snow to show spreading pattern.

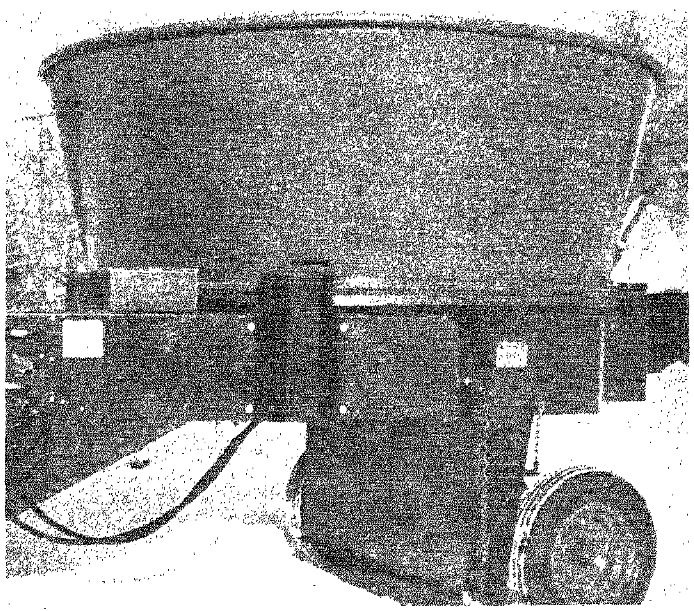


Figure 19.--Roto Grind Mulchmaster.

Spread distance: 60 to 70 feet

Labor and Equipment.--Two people are required for effective operation and probably a third where tacking mulch is necessary.

Availability.

Burrows Enterprises, Inc.
6340 West 10th St.
Greeley, CO 80631
(303)-353-3769

Power Mulchers

Function.--Power mulchers blow dry fiber mulch, mostly straw and hay, onto treatment areas.

Description.--A power mulcher blows dry fiber mulch with air pressure generated by a motor-driven, high-pressure fan. The mulcher has an adjustable-height loading chute with either gravity feed or variable-speed conveyor feed. The blower mechanism consists of rotary beaters to break up the mulch, a paddlewheel fan to generate pressure, and a discharge chute. The chute can rotate in a full circle horizontally and up to 70 degrees vertically (Fig. 20).

Techniques.--Bales of mulch are transported on the mulcher's prime mover and placed on the loading chute one at a time. They either slide or are conveyed into the chamber with the rotary beater. The rotary beater breaks the bales apart and separates the mulch fibers. The mulch fibers are then sucked into a fan and blown out the discharge chute directed toward the slope. An adhesive (tackifier) can be atomized in the airstream and combined with the mulch fibers.

Capabilities.--Power mulchers provide the ability to cover inaccessible slopes (both up and down) with self-attaching mulch from a nearby bench or road. The mulcher can use any long-fiber, dry mulch, but not all mulches produce similar results.

Limitations.--Small light materials, such as sawdust, are difficult to blow far and are subject to drift. Heavy materials such as large wood chips, chunk bark, or shredded bark will not carry far and tend to tear up the beater and fan mechanisms. An impactor is needed to propel heavy mulches.

Specifications.

Spread rates: To 15 tons per hour; about 40 acres in an 8 hour day

Spread distance: To 70 feet

Adhesive pump capacity: To 50 gallons per minute

Power ratings: 30 to 109 horse power

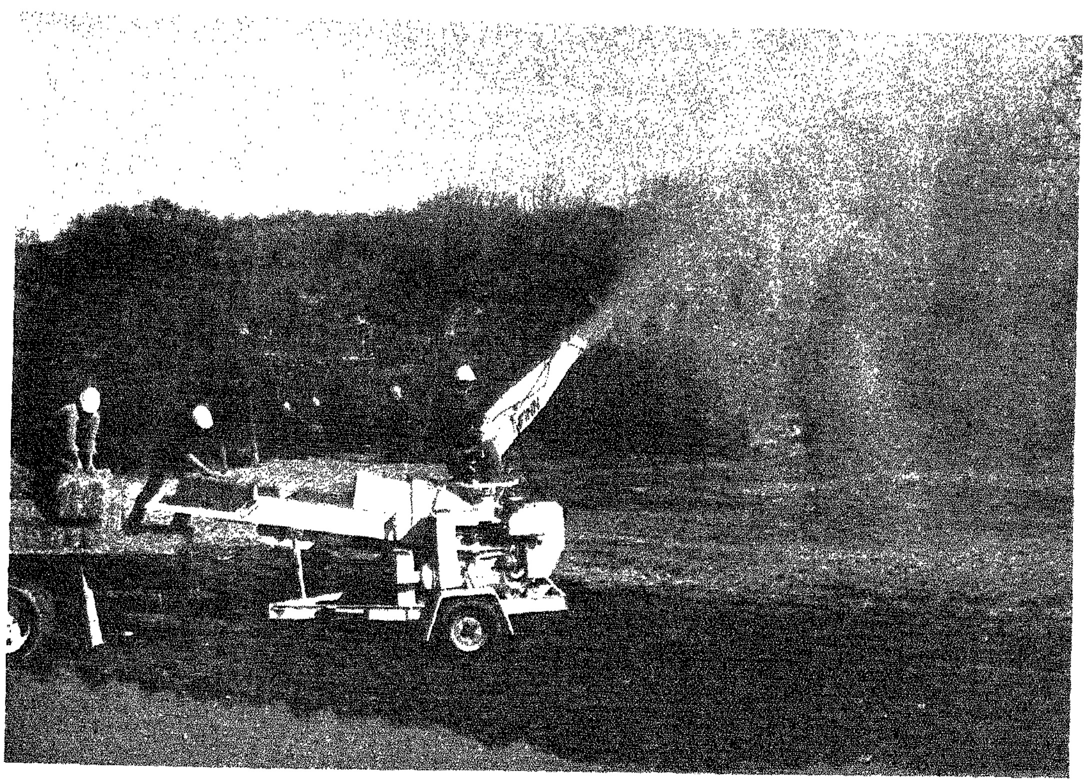


Figure 20.--Power mulcher spreading straw.

Labor and Equipment.--Four people are needed to efficiently operate a power mulcher--the mulcher operator, a prime-mover operator, supply-truck driver, and end-loader operator. A fifth person is needed where a machine is required to crimp the mulch into the soil, or when water trailer or asphalt emulsion trailer is needed for tackifier. This machine requires more manpower than truck-mounted blowers.

Availability.

Finn Equipment Co.
2525 Duck Creek Road
Cincinnati, OH 45208
(513)871-2529

Reinco
Box 584
Plainfield, NJ 07061
(201)755-0921

Estes Blower Spreader

Function.--The Estes blower spreader applies solid materials such as lime, fertilizer, shredded or chunk bark, sawdust, wood chips, corn cobs, or composted municipal wastes. The amendments or mulches, singly or in combination, can be blown 75 feet up or down a 60 degree slope and up to 125 feet horizontally.

Description.--The Estes blower spreader is a blower/impactor that attaches to the hopper of a large, truck-mounted rotary spreader. The conveyor within the hopper transports the amendments into a blower/impactor mechanism with a large fan driven by a separate gasoline engine. A hydraulic cylinder, operated from the cab, controls the vertical angle of the flow of the discharged materials. Spinners, such as those of most rotary spreaders, can accompany the Estes spreader to distribute amendments near the truck (Fig. 21).

Techniques.--The Estes blower spreader is driven along a road or terrace above or below the slope to be treated. The amendments are blown up or down slope from the truck. The hydraulic direction control allows adequate coverage of changing slopes. Application rates are determined by the speed of the truck and the blower speed. To fully cover an area, spinners are needed to spread close to the truck.

Capabilities.--The Estes blower spreader is useful for roadside stabilization or surface-mine reclamation. It enables liming, fertilizing, mulching, and seeding of steep slopes without water and without mechanical disturbance.

Limitations.--The Estes blower spreader is limited to accessible areas. The mouth of the blower discharge is located on the left side and cannot be rotated horizontally. Wind affects the distribution of light materials. Heavy materials tend to carry farther, resulting in uneven distribution of materials with different weights. A safety problem is presented when large chunks of hard material are ejected from the blower at high velocity.

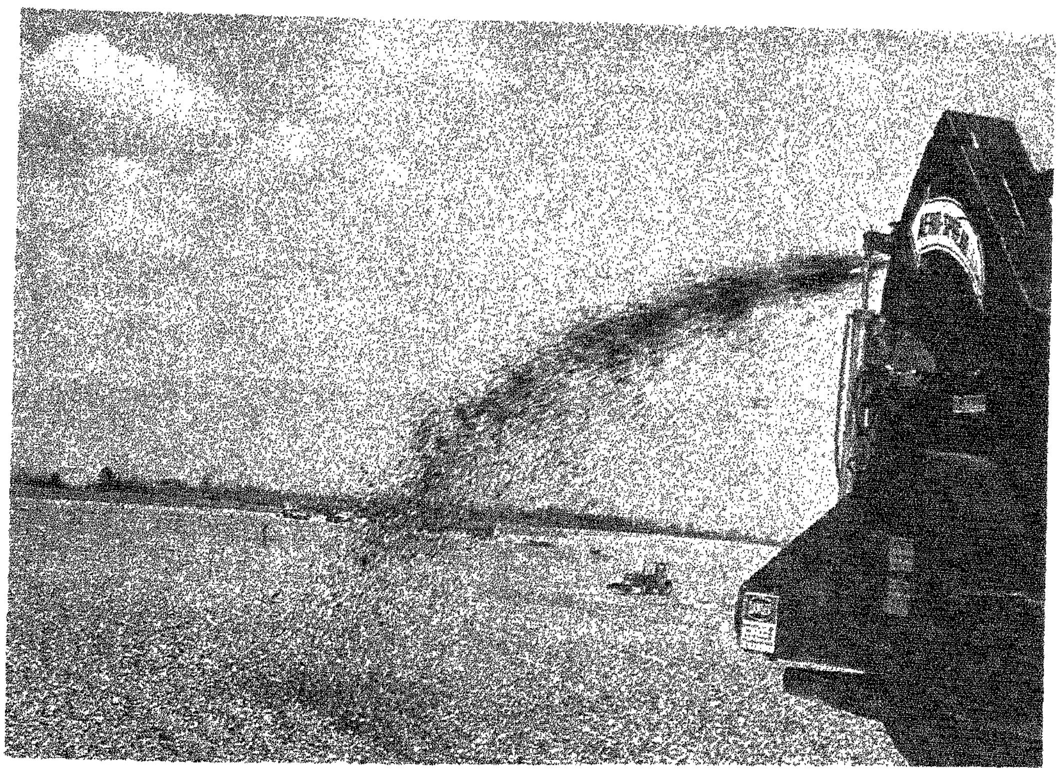


Figure 21.--Estes spreader mounted on a truck hopper.

Specifications.

Spread width (blower spreads only on the left side of the vehicle):

Blower: 75 feet on 60 degree slope

Blower: 125 feet on level ground

Spinners: To 40 feet

Spread rate: 50 cubic yards per hour

Pay load: 15 to 17 cubic yards

Power rating: 56 horsepower

Labor and Equipment.--This machine requires two people for efficient operation, a spreader truck driver and front-end loader operator, and probably a third where tacking the mulch is required.

Availability.

Estes Equipment Inc.
Route 4, Bybee Road
Winchester, KY 40391
(606)-744-5900

Hydraulic Seeder-Mulcher

Function.--Hydraulic seeder-mulchers can apply seed, fertilizer, and soil amendments including wood fiber and cellulose mulch, in a hydraulic spray. They provide a method of seeding and mulching steep slopes without operating a prime mover on the slopes.

Description.--Hydraulic seeder-mulchers consist of a tank, a pump powered by a separate engine, and a discharge-nozzle assembly. The tanks are equipped with various types of agitators to assure uniform mixtures. Large centrifugal pumps can spray the mixtures up to 200 feet and have particle clearances of up to 1-1/2 inches. Interchangeable discharge nozzles provide a variety of spray patterns. The nozzle assemblies can rotate a full 360 degrees horizontally and from 120 to 180 degrees vertically to provide complete coverage. Hydraulic seeder-mulchers may be mounted on either a trailer or truck frame (Fig. 22).

Techniques.--The tank is filled with a slurry containing 3 to 6 percent solids by weight. The operator sprays the mixture over the area, controlling the spray pressure and volume. The hydraulic seeder-mulcher can be operated while stationary or moving. A separate hand-held hose is available for small-scale or spot treatments.

Capabilities.--Hydraulic seeding and mulching is a fast, efficient method of mulching steep, hard-to-reach areas. Application rates may be varied to suit conditions. Dyed wood fiber enables the operator to visually determine what areas have been covered.

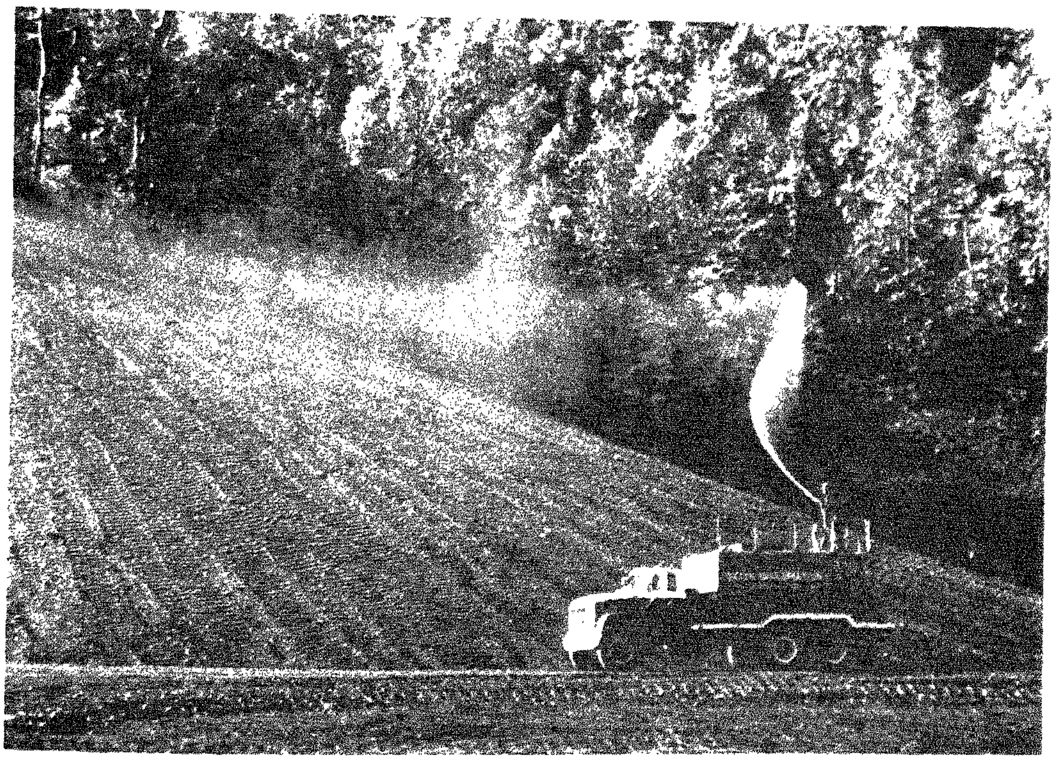


Figure 22.--Truck-mounted hydraulic seeder-mulcher treating a slope.

Limitations.--Hydraulic seeding or mulching demands large amounts of water, which may not be readily available. Only a relatively small area (1 to 2 acres) can be treated with each load of material. It is preferable that seeding and mulching are done in separate operations so the seed are not held off the ground by the mulch fibers. Many seeds may be damaged by the agitators and pumps. When wood-cellulose fiber mulch is added to the slurry, the area covered by a single fill is reduced by 50 percent. Wood-cellulose fiber should contain no more than 10 percent moisture, air-dry weight basis.

Specifications.

Spray range:

20 to 200 feet

360 degrees horizontal rotation

120 to 160 degrees vertical travel

Spread rate: 3,000 gallons per hour

Tank capacity: 150 to 3,000 gallons

Pump capacity: 70 to 950 gallon per minute

Power ratings: 8 to 151 horsepower

Labor and Equipment.--At least four people are needed to operate this machine. A prime-mover operator, spray-nozzle operator, tank-truck operator, and fiber-supply truck driver.

Availability.

Bowie Industries
Box 931
Bowie, TX 76230
(817)872-2286

Finn Equipment Co.
2525 Duck Creek Road
Cincinnati, OH 45208
(513)871-2529

Reinco
Box 584
Plainfield, NJ 07061
(201)755-0921

Tank Truck

Function.--Commercial tank trucks and tank wagons spread slurry or liquid animal wastes, sewage sludge, and industrial wastes directly on the surface of the soil. The material may be absorbed directly by the soil and acted on by soil microorganisms.

Description.--Tank trucks consist of tank for the liquid with quick opening/closing valve and deflector plate to fan the slurry over a wide area. Usually, gravity discharge is used, but some commercial tanks can be pressurized or pumped. Tank systems may be mounted on regular trucks, trailers, or high-flotation equipment.

Techniques.--The tank truck or wagon with high flotation tires is driven or pulled across the area to be treated. The liquified waste is spread with either gravity flow or pressurized spray from the rear of the tank. The swaths are overlapped to ensure complete coverage. Application rates are determined by the speed of the truck and the discharge flow. With optional hydraulic hoist, the tank may be elevated for ease of complete emptying of liquids and semiliquids (slurries). On some trucks, leak-proof, full-opening rear doors facilitate tank cleaning, repair, or service. Tanks with pressure pumps can be driven along a road terrace or bench above or below the area or slope to be treated. The waste is sprayed over the area with discharge nozzles on the truck.

Capabilities.--Tank trucks or wagons spread liquified sewage wastes directly on the soil. The materials are not readily removed by surface winds or runoff. High-flotation equipment can be used on soft ground. Pressurized tanks permit steep slope treatment without mechanical disturbance.

Limitations.--Regulations may restrict or prohibit pressurized spraying in certain locations. Odor may be a nuisance when waste is not incorporated into the soil. Tanks with gravity discharge are limited to level or slightly rolling terrain. Equipment with high-flotation tires may have a restricted hauling range. Regular trucks and trailers can be used only on dry or grass-covered areas.

Specifications

Truck mounted and high flotation:

Tank capacities: 1,600 to 4,000 gallons

Tank diameters: 48 to 72 inches

Tank length: As long as necessary to obtain given capacity

Pressure/vacuum pump: High-speed, self-lubricating, air or oil cooled

Auxiliary engine with two-way valve

Hydraulic pump and hoist control

Pattern width: 12-foot swath at speed of 10 miles per hour

Flotation tire: 15 pounds per square inch ground pressure

Trailer mounted:

Tank capacities:

Regular trailer: 500 to 3,300 gallons

Semitrailer: 4,600 to 6,000 gallons

Tank diameter: 48 to 72 inches

Tank length: As long as necessary to obtain given capacity

Pressure/vacuum pump: High-speed, self-lubricating, air or oil cooled with two-way valve

Auxiliary engine

Hydraulic pump and hoist controls

Pattern width: 12 foot swath at speed of 10 miles per hour

Flotation tire: 15 pounds per square inch ground pressure

Availability.

Ag-Chem Equipment Co., Inc.
4900 Viking Drive
Minneapolis, MN 55935
(612)835-2476

Big A
Rachel Manufacturing Corp.
Box 897
Salina, KS 67401
(913)825-1631

Big Wheels, Inc.
Box 113
Paxton, IL 60957
(217)379-2369

The Calument Co.
340 North Water Street
Algoma, WI 54201
(414)487-5251

Dempster Industries, Inc.
Box 848
Beatrice, NB 68310
(402)223-4026

Industrial and Municipal Eng.
Route 34E
Box N
Galva, IL 61434
(309)932-2036

Finn Krimper

Function.--The Finn Krimper anchors straw or long-fiber mulch by partially incorporating it into the soil.

Description.--The Finn Krimper consists of a series of 20-inch disks spaced 8 inches apart along a horizontal axle. The axle is attached to a heavy frame equipped with steel boxes. The boxes can be filled with rocks for additional weight. The Krimper may be mounted in a three-point hitch or towed. Wheels are available that can be raised and lowered hydraulically for transport. Disk scrapers are standard (Fig. 23).

Techniques.--The disks roll parallel to the direction of travel, cutting narrow grooves in the soil. Some of the mulch fibers are punched into these grooves thereby anchoring the mulch to the soil surface. Penetration should be 2 to 3 inches.

Capabilities.--The Finn Krimper incorporates mulch, such as straw, hay, and leaves, into the soil. Mulch fibers protrude vertically and act as crop stubble to help prevent wind erosion and aid infiltration.

Limitations.--The Finn Krimper should be operated on the contour to prevent water erosion in the grooves. Tractor drawn implements are limited to 3:1 slopes no greater than on which the tractor can operate safely.

Specifications.

Width: 6 or 8 feet

Depth: 1 to 3 inches

Weight: 1,000 to 1,300 pounds

Power requirements (drawbar): 20 to 50 horsepower

Labor and Equipment.--Requires one person to operate the prime mover.

Availability

Finn Equipment Co.
2525 Duck Creek Rod
Cincinnati, OH 45208
(513)-871-2529

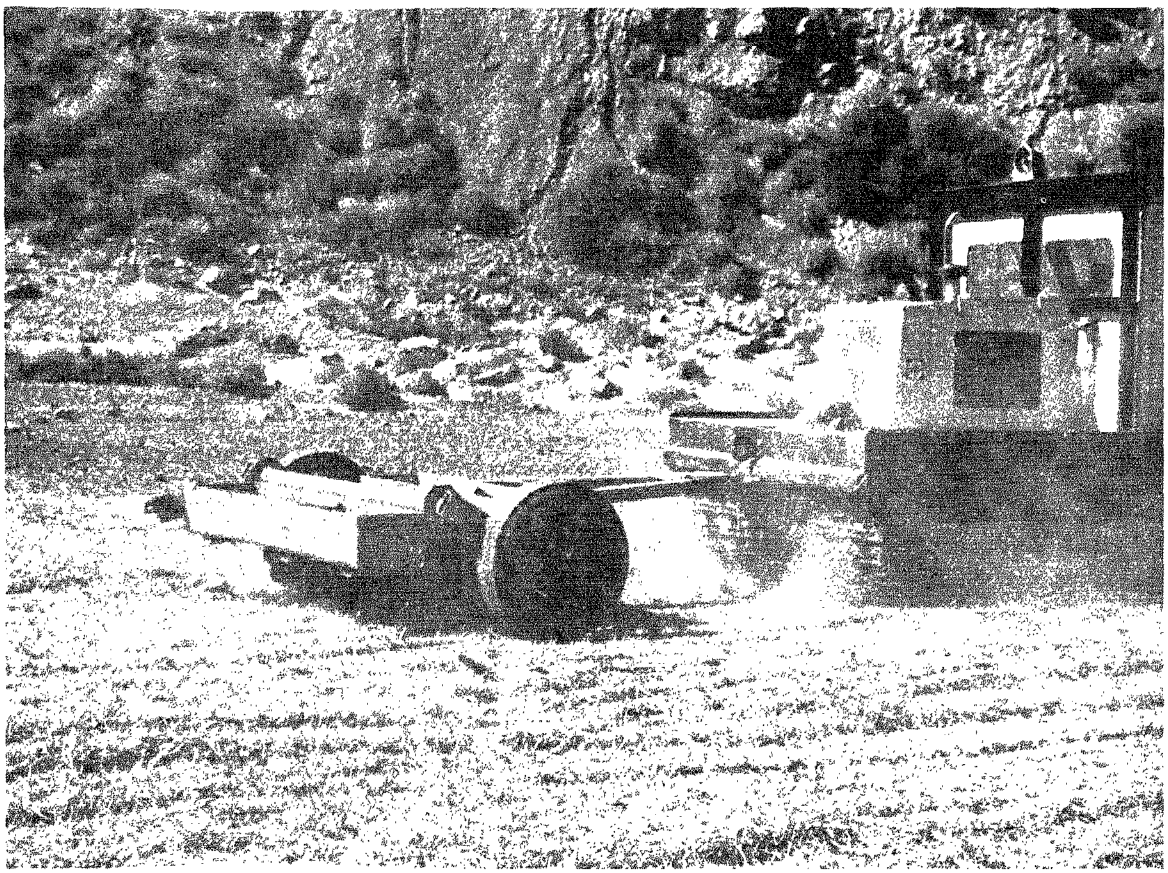


Figure 23.--The Finn Krimper.

Traveling Irrigation Systems

Function.--Self-propelled traveling reel and gun sprinklers are used for irrigating areas with liquid manure or municipal sewage wastewater.

Description.--A self-propelled traveling reel and gun irrigator consists of two pieces of equipment; a gun cart and a hose reel and trailer. The gun or sprinkler is mounted on a tricycle-type carriage with adjustable wheel tread. The hose reel is mounted on a turntable fastened to a high flotation four-wheel trailer. The reel turntable is on ball bearings and will swivel 360 degrees. Hoses are flexible polyethylene. The gun cart is mounted on the reel for transport (Fig. 24).

Techniques.--The reel trailer is towed to the area to be irrigated and connected to the wastewater supply-line hydrant or pump at the mid-point of the first run. The gun cart is lowered to the ground from the reel and hitched to a tractor and towed out unreeling the hose to the distance required (maximum 1,250 feet). The valve is turned on and the tachometer set for the proper ground speed. The gun cart and hose are reeled in at the prescribed speed, stopping automatically when the cart reaches the reel trailer. After irrigating in one direction, the reel is swiveled to irrigate in the opposite direction. The power drive is a radial inflow turbine drive. Engine drive or PTO drive are options.

Capabilities.--Wastewater can be applied to areas 160 to 365 feet wide and up to one-half mile long without relocating the reel. The reel irrigator is especially adaptable to odd-shaped areas. They are easily towed from place to place. They can be set up and operational within minutes. The gun cart does not need to be disconnected for transport. It can be lifted onto the reel trailer with hand-operated jack screw. Flotation tires make units usable on soft ground with little or no compaction of soil. The gun-cart axle is adjustable. The nozzle of the sprinkler will usually clear any solids that pass through the pump screen.

Limitations.--Self-propelled traveling reel and gun irrigators are limited to level to moderate-sloping terrain suitable for agricultural crops. Where wastewater contains solids that may clog the turbine, an engine drive is usually used.

Specifications.

Operating pressure: 60 to 150 pounds per square inch or more at sprinkler head. Minimum pressure at inlet 70 pounds per square inch.

Drive: Radial inflow turbine propulsion, 3-horsepower engine or PTO.

Travel speed: Turbine drive adjustable from 6 to 48 inches per minute. Engine drive 6 to 72 inches per minute. Automatic speed compensator maintains uniform travel speed.

Travel distance: 900 to 1,250 feet each direction (one-half mile total).

Line spacing: 110 to 365 feet wide.

Hose: Polyethylene, 2-1/2 to 4-1/2 inches, inside diameter.

Hose length: 900 to 1,250 feet.

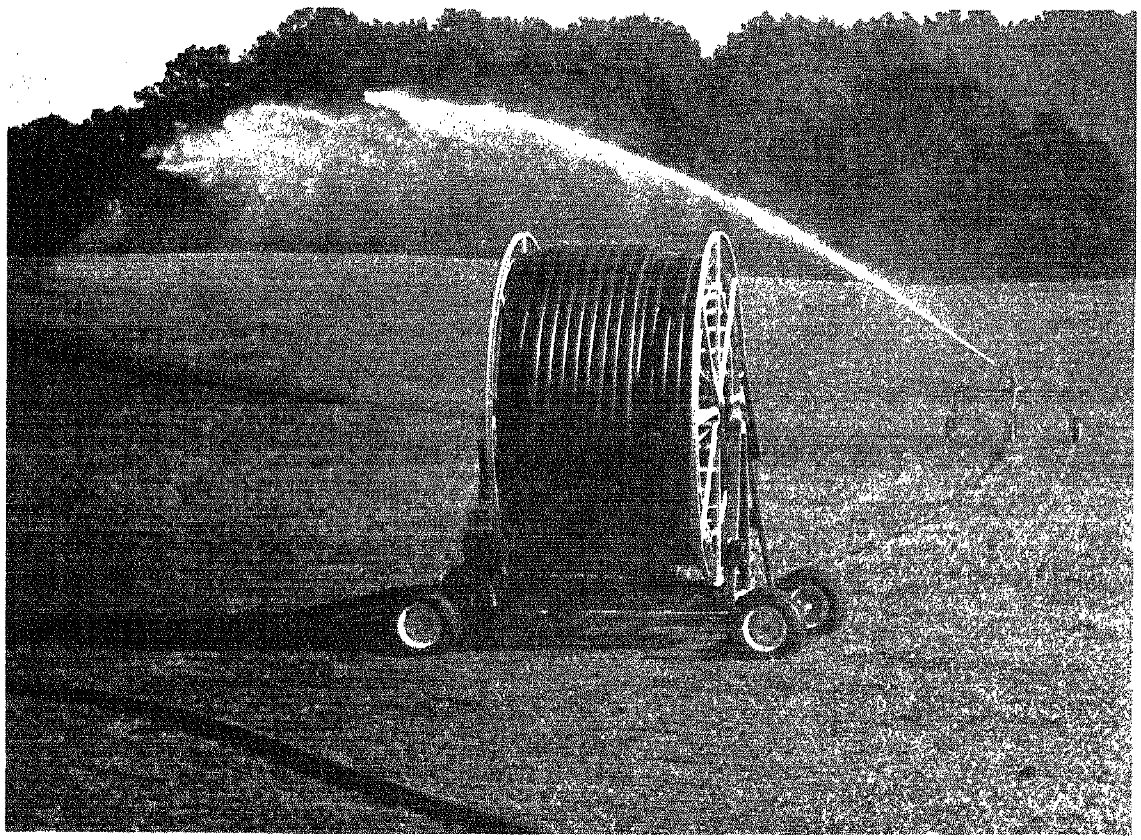


Figure 24.--Water-reel traveling sprinkler irrigation system.
(Photo courtesy of Deverman Advertising)

Capacity: 200 to 600 gallons per minute in depths from 1/4 to 6 inches.

Gun cart: Tricycle-type carriage with rubber tires with adjustable axle from 53 to 144 inches. Crop clearance from 39 to 66 inches high. Nozzle height, 75 inches.

Sprinkler: Nelson P150 to 200R, or equal.

Hose reel: Mounted on two- or four-wheel trailers; core diameter, 96 inches; reel mounted on a swiveling 360 degree turntable.

Towing: 3 miles per hour in field; up to 12 miles per hour on roadway.

Dimensions:

Height: 12 feet 6 inches

Width: 9 feet 8 inches

Length: 20 feet 5 inches

Labor and Equipment.--One person is needed to operate a tractor for transporting the reel and for setting up and towing and placing the gun cart.

Availability.

Ag-Rain, Inc
600 S. Schroder
Havana, IL 62644
(309)543-4425

Long Manufacturing
Box 1139
Tarbo, NC 27886

Center-Pivot Irrigation System

Function.--Center-pivot irrigation systems are used to evenly disperse liquid livestock manures, municipal sewage wastewater, or supplemental irrigation water in land-treatment operations.

Description.--A center-pivot irrigation system has a slurry lagoon or waste pit; an electrical power supply; a turbine pump; and variable sections of 6- to 8-inch, galvanized, flexible, tubular, steel pipeline with uniformly spaced spray nozzles. The pipeline is mounted on an under-truss system supported by triangular steel towers attached to electric drive units with high-flotation or maxi-float rubber tires (Fig. 25).

Techniques.--The slurry material to be sprayed is pumped from the storage lagoon to the center pivot by the turbine pump. The waste is distributed down the entire length of the system as it slowly rotates in a circle around the pivot. A computer is used to calculate the most efficient sprinkler package and the most precise distribution of slurry from one end of the system to the other.

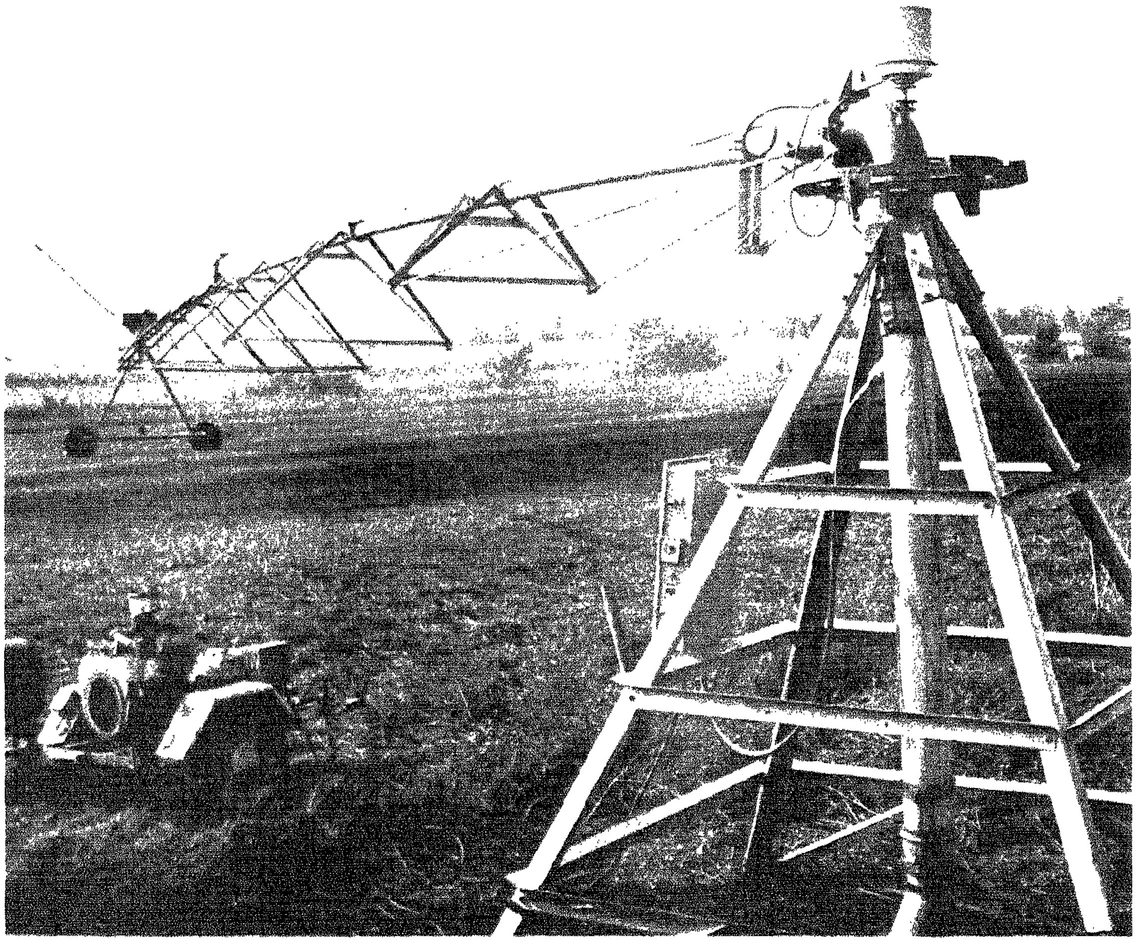


Figure 25.--Center-pivot irrigation system.

Capabilities.--For a quarter section, you can choose an all-terrain, standard span (1,300 feet) system with 7, 8, 9, or 10 drive units with five different span lengths from 105 to 185 feet and capable of climbing 6 to 12-inch ridges and handling stresses on slopes up to 30 percent. There are low- or high-profile units. Low-profile units minimize wind drift and evaporation. High-profile units clear tall crops, dwarf trees, or other objects.

Because a single system travels in a circle or a constant track 8 to 12 inches wide, it eliminates accidental overlapping and over or under application due to variance in spreading volume. It can cover from 10 to 150 acres and is capable of spreading wastes over rolling ground with slopes up to 30 percent. There are tow or no-tow systems. The smaller systems are usually towable and can easily be moved from field to field.

An output of 800 gallons per minute spreads as much as 48,000 gallons of waste per hour. This compares with a 3,000 gallon liquid tank wagon that spreads two loads (6,000 gallons) per hour. Water carries the nutrients down into the soil so tillage is not needed to get waste material into the ground.

Soil compaction is minimal because the wheel track in the circle is always the same, and high-flotation tires minimize rutting.

Limitations.--Only operates in a circle. Works most efficiently above 40°F and when soil is not frozen. Limited to level ground and moderate-sloping terrain (up to 30 percent). Suitable for agricultural crops.

Specifications.

System size:

Length: 1,298 feet

Drive units per quarter section: 10

Rotation time:

Standard (30 rpm): 16.9 hours

Optional (56 rpm): 9.3 hours

Pipe size (12 gage wall):

Outside diameter: 6.625 inches

Pipe height (at drive unit): 12.0 feet

Crop clearance: 9.0 feet

Sprinkler packages:

Standard: 250 gallons per minute

Pressure: 60 pounds per square inch

Spacing equal impact sprinklers: 126 feet

Nozzles: Anticlog

Drive unit:

Tower gear motor: 1 horsepower

Output outer towers: 37 revolutions per minute

Output inner towers: 30 revolutions per minute

Gear case reduction ratio: 52:1

Electrical system:

Motor: 3 phase, 460 volts

Span length: 105 to 185 feet

Maximum slope limitation:

Climbing 0 to 6 inch ridges: 30 percent

Climbing 6 to 12-inch ridges: 30 percent

Tires, high flotation: 14.9 by 24

Labor and Equipment.--One person is needed to operate a tractor for transporting towable systems and for setting up and placing span system.

Availability.

Valmont Industries, Inc.
Valley, NB 68064
(402)359-2201

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CONVERSION TABLE - ENGLISH TO METRIC

English unit	Metric unit	Conversion factor
	Length	
inch, in	centimeter, cm	2.54
foot, ft	meter, m	0.305
mile, mi	kilometer, km	1.609
	Area	
square feet, ft^2	square centimeter, cm^2	929.030
Acre, Acre	hectare, ha	0.405
	Weight	
pound, lb	kilogram, kg	0.454
short ton, ton	ton	0.907
short ton, ton	kilogram, kg	907.184
	Volume	
gallon, gal	liter, l	3.785
cubic yard, yd^3	cubic meter, m^3	0.764
	Yield or Rate	
pounds/acre	kilogram/hectare	1.121
short tons/acre	tons/hectare	2.242
cubic yards/acre	cubic meters/hectare	1.886
gallons/acre	liters/hectare	9.346
	Temperature	
Fahrenheit, °F	Celsius, °C	0.555(F-32)