MULCHES FOR WIND AND WATER EROSION CONTROL

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CONTENTS

MULCHES FOR WIND AND WATER EROSION CONTROL

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Wind and water erosion have long been an agricultural concern. But military forces, highway departments, and industry also must combat this problem on bare soils resulting from various types of construction. Where installations are built along coastlines and on sandblown islands, immediate sand stabilization during construction periods is necessary. Therefore the demand is great for effective and economical materials and quick methods of protecting bare soils from erosion until permanent vegetation can be established.

This report deals with procedures for establishing various kinds of protective mulch and for establishing and maintaining permanent vegetation. The word "mulch" means any substance, such as straw, hay, paper, gravel, organic or inorganic film, brush spread upon the ground, or produced and killed or allowed to die and left on the ground as a stubble mulch, or formed and left on the ground as a layer of clods or dust, for the purpose of protecting the soil from erosion or the plants from heat, cold, or drought. The limitation on what is called a mulch is not the kind of material from which it is derived but that it be dead when left or placed on the ground. On the other hand, the term "permanent vegetation" means perennial vegetation such as grasses, shrubs, or trees growing on the land. Permanent vegetation is a living cover, whereas mulch is a dead cover. A mulch may be temporary such as dead vegetation, or permanent such as a layer of stones or gravel.

This report includes information on stabilization of level and sloping ground, but not waterways (21).[3] The information was obtained in part from a series of experiments started in 1959 on contract with the Bureau of Yards and Docks, Department of the Navy. Explanations of various research procedures and data pertaining to the contracted series of experiments are contained in other reports (5, 6, 8, 9).

A portable wind tunnel was used to determine the effectiveness of the various mulching treatments under field conditions (fig. 1). Limited information also was obtained on the relative effectiveness of some of the treatments against erosion by water. From results of the wind tunnel tests, the wind erosion climatic factor (4) and the universal wind erosion equation (1) were used to estimate the relative quantities of mulch required in various sections of the United States. An effective wind erosion control treatment is considered as one that will resist an 85-mile-per-hour wind as measured at 50-foot height.

Because wind and water erosion usually occur together and either one may affect the intensity of the other, the amount and anchorage of mulch must be adequate to control both types of erosion. Therefore, some of the recommended rates of mulch application are

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[3] Underscored numbers in parentheses refer to Literature Cited listed at end of report.

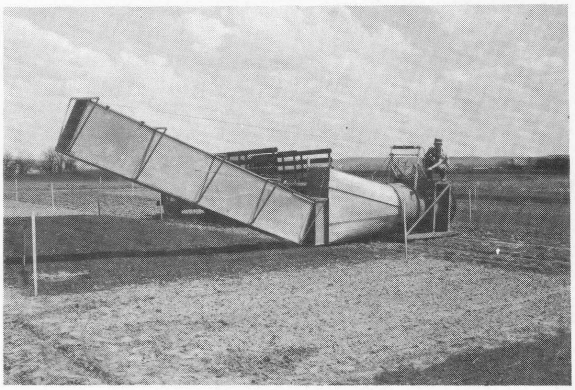


Figure 1.--A portable wind tunnel was used to test the effectiveness of various types of mulch. Here, the tunnel is partly raised to be hauled to another location. Soil and mulch traps (not shown) were used to estimate the amount of soil erosion and the degree of mulch anchorage.

greater than the rate required to control wind erosion, but are the minimum rates required to control water erosion.

VEGETATIVE MULCHES PRODUCED IN PLACE

For large areas of wind-eroded land, crops grown and converted to a temporary mulch in place rather than hauled-in may be the only feasible method for stabilizing the soil. Planting crops to produce a temporary mulch is slower but generally more practical and less expensive than hauling the mulch in.

First, it is necessary to stop any movement of drifting soil (11, 26). This is best accomplished during the season when precipitation is most plentiful and wind velocity is lowest. A deep-furrow and a chisel-point cultivator and a lister are useful for initial stabilization of drifting soil (7). The cultivators are satisfactory where soil accumulations are less than 3 inches deep so that some clods may be brought to the surface (fig. 2). The lister is more satisfactory on accumulations from about 3 to 6 inches deep. With these implements, the land should be worked by starting on the side facing the prevailing wind direction.

The land initially stabilized with the deep-furrow cultivator or lister may be seeded to broomcorn, sudangrass, or a small-grain crop such as rye (fig. 3). Then the crop may be harvested and killed or allowed to die and its residue made to serve as a temporary mulch. The ground covered with mulch should then be seeded or planted to perennial grasses, legumes, shrubs, vines, or trees to produce a permanent vegetative cover (fig. 4). It is essential that no weeds or crop plants grow in the temporary mulch at seeding or planting of the permanent species.

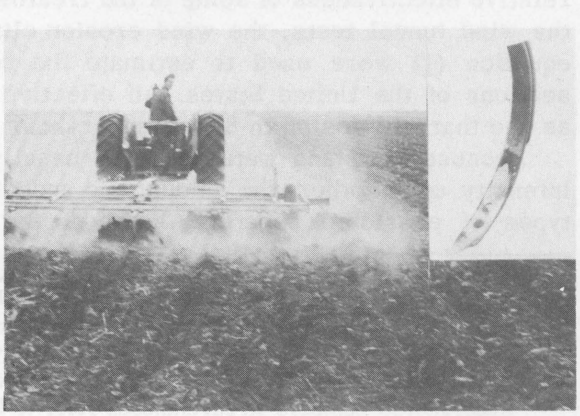


Figure 2.--A chisel-point cultivator here is stopping wind erosion by forming a somewhat rough, cloddy soil surface. After this, the ground can be seeded with little danger of seedlings being destroyed by abrasion from windblown soil. (Inset shows the type of chisel point on the cultivator.)

Figure 3.--If movement of sand is not too intense, rye (as shown here), sudangrass, sweetclover, corn, or sorghum may be grown and its residue left to give a quick, temporary vegetative mulch on the land, which then may be seeded to grass for more permanent stabilization.

Figure 4.--Here, four 100-inch grass drills are seeding directly into sorghum stubble and dead weeds. Seed should be drilled into dead vegetation so mulch will not compete with young grass seedlings for moisture.

On sand accumulations deeper than about 6 inches, it is impossible to stop soil movement temporarily with a cultivator or lister. On such accumulations it may be most convenient and economical to establish plant barriers or artificial barriers such as lath or picket fences (fig. 5) in rows running at right angles to prevailing winds (19, 24). Rows should be spaced no farther apart than five to ten times the height of the mature plants or the erected barrier. The stronger the winds and the drier the climate, the closer the barriers should be spaced. Some of the annual plants suited for temporary barriers are broomcorn, amber cane, pearl millet, and sorghum almum.

As soon as the plant barriers are developed, or the artificial barriers are erected, the ground should be seeded to a quick-growing crop such a sudangrass or rye. When the crop has made sufficient growth, it should be harvested for grain and its residue left on the ground, or it may be destroyed or allowed to die to form a temporary mulch.

However, a temporary mulch is not necessary if permanent plant species highly resistant to abrasive action of drifting sand can be used. Such species include American and European beach grasses (fig. 5). These, and others like them, can be planted directly on bare soil or sand dunes without previous establishment of a temporary vegetative mulch (3, 18, 19, 24). Mechanical planters, where they can be used, speed up the planting and lower the cost.

The ground covered with a temporary mulch should then be seeded or planted to perennial species in a manner described under "Permanent Vegetation."

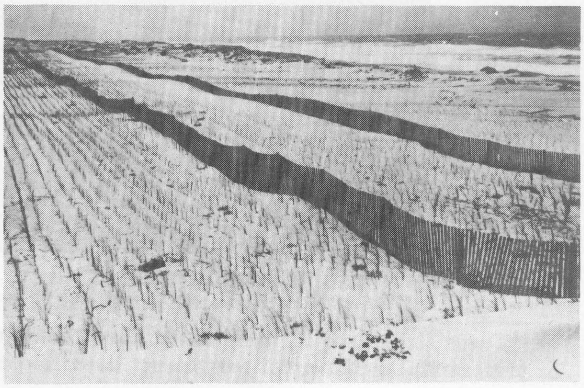


Figure 5.--Barriers, such as picket fences shown here, can be used to partially stop sand movement. Beach grass, which has been planted and is beginning to grow, will continue to trap the sand and build up the dune. (Courtesy U.S. Corps of Engineers.)

HAULED-IN MULCHES

Where soil erosion cannot be stopped with tillage and where it is imperative to stabilize the soil quickly, the following general method with alternative mulching materials may be used: Cover the whole surface of the ground with hauled-in unprocessed straw, hay, stover, or brush, or with processed vegetative or nonvegetative materials such as wood cellulose fiber, asphalt, resin, latex, gravel, or crushed rock.

Which mulching material to use depends on its effectiveness and cost. Cost of raw material is determined by its availability, bulkiness, processing required, and distance of transportation. Other costs include investments in equipment and labor necessary to prepare the land and apply the material. Costs also vary with place and time.

Unit costs of most of the hauled-in materials referred to in this report are listed below, on a carload basis, delivered to site at Manhattan, Kans., in 1962:

- Wheat straw and prairie hay--$15 per ton (air-dry basis); baled; locally available.
- Sorghum stover--$10 per ton (air-dry basis); chopped; loose; locally available.
- Fine natural gravel--$1.50 per ton, delivered 10 miles.
- Crushed limestone--$3.50 per ton, delivered 10 miles.
- Rapid-curing (RC 3) cutback asphalt (a product of natural petroleum)--12 cents per gallon in 55-gallon drums; supplied at cost by the Kansas State Highway Commission.
- Rapid-setting asphalt-in-water emulsion (a product of natural petroleum)--25 cents per gallon in 55-gallon drums; shipped from American Bitumuls and Asphalt Co., St. Louis, Mo.[4]
- Resin-in-water emulsion (a product of natural petroleum)--30 1/2 cents per gallon in 55-gallon drums; shipped from Golden Bear Oil Company, Bakersfield, Calif.
- Wood cellulose fiber--$120 per ton; baled; shipped from International Paper Company, Mobile, Ala.
- Latex-in-water emulsion (latex polymer)--$1.60 per gallon in 50-gallon drums; shipped from Alco Oil and Chemical Corporation, Philadelphia, Pa.
- Water-soluble (hydrated, pregelatinized) starch--experimental; price unknown.
- Ammonium lignin sulfonates and sugars (a byproduct of the paper pulp industry)--experimental; price unknown.
- Sodium silicate and calcium chloride mixtures--commonly available at various prices, depending on purification and distance from source.

Unprocessed Vegetative Mulches

The procedure for temporary stabilization of soils with hauled-in vegetative mulches generally consists of: (1) preparing a suitable seedbed; (2) seeding permanent grasses and legumes, when appropriate; (3) choosing and applying a vegetative mulch; and (4) anchoring the mulch (6, 7, 8, 9, 10).

Preparing a Seedbed

Seedbed preparation varies with prevailing climatic conditions and with different seeding, planting, and anchoring machines.

[4] Trade names and company names are included for the benefit of the reader and do not infer any endorsement or preferential treatment of the product listed by the U.S. Department of Agriculture.

It is best not to attempt to create any special seedbed on sand dunes. Leveling dunes is costly and seldom warranted, except to smooth out crests. A dragpole or bulldozer can be used to level the crests (26).

On bare construction slopes and level land, some preparation of a suitable seedbed is generally necessary. If small seeds, such as grasses and legumes, are to be planted, a firm seedbed with moist soil at or near the surface is essential. Pulverizing the soil should be avoided. Moderate soil cloddiness reduces wind and water erosion and helps anchor the vegetative mulch. If seeds are to be drilled, it is best to leave a reasonably smooth soil surface with clods or ridges not over 2 inches high (fig. 6). If seeds are to be broadcast, surface roughness should be between 1 and 4 inches high. Ground too rough is as bad as too smooth. If roughness is greater than 4 inches, fine-stemmed mulch spread on the surface with a blower-type spreader collects on one side. When the wind changes in direction, the mulch rolls into depressions and the soil may be removed. If ground is too smooth, the mulch will tend to blow away before it is anchored.

Ordinarily, land should be free from all vegetative growth before seeding. An exception is highly erodible dune sand. On such soils, vegetation helps to hold the mulch without interfering too much with grass germination.

Seeding Permanent Grasses and Legumes

Seeds should be planted during the optimum planting season if possible. The optimum date in many regions is early spring; in others it is midsummer, when rainfall is highest. Local authorities can recommend the most suitable varieties and best rates and dates for seeding and fertilizing.

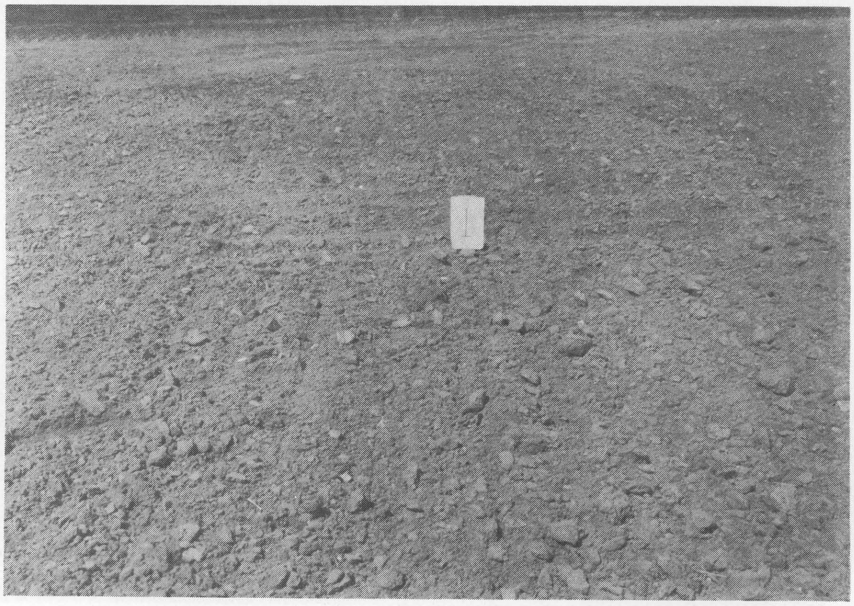


Figure 6.--Soil surface immediately after drilling grass seeds and before mulching. Firm soil surface is essential for seed germination. A cloddy surface helps to anchor the mulch.

Drilling small seeds deep enough to reach moist soil, but not deeper than about 1 inch, is preferable to wet or dry broadcasting. Grass seed drills that can seed through a vegetative mulch or into bare ground are preferable to ordinary grain drills (fig. 4). Running a packer or packer wheels just behind the drill generally hastens and improves germination. Where drills cannot be used, such as on steep construction slopes, seeds may be broadcast. Broadcasting seeds and fertilizer immersed in water, called hydroseeding (fig. 7), is preferable to dry broadcasting by hand or with broadcasting machine.

Soil covered with a vegetative mulch other than brush generally requires about 25 percent more nitrogen than does unmulched soil. Bacteria that decompose the mulch use considerable nitrogen. If nitrogen is limited, the bacteria rob it from the young grass seedlings, thus preventing their becoming established. Needs for other nutrient elements should be determined (12, 14).

Choosing a Vegetative Mulch

Wheat straw and prairie hay are the two natural (nonprocessed) vegetative materials most commonly used to stabilize temporarily any kind of bare soil against erosion by wind and water (6, 13, 17, 20). Pound for pound, wheat straw is somewhat less effective than hay because it is smooth (has no barbs) and, therefore, is more difficult to anchor. Straws of other grains, such as oats, barley, rye, and rice, are about as effective as wheat straw. Tame hay such as sudangrass, brome, and other annual and perennial fine-stemmed grasses can be used effectively. Corn, sorghum, and other coarse-stemmed stovers are less effective than hay or wheat straw, because they have less protective surface and are more difficult to punch into the ground; however, they can be effective if applied in sufficient

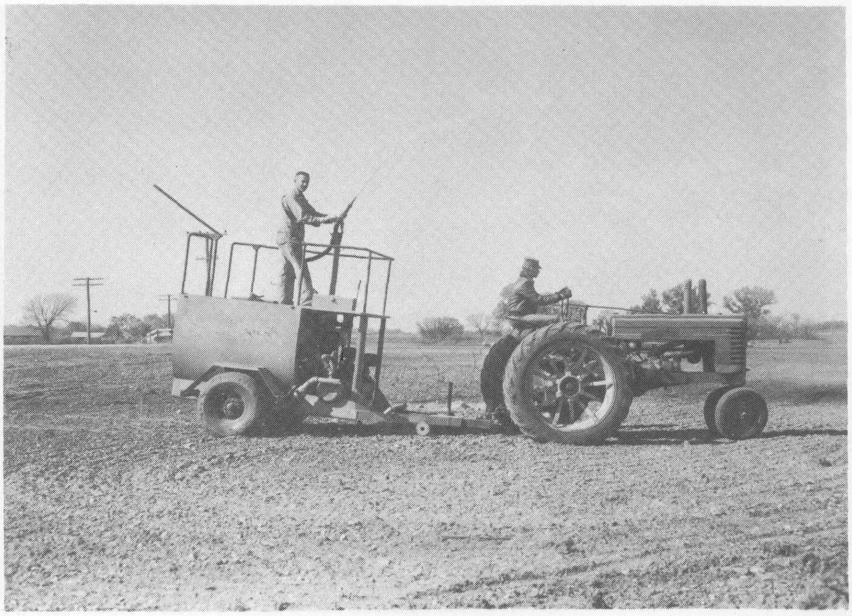


Figure 7.--Hydroseeder sprays seeds and fertilizer mixed with water. The seeder sprays 500 gallons of mixture covering 1 acre in about 15 minutes. Larger units also are available commercially.

amount and if well anchored. Cotton lint (gin trash) also can be effective if enough is applied and if it is well anchored. In wooded areas, brush has been used effectively to stabilize sand dunes temporarily (19).

The best mulch to use is generally the one that is most available and nearest. For mechanical spreading, fine-stemmed baled mulch is preferable to loose mulch. Coarse-stemmed stover is difficult to bale; therefore, it is more practical to haul it loose directly from a field chopper in a wagon equipped with a beater-type spreader (fig. 8).

Mulch containing considerable quantities of volunteer grain or weed seeds often interferes with germination and growth of grass. If possible, mulch free from seeds should be used.

Spreading the Mulch

Either a beater or blower-type spreader may be used to spread a vegetative mulch other than brush on relatively level land (figs. 8 and 9). A blower-type spreader equipped with asphalt-spraying mechanism is convenient to use on short slopes such as highway right-of-ways (8). The method that uses the least hand labor most likely will be the least expensive. Several types of commercial spreaders are available that can spread mulch such as straw, hay, fodder, and cotton lint quickly and effectively with little hand labor.

Spreading should be uniform. Baled mulches tend to fall in bunches unless the mulch going through the spreader is thoroughly chopped (cut), shredded, or beaten, and is

Figure 8.--A beater-type mulch spreader is shown here distributing straw. This type is most suitable for spreading coarse-stemmed stovers such as corn and sorghum. It can be used only on reasonably level ground. (Courtesy of U.S. Corps of Engineers.)

Figure 9.--Blower-type mulch spreader showing application of a mixture of hay and asphalt. This spreader can be used on short slopes such as highway right-of-ways. It can be equipped with extension pipes and hoses for use on longer slopes.

scattered or blown with considerable force. Spreaders that shred the mulch are better than those that cut because they leave longer stems, but those that chop the mulch facilitate more even spreading. The average length of chopped stems should not be less than 6 inches if the mulch is to be anchored with a mechanical packer. Spreading should be done on a calm day so that the mulch will not blow away before it is anchored.

Brush has to be spread by hand and is therefore costly and limited primarily to sand dunes in forested areas (fig. 10). It has one advantage over straw or hay mulch: It decomposes much less rapidly.

Anchoring the Mulch

Vegetative mulch other than brush is anchored to the soil either with mechanical equipment or with an anchoring agent mixed with the mulch. Anchoring with mechanical equipment is less expensive wherever such equipment can be used conveniently.

Mechanical equipment.--Packing should be done immediately after spreading the mulch. The best packer presently available to anchor mulches other than brush and cotton lint is a disk packer with smooth or serrated disks (figs. 11 and 12). It leaves much of the mulch erect--a position most effective for controlling wind erosion and reducing smothering of grass seedlings. The sheltered bare spaces between the rows of mulch are ideal for germination and growth of grass. Bacteria that decompose the mulch have less contact with the seedlings and, therefore, compete less for nitrogen.

Figure 10.--Tree branches (brush) are spread on sand to stop movement by wind. Sage plants are beginning to cover the surface and give more permanent stabilization.

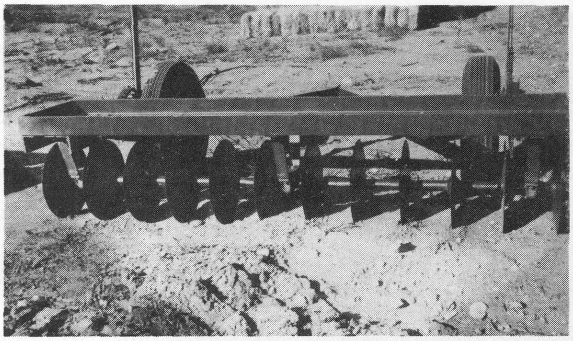


Figure 11.--Disk packer with smooth disks spaced 8 inches apart. This type of packer equipped with either smooth or serrated disks was found most effective for anchoring mulch, controlling wind erosion, and facilitating grass seedling development.

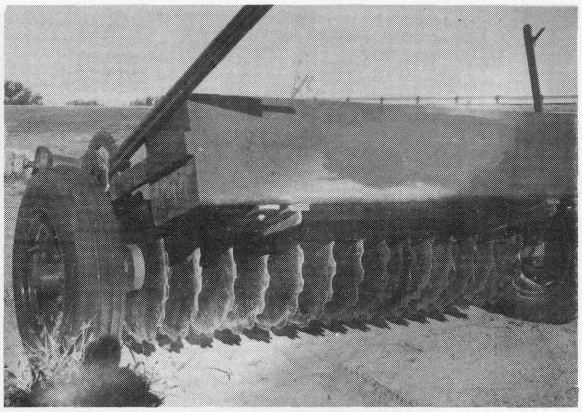


Figure 12.--Cutaway rolling disk packer with 1/4-inch thick disks spaced 4 inches apart. This disk spacing is desirable for anchoring mulch on dune sand.

The smooth or the serrated (cutaway) disks are about equally effective for anchoring the vegetative mulch if the disks are no smaller than 20 inches in diameter and penetrate the soil no deeper than about 3 inches. The disk edges should be dull enough not to cut the mulch too readily; however, cutting is not serious provided the cut pieces are punched into the ground sufficiently deep to remain anchored. The best spacing of disks is about 4 inches on coarse-textured soils such as dune sand. On finer textured soils, where penetration and clogging may be a problem, disks must be spaced about 8 inches apart for packing once (fig. 13), or 12 inches apart for packing once in one direction and then once across at right angles to form a grid system of rows. The 8-inch spacing will not produce a grid system because almost all the mulch is pulled into the rows and punched into the ground the first time over.

The disks should penetrate at least 2 inches, but not more than 3 inches, for proper anchorage and effectiveness. If the ground is too hard for disks to penetrate to proper depth, it should be loosened by tillage to the depth of desired disk penetration. If the ground is too loose, penetration may be too deep, unless the packer is equipped with depth-gage wheels, as shown in figures 11 and 12.

The V-tread, rolling-wheel packer (fig. 14), with wheels no thicker than 1 inch and spaced no farther than 6 inches apart, anchors the mulch somewhat less effectively than the disk packer. For proper depth of penetration, the V-tread requires more weights than the disk packer. Cast-iron wheels sometimes break under heavy weights; therefore, steel wheels are imperative if they are narrow. Use of broader V-tread wheels often fails to anchor the mulch sufficiently, even with maximum weighting.

Various types of plate, rod, and sheepsfoot packers equipped with special lugs have been used but without success. These packers anchor the mulch but leave most of it flat--a condition suitable for control of erosion by water but not by strong wind.

A packer cannot be used on 3:1 or steeper slopes unless the packer and the tractor that pulls it are suspended by cable from a truck or track-type tractor driven on level ground above the slope (23). Such an arrangement can be used to cultivate, seed, and apply the mulch (fig. 15).

Figure 13.--Four thousand pounds wheat straw per acre packed with disks spaced 8 inches apart. This treatment was fully effective in controlling wind erosion on all but extremely erodible dune sand.

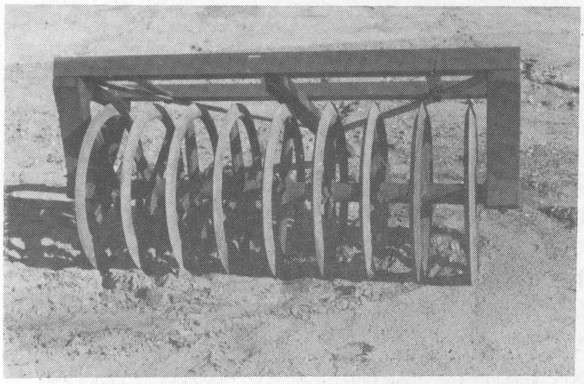


Figure 14.--V-tread rolling wheel packer with 1-inch-thick wheels spaced 5 inches apart is somewhat less effective than a disk packer for anchoring vegetative mulch.

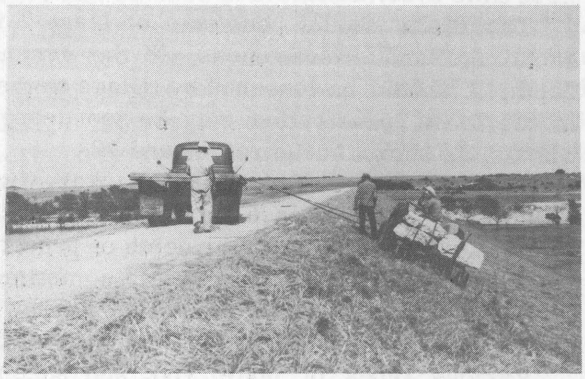


Figure 15.--Mulch packer (disk type) and tractor are held on the 2:1 slope with a winch line hooked to a truck. Cultivating and seeding were done the same way.

Also, a slope harrow can be used to prepare a seedbed and anchor the mulch on 3:1 or steeper slopes (fig. 16). This implement consists of a rolling chain to which rods 15 inches long and 1 inch thick, with sharpened ends, are welded. A rotating weight at the bottom of the slope keeps the harrow from pulling up the slope. The harrow smooths any rills that may be present, roughens the surface, and anchors some of the mulch. It must be pulled over the surface at least several times to anchor the straw or hay mulch sufficiently (9). Space must be available on top of the slope for a tractor to drive and to turn around.

Because cotton lint is difficult to anchor, chiseling to bury the lint partially is the usual method (fig. 17).

Brush does not need to be anchored because it is generally too heavy to be moved by wind or runoff water.

Anchoring agents mixed with mulch.--Rapid-curing (RC) cutback asphalt and rapid-setting (RS) asphalt emulsion mixed with vegetative mulch other than brush are effective anchoring agents (8, 20). The most convenient and inexpensive method is to inject a spray of liquid asphalt directly into the stream of mulch as it comes out of the blower-type spreader (fig. 9). Some commercial blower-type spreaders are equipped with an asphalt-spraying mechanism.

To be completely effective, the mulch must cover the ground uniformly and be anchored adequately; yet it must be thin enough to allow grass seedlings to emerge readily. On loose sand, little anchorage of the mulch to the ground occurs, so that the stability of the mulch cover depends primarily on the rigidity with which the individual pieces of straw, hay, or stover are held together by the anchoring agent. Many failures in attempting to anchor mulch this way have resulted from the use of slow-curing or soft-setting cements. Such cements are easily deformed by the wind so that the mulch blows away or rolls with the wind (fig. 18).

It is important that the liquid asphalt be spread uniformly with the mulch. Intermittent shots of asphalt into a stream of mulch are not satisfactory. Rather than control the quantity of asphalt that way, it is preferable to reduce the size of the asphalt nozzle and apply the asphalt continuously into the stream of mulch. The finer the spray, the less the amount of asphalt needed to anchor the mulch. A heating unit for concentrated liquid asphalt, especially for cutback asphalt, is essential for producing a fine spray. Dilution of liquid asphalt weakens its cementing property.

Figure 16.--Leveling small rills on 3:1 slope with slope harrow in preparation for seeding and mulching. The weight at the bottom prevents the harrow from pulling up the slope.

Figure 17.--Four tons of cotton lint per acre were spread on the surface, and a chisel cultivator used to partially cover and anchor the lint.

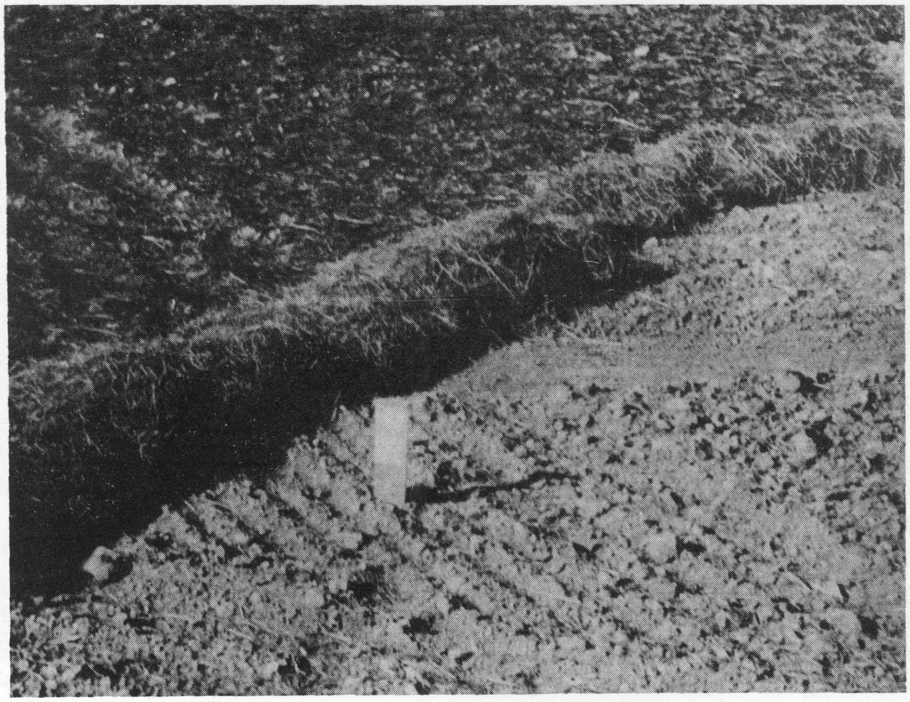


Figure 18.--Hay at 4,000 pounds per acre mixed with 200 gallons of slow curing (SC) cutback asphalt per acre rolled by strong natural wind. In later experiments, rapid curing (RC) asphalt held well against strong winds.

Attempts to anchor vegetative mulch on construction slopes by applying a jet of water to bury part of the mulch with the soil generally have been unsuccessful. About 2,000 gallons of water per acre are needed to give maximum anchorage of the mulch. More than 2,000 gallons of water washes the mulch down the slope.

Rates of Application and Costs

Average quantities (air-dry basis) of well-anchored mulch required for effective soil stabilization against wind erosion are shown in table 1. Costs include preparing a seedbed, seeding, applying the mulch with a blower-type spreader, and anchoring the mulch, but do not include the costs for seeds and fertilizer. The higher rates and costs apply only to dune sands west of the 95th meridian, which lies on the average about 200 miles west of the Mississippi River. The lower rates and costs apply to all other soils and regions. Quantities greater than those listed should be avoided because they cause excessive smothering of grass seedlings.

Quantities of mulch listed for the humid area (east of the 95th meridian) are generally higher than is necessary to control wind erosion in this area. But as wind erosion diminishes from arid to more humid areas, water erosion increases. Also the soils that are less erodible by wind are usually more erodible by water. The quantities of mulch listed for the humid areas are the quantities tentatively believed needed to control water erosion (6, 8, 9, 13, 17, 20). They are sufficient to control wind erosion even on dune sand.

TABLE 1.--Comparative application rates and costs per acre for mulch anchored with mechanical equipment and with asphalt[1]

Method of anchoring and mulch	Rate for mulch	Rate for asphalt	Cost[2]
	Pounds	Gallons	
Anchored with disk packer:			
Prairie or tame hay.................	4,000-5,000	--	$90-$105
Small-grain straw...................	5,000-6,000	--	105-120
Coarse-stemmed stover[3]..............	8,000-10,000	--	130-150
Anchored with cutback asphalt:			
Prairie or tame hay.................	4,000	300-400	145-160
Small-grain straw...................	5,000	500-700	200-220
Coarse-stemmed stover[3]..............	8,000	500-700	230-255
Anchored with asphalt emulsion:			
Prairie or tame hay.................	4,000	300-400	185-210
Small-grain straw...................	5,000	500-700	260-310
Coarse-stemmed stover[3]..............	8,000	500-700	295-345

[1] Higher figures for rates and costs apply only to dune sands west of the 95th meridian; the lower rates and costs apply to all other soils and regions.

[2] Includes cost of seedbed preparation, seeding, applying and anchoring the mulch, and cost of mulch material.

[3] Corn, sorghum, etc.

Wood Cellulose Fiber

Recently, wood cellulose fiber has become available as a temporary mulch (16). It is processed wood cellulose fibers pressed in bales for convenience of transporation. When agitated with water, fertilizer, grass seed, and anchoring agent (if necessary), the individual fibers become suspended to form a uniform slurry. The slurry is sprayed on the ground with a hydroseeder, and it forms a blotterlike ground cover impregnated with grass seeds (fig. 19).

The hydroseeder should give sufficient agitation and have sufficient pump capacity to spary a uniform mixture. With the agitators working at full speed, water is added until good recirculation is obtained. Seeds are added while continuing to add water, then fertilizer, lime (if necessary), and fiber, in that order.

The amount and kind of seed and fertilizer needed depends on local geographic conditions and, therefore, should be determined from local authorities.

The bright color of the fiber serves as a guide for the operator to spray a uniform visible coat until no bare ground is showing. A uniform application requires a proper slurry nozzle that separates individual fibers well. A firehose-type nozzle composed of a single streamline orifice appears to be most satisfactory.

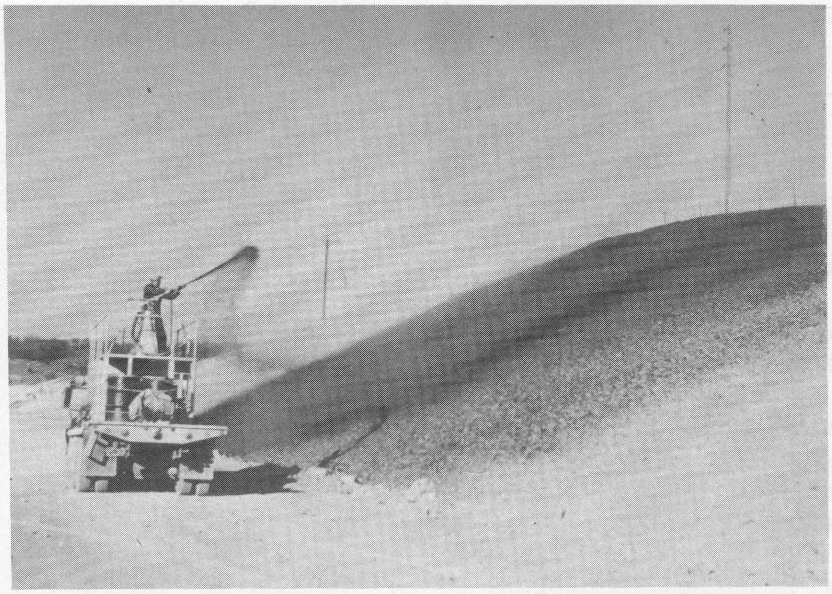


Figure 19.--A slurry composed of wood cellulose fiber, water, fertilizer, and grass seeds is sprayed on a new roadside shoulder. (Courtesy International Paper Co.)

For wind erosion control, provided the fiber is not washed away by rain, 1,000 pounds of fiber (on air-dry basis) in 1,000 gallons of water per acre is ample for most soils and about 1,000 pounds of fiber in 1,500 gallons of water per acre for dune sand. Cost of this mulch treatment (excluding seeds and fertilizer) at Manhattan, Kans., in 1962 was $95 and $130 per acre, respectively. The treatments are not entirely satisfactory for water erosion control, however, because heavy rains tend to wash the fiber away. The rains expose the soil surface, which subsequently may be eroded by wind. Less damage is done on sand than on finer textured soils, because water enters sand more freely.

Various organic anchoring agents have been added to the slurry to cement the fibers together so they will resist erosion by water. A suitable anchoring agent must be dispersible in the slurry, adhere to the fibers, and be insoluble in water. Asphalt-in-water emulsion and resin-in-water emulsion meet such specifications. From 200 to 300 gallons of asphalt or resin emulsion per acre mixed with 1,000 to 1,250 pounds of wood cellulose fiber per acre, depending on the geographic location and the soil texture, appear to be sufficient for both wind and water erosion control.

Unfortunately, more than 60 gallons of asphalt or resin emulsion per acre added to the slurry (composed of 1,000 pounds of fiber in 1,000 gallons of water, plus grass seed and fertilizer) is detrimental to the germination of seeds. The asphalt and resin apparently coat the seeds and restrict imbibition of water needed for germination. But 60 gallons per acre is not sufficient to anchor the fiber. Therefore, the two alternatives for effective germination and soil stabilization appear to be to drill or broadcast (hydroseed) the seeds first, then apply the fiber mixed with sufficient anchoring agent, or to hydroseed the seed and fiber mixture and then spray a thin coat (100 to 150 gallons per acre) of asphalt or resin. Per acre costs for such procedures at Manhattan, Kans., in 1962 ranged from $140 to $210 for fiber plus asphalt emulsion, and from $150 to $227 for fiber plus resin emulsion.

Resin and asphalt emulsions are about equally effective in holding the fiber. Cold water and resin tend to ball up the fiber more than warm water and resin. The asphalt-in-water emulsion, even with warm (75° F.) water, tends to plug up (freeze) the pump, and therefore, is difficult to apply. The resin-in-water emulsion presents no such difficulty.

Organic and Inorganic Liquids

Where vegetative mulches cannot be produced in place or hauled in, organic or inorganic liquids such as resin, asphalt, and latex emulsions and cutback asphalt can be sprayed on bare soil to stabilize it against erosion until permanent vegetation can be established. The liquid sprayed on the surface dries to form a thin erosion-resistant film.

Seeds of permanent vegetation must be planted before the liquid is sprayed. Where possible, the seeds should be drilled to get them down to moist soil. Broadcasting, as with a hydroseeder, is satisfactory if the soil surface is moist or if the material sprayed on the surface produces a sufficiently porous film so rain can moisten the seeds. Placing the seeds in dry soil and then spraying the surface to form a water-impermeable film makes it impossible for seeds to germinate.

For best results, spray the surface with as concentrated a liquid as possible. Dilution generally weakens the resistance of the film against erosion because it allows the material to penetrate the surface, to disperse in the soil, and to weaken the bond between it and the soil particles. The object is to place the material <u>on</u> the soil surface and not <u>in</u> the soil.

For uniform coverage of the surface, the spray should be as fine as possible. High pressure (60 pounds per square inch) and fine nozzles are essential. Heating the liquid, such as asphalt, is essential to produce a fine spray.

A mobile sprayer that will reach as far as possible and cover the surface quickly should be used. A spray unit such as on a blower-type mulch spreader (fig. 9) is useful because it is equipped with a convenient heating unit and employs the airstream and the pump pressure to disperse the liquid into a fine spray.

An ideal surface film is stable against erosion by wind and water, sufficiently porous to allow water to enter freely, insoluble in water, and resistant enough to disintegrating forces of the weather so that it will last as long as is necessary for permanent vegetation to become established. Next to well-anchored vegetative covers, resin-in-water emulsion comes closest to meeting these requirements.

Resin-in-water Emulsion

This liquid emulsion of water and natural petroleum resins is highly stable and can be diluted with large quantities of water without breaking the emulsion. The resins are highly resistant to weathering and soil bacteria.

When no traffic is involved, the material can be used in concentrated or slightly diluted form to produce a thin surface film resistant to wind and water erosion. On sandy soils (sands, loamy sands, sandy loams) and to a lesser degree on medium-textured soils (loams, silt loams, clay loams, silty clay loams) the resin-in-water emulsion readily penetrates the soil surface. The emulsion leaves the surface highly permeable to water and stabilizes the soil against erosion by wind and water for 6 months to several years, depending on the proportion of sand in the soil. The more sand, the longer the resinous film remains on the soil.

Water from heavy rains (about 3 inches per hour) penetrated the treated surface readily and left the clods virtually intact. The untreated surface on the other hand slaked smooth, and much of the water apparently ran off. Also, when diluted with water and sprayed in sufficient quantity to penetrate the soil 1 to 2 inches deep, the material will keep down dust that otherwise would arise from foot or vehicle traffic. Quantities and dilutions required for this purpose on different soil textures are given in a manual by Rostler and Vallerga (22).

Although the film is highly stable on and in sandy soils, unfortunately it disintegrates within a few weeks on very-fine-textured soils such as silty clay and clay. Apparently, the clay absorbs the material, causing the formation of loose granules that are readily eroded by wind and water. The material therefore is not recommended on such soils.

Immersing the seeds in resin-in-water emulsion restricts their germination. Therefore, it is best that seeds be drilled or broadcast and raked into the soil before the emulsion is sprayed on the surface.

Seeds of grasses, alfalfa, and sweetclover emerge readily through the resin-in-water film produced by rates up to 3/8 gallon of concentrate per square yard (1,800 gallons per acre). Germination and growth are generally much better than on untreated, bare areas where many of the seeds are often washed away by rains. Emergence is generally better through the resin-in-water film than through the asphalt and latex films.

The average quantities of resin-in-water emulsion concentrate required to produce surface films resistant to wind erosion on various soil textures are given below. Costs are based on those at Manhattan, Kans., in 1962, and include preparing a seedbed, seeding, and then spraying the surface with the emulsion with a mobile blower-type mulch spreader; costs do not include seeds and fertilizer.

- For loamy sands and sandy loams--1/8 gal./sq. yd. (600 gal./acre), diluted 1:1 with water, $225.
- For dune sands, sands, loams, silt loams, clay loams, and silty clay loams--1/4 gal./sq. yd. (1,200 gal./acre), concentrated, $415.
- For silty clays and clays--not recommended.

Asphalt Emulsion and Cutback Asphalt

The asphalts are natural bituminous materials in liquid form, products of the oil industry, and either positively or negatively charged (cationic or anionic). Slow, medium, and rapid curing (SC, MC, and RC) materials are available for cutbacks. The asphalt-in-water emulsion are usually rapid setting (setting rapidly to various degrees of hardness).

Asphalts for surface films should be slow curing or slow setting, contrary to the rapid-curing and setting kinds needed to anchor a vegetative mulch. The slow-curing kinds allow the grass seedlings to penetrate the film more easily.

Neither the asphalt emulsion nor the cutback asphalt penetrates the soil as readily as does resin-in-water emulsion; but for an effective erosion-resistant film, spraying concentrated emulsion is recommended. Heating is required to make concentrated cutback sprayable, and is usually needed with asphalt emulsion also.

The undiluted asphalt emulsion is somewhat less effective in controlling erosion than the undiluted cutback asphalt. In numerous tests, the asphalt emulsion film, unlike that of cutback, showed considerable contraction and cracking during the winter. This behavior is probably due to asphalt emulsion film being partially dispersible in water. Contraction of the film is somewhat detrimental from the standpoint of controlling erosion, but limited cracking may be beneficial under more humid conditions by allowing more water to penetrate the film instead of running off.

On sandy soils, the asphalt emulsion films from a 1,200-gallon-per-acre rate undergo the winter almost intact. On loam soils they disintegrate somewhat after going through the winter, but on silty clay and clay they disintegrate within 2 weeks to 3 months because of swelling and contracting of the soil. On the other hand, the cutabck asphalt films are much more resistant to the weathering forces and remain virtually intact for at least 6 months to more than a year, depending on soil texture.

The asphalt films are virtually nonporous and, consequently, much of the rainwater that falls on them runs off. Therefore, seeds may fail to germinate if insufficient moisture is present in the soil before the asphalt is sprayed on the surface. However, if the seeds are placed in or on moist soil before the asphaltic film is applied on the surface, germination and emergence of seedlings is almost unrestricted by the film when the rate of application does not exceed 1,200 gallons of concentrate per acre. Higher rates restrict emergence considerably.

The average quantity of asphalt emulsion or cutback asphalt required for effective control of erosion on bare soils on any texture is about 1/4 gallon per square yard (1,200 gallons per acre), sprayed in concentrated form. The cost of this treatment (excluding seeds and fertilizer) at Manhattan, Kans., in 1962 was $250 per acre for cutback asphalt and $350 per acre for asphalt emulsion.

The above-mentioned quantity is more than ample to control wind erosion on some bare soils, especially in the humid region. However, this quantity is needed for water erosion control on bare soils (fig. 20), and lower rates will not meet the uniform standard that has been set for all types of mulches discussed in this report.

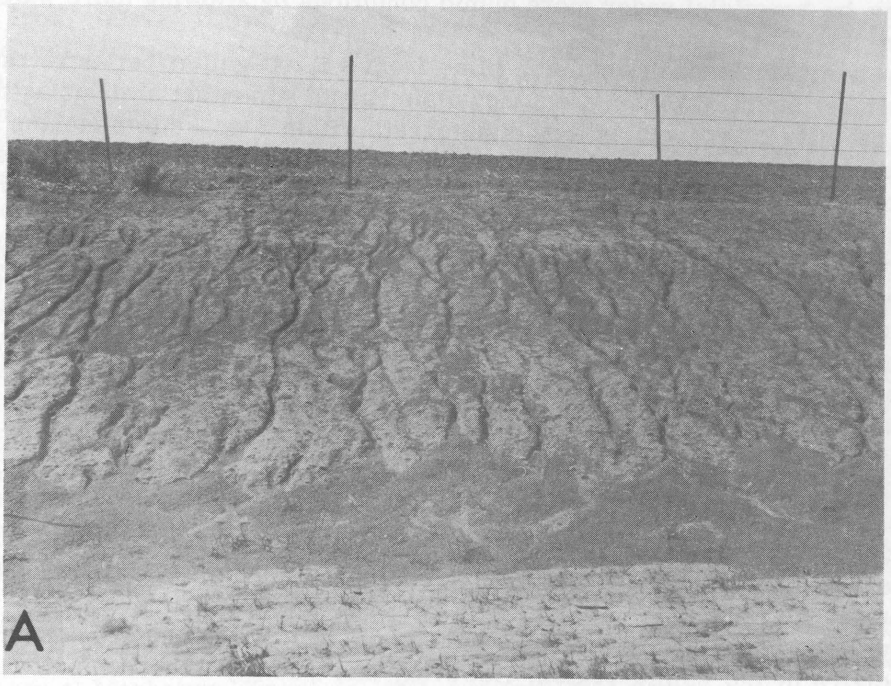
Latex-in-water Emulsion

This is an elastomeric polymer emulsion that, when diluted with water and sprayed on the soil surface, produces a rubbery film resistant to erosion by wind and water (15). The emulsion breaks readily on contact with the soil and therefore does not penetrate the surface readily. Unfortunately, it does not control wind and water erosion sufficiently unless the film is virtually continuous over the surface. Then, as with asphalts, the film limits percolation of water into the soil. Restricted percolation is not serious, provided seeds are placed in or on moist soil prior to application so they will germinate. Germinated grass and legume seeds penetrate the film readily at effective rates of latex application.

To avoid breaking the emulsion, it should be diluted only with neutral water (about pH 7.0). For effective spraying of unheated emulsion, the concentrate must be diluted at least 1:1 with water.

The average quantity of latex emulsion for effective control of wind and water erosion of bare soils of any texture is about the same as for cutback asphalt or asphalt emulsion; namely, 1,200 gallons of concentrate per acre. At $1.60 per gallon, as at Manhattan, Kans., in 1962, the cost is prohibitive.

As with asphalts, the above quantity is more than ample to control wind erosion in areas where water erosion is a major problem, but lower rates to control only wind erosion are not recommended except for areas where water erosion is not a problem.



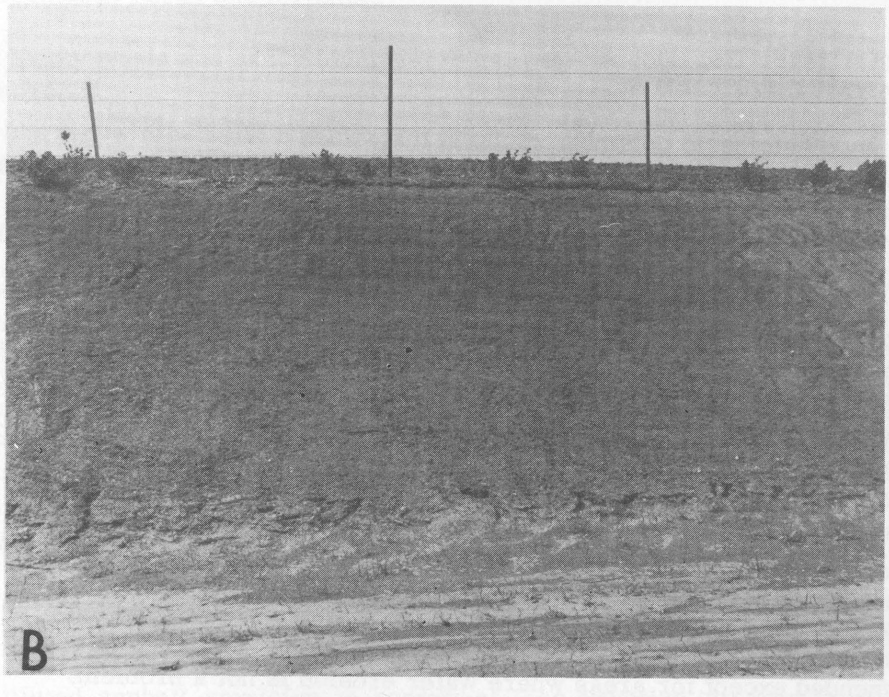


Figure 20.--A, Highway right-of-way with 3:1 slope where grass seeds, fertilizer, and surface soil were washed away by rains. B, Same right-of-way seeded, fertilized, and then treated with asphalt emulsion at rate of 1/4 gallon per square yard, showed no erosion. Seedlings emerged readily through the asphalt film. Part of the plot not treated with asphalt is shown on the extreme right.

Gelatinized Starch Solution

This hydrolized starch produced a wind-resistant film only until a rain fell. It was found completely ineffective after going through a winter. The starch appeared to have decomposed or leached from the surface soil. The darker color of the treated compared with untreated plots indicated that at least some of the starch was decomposed 6 months after application. At that time the starch-treated plots were more wind erodible than the untreated plots.

Ammonium Lignin Sulfonates and Sugars Solution

This water-soluble byproduct of the paper pulp industry, like hydrolized starch, was effective only until a rain fell. It increased wind erosion after undergoing the weathering influence of winter.

Sodium Silicate and Calcium Chloride Solution

Both of these inorganic compounds were dissolved in water together. Like other water-soluble compounds, they washed away with rains. Sodium silicate alone was toxic to emerging grass and legume seedlings. Calcium chloride tended to reduce the toxicity but did not entirely overcome it.

Gravel, Stones, and Crushed Rock

Gravel, stones, and crushed rock have one advantage over hauled-in vegetative mulches for controlling wind and water erosion--they are permanent (6). On soil subject to rill and gully erosion, however, quantities required for water erosion control have not been determined. Gravel, stones, and crushed rock are generally stable against wind erosion if the individual pieces are no smaller than about 2 millimeters (1/12 inch) in diameter. This diameter of gravel of 2.65 density generally requires a wind velocity of about 85 miles per hour at 50-foot height to set it in motion. Such wind velocity is extremely rare.

To control wind erosion, gravel, stones, or crushed rock must almost cover the soil surface (fig. 21). A cover composed of one gravel diameter thickness will protect the soil from wind no matter how erodible the soil may be. The finer the gravel, the less is required to cover the ground. It is important that the soil surface be smooth before applying the gravel and that a spreader capable of applying a uniform cover be used.

The per-acre quantities and costs (as at Manhattan, Kans., in 1962) of gravel or crushed limestone needed to control wind erosion (even on the most erodible dune sand or anywhere that water will not remove it) were:

- Fine gravel (1/12 to 1/4 inch in diameter)--20 tons, $55.
- Medium gravel or crushed limestone (1/4 to 1/2 inch in diameter)--50 tons, $200.
- Coarse gravel or crushed limestone (1/2 to 1-1/2 inches in diameter)--100 tons, $375.

Costs include preparing a seedbed, seeding, and hauling and applying the material, with source of supply not over 10 miles from site. Natural gravel is usually much less expensive than crushed limestone and may be obtained for little more than the cost of hauling.

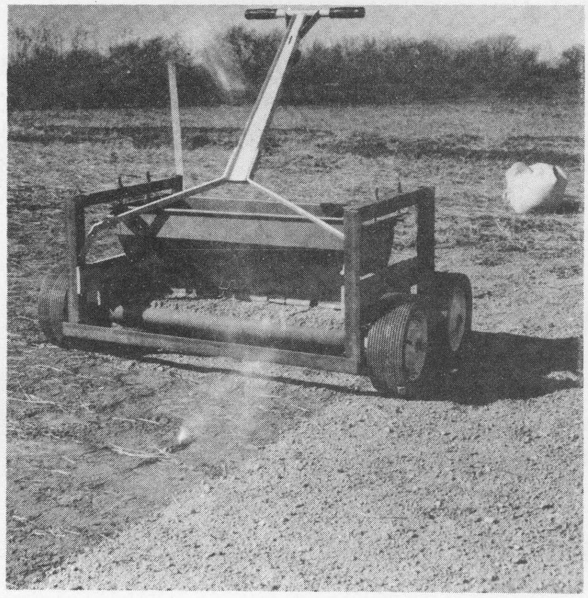


Figure 21.--Experimental gravel spreader, 30 inches wide, is shown spreading 20 tons of fine gravel per acre. The spreader is adjustable for rates of 5 to 50 tons per acre. For rates greater than 50 tons, repeated spreading is required.

A certain proportion (probably up to 25 percent) of sand in natural gravel is not serious but should not be considered as part of the gravel. It may be more economical to separate it from the gravel rather than to haul it to and spread it on the site.

Permanent, economical stabilization of sand dunes may be possible with gravel, stone, or crushed rock mulches in desert areas where vegetation cannot be grown; they may also be used in humid areas where the source is plentiful and near.

Because gravel, stone, and crushed rock remain on the ground permanently, if not removed by running water, seeding may be unnecessary. The land may be left idle until natural vegetation takes over.

PERMANENT VEGETATION

The final objective in stabilizing bare soil is to establish permanent vegetation commonly prevailing in the region. The most suitable type of permanent vegetation usually is the climax vegetation, but not always. For example, perennial grasses and legumes are most suitable on highway right-of-ways although the climax vegetation in a forested region through which a highway may run is trees. Grasses are the climax vegetation in most of the Western and Central United States (2, 12, 18, 25). Local authorities should be consulted for species of grasses and legumes, vines, shrubs, or trees most suited to a specific region and for a specific purpose.

It is important to emphasize that no weeds or crop plants be allowed to grow, in the temporary mulch at or soon after seeding or planting of the permanent species. Otherwise, the weeds or crop plants will compete with seedlings of the permanent species for moisture.

In planting vegetative stock of grasses (such as bermudagrass) it is better to plant them directly into the vegetative mulch rather than to plant them on bare ground and then apply the mulch.

Where grasses constitute permanent vegetation, mowing is essential, especially during the early stages of grass development when weeds or volunteer grain are most prevalent. Selective herbicides may be sprayed to kill the weeds and encourage the grass. Adequate fertilizing is usually necessary to maintain and improve the grass.

Where vines, shrubs, or trees constitute permanent vegetation, it is essential to keep other types of vegetation down until the permanent species become established. In humid areas, weeds among the permanent species may be kept down by mowing; in dry areas they may have to be kept down by cultivation.

Land in permanent vegetation should be guarded from fire, overgrazing, and excessive cutting of shrubs and trees. Fencing may be desirable to keep livestock out.

SUMMARY

No mulching material tested excelled well-anchored vegetative mulch in both cost and effectiveness in controlling wind and water erosion of denuded land. All other materials tested, except those that form water-soluble surface films, controlled erosion by wind and water when applied in sufficient quantity and concentration, but at a cost generally higher than that for the well-anchored vegetative mulch.

Resin-in-water emulsion was the only nonvegetative material that produced a surface film resistant to wind and water erosion porous enough to allow percolation of water for adequate seedling emergence; however, the surface film maintained these characteristics sufficiently long only on sandy and medium-textured soils, not on clays and silty clays.

Cutback asphalt, asphalt emulsion, and latex emulsion, when applied in quantities sufficient to control wind and water erosion, produced nonporous films that restricted percolation of water into the soil, thereby reducing seedling emergence when soil moisture was inadequate.

Excessive dilution of organic and inorganic liquids reduced their effectiveness in controlling wind and water erosion. A fine spray produced a more durable film than a coarse spray. Concentrate liquid asphalts had to be heated to produce a fine spray.

Materials that produced water-soluble surface films were inadequate for wind and water erosion control, because the films washed away with the first substantial rain. These materials might have some benefit in arid regions.

Gravel and stone mulches, sufficient to barely cover the surface, effectively controlled wind erosion, even on dune sand.

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