Cost Analysis for Several Mulching Systems Used in Surface-Mine Reclamation in Eastern Kentucky

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Several mulching agents were evaluated for their economic feasibility and revegetative responses on surface mines in eastern Kentucky. The most widely used soil amendments are wood fiber mulches. Wood fiber mulch, along with a seed and fertilizer mixture, is suspended in water for a one-step revegetative effort. Alternative mulches, such as processed municipal waste, bark, general sawmill residues, and straw and hay with asphalt binders, were evaluated for their economic feasibility. Each mulching system's equipment, labor, and daily area of application were evaluated. Costs per acre indicated that processed bark was the least expensive to apply on outslopes and hollow fills. The machinery for applying mill residue was more complex and required that the mulch be processed before its application with a truck-mounted thrower unit. In the two most heavily mined regions of eastern Kentucky, bark resources were available in sufficient quantity to revegetate 2956 acres annually at the recommended rate of 45 yd^3/acre. Almost all these mill residues required processing to improve quality, reduce equipment breakage, and increase ease of handling.

More than 90 percent of the nation's coal came from deep mines as recently as 30 years ago. Today, more than 50 percent of all coal produced in the United States is produced by surface mining. The federal government's proposed energy program calls for a 67 percent expansion in the coal industry, and the amount of coal mined is projected to rise to more than one billion tons/year by 1985.

The increased rate of mining and the recently enacted Surface Mining Control and Reclamation Act of 1977 (P.L. 95-87) require the rapid development of improved surface-mine-revegetation techniques. Environmental performance standards in P.L. 95-87, such as those defined under the sections on prime farmland, post-mining land use, approximate original contour, topsoil segregation and storage, revegetation, and protection of the hydrologic system, require that coal extraction must be planned and monitored in such a way that the post-mining conditions are as good as or better than the premined land conditions. The first four environmental standards may be achieved through good planning during the premining phase and sound engineering practices both during and after mining, whereas the latter two elements are biological in nature.

This paper addresses results of research aimed at improving conditions for effective revegetation of mined sites. A series of studies at the University of Kentucky indicate that the microenvironment of the surface spoil is greatly enhanced when some type of insulating mulch is applied, which improves the chances of success for initial revegetation efforts.

Currently, a simultaneous application of seed, fertilizer, and a processed wood fiber mulch (WFM) is used almost exclusively for revegetation of areas disturbed by surface mining in eastern Kentucky. Kentucky state law requires only that mulch be applied to the outslopes and hollow fills, where outslope means the face of the spoil or embankment that slopes downward from the highest elevation to the toe of the moved material, and hollow fill refers to a fill structure that consists of any material other than coal processing waste and organic material that is placed in the upper-most reaches of a hollow for either temporary or permanent storage.

The application of tree bark or sawmill waste, other composted organic residues, and hay or straw on disturbed sites can increase vegetative cover and reduce erosion losses (1). The environmental problems associated with disposal of sawmill residues and processed municipal waste make these mulches attractive for use in surface-mine reclamation.

Area application of these waste products has not been practical until recently because equipment capable of applying these materials had not been developed (2). This obstacle has been eliminated by the recent development of a truck-mounted power thrower constructed by the Estes Aero-Spread Equipment Company of Winchester, Kentucky.

METHODS

Time studies at the University of Kentucky were conducted with two 2500-gal Finn hydroseeders and compared with those attained with the Estes truck that applied unprocessed bark, processed bark, and composted municipal waste (3). Straw and hay (with asphalt binder) mulching system production rates were compiled through interviews with reclamation personnel that use these materials as a mulching medium. These studies formed the basis for determining the costs and production rates of each system evaluated.

Depreciation of the equipment was computed by using the straight-line procedure over its expected life. In computing hourly machinery costs, an operation year is assumed to consist of 180 days. The 180-day period allows 10 percent equipment down time and assumes that no revegetative efforts are conducted during the winter months of December, January, and February.

Other important costs that are not included in this study are the costs of site preparation prior to seeding, fertilizer, and seed. These were not considered part of the analysis because of the inherent variations in soil structure, topography, types of surface mining, and management decisions that concern final land use. These should be treated as fixed costs because the cost of seed, fertilizer, and site preparation is essentially common to each site.

RESULTS

Wood Fiber Mulch

Kentucky law requires that mulches be applied at rates that are consistent with the revegetation plan. Suggested rates for application of WFM on outslopes and hollow fills are 1500 lb/acre. Mulching may not be required on areas not subject to erosion. Two 2500-gal Finn hydroseeders that were used on two different mining sites were evaluated to determine the average daily area that could be mulched. Data from both locations were combined. Travel time to available water was important, but the factor most limiting production was the time necessary for the two-man crew to lift and load the 1100 lb of mulch, fertilizer, and seed required for each trip. Average water-filling time was 6.86 min. Discharge time for the mulch, fertilizer, and seed mixture was 11.98 min. Standard deviations were 0.43 and 0.80 min, respectively.

The average round-trip cycle time was 59 min when

Table 1. Equipment, depreciation schedule, and calculated cost of applying hydromulch at 1500 lb/acre.

Item	Equipment Cost ($)	Straight-Line Depreciation Schedule (years)	Yearly Charge ($)	180-Day Operating Year ($/day)	Cost per Acre[a] ($)
Dual axle truck (Mack)	45 000	7	6428	35.71	7.44
2500-gal hydroseeder (Finn)	13 600	7	1943	10.79	2.25
Hydromulch					165.00
Two operators (each at $10/h)					33.33
Total	58 600				208.02

[a]Cost calculated by using the 4.8 mulched acres/day derived through time studies.

an available water-supply point was within a 1-mile radius of the reclamation site. Each full load mulched 0.6 acre at a rate of 1500 lb/acre. A two-man crew could apply mulch, seed, and fertilizer to 4.8 acres in an 8-h work day. By using this production rate, the itemized cost of $208.02/acre was calculated for the application of WFM (see Table 1). The largest single cost item for this system of mulching was the price of WFM. The spring 1978 price of $220.00/ton was used in calculating this value.

Bark

When bark is applied as a mulch to outslopes and hollow fills in Kentucky, the state-suggested rate of application is 45 yd³/acre. This rate provides a protective insulating layer of approximately 0.32 in, and it is close to the recommended application rates of 30-50 yd³/acre suggested by Sarles and Emanual (1) and 35 yd³/acre suggested by Allison (4) to provide good erosion control and vegetative cover.

Unprocessed bark was applied with the Estes aero-spread truck in the fall 1977. The material was loaded directly onto the transport vehicles from a residue pile that was generated from a carbon-tip, rosserhead debarker. Application was slow because the larger particles tended to bridge between the slope sides of the aero-spread truck, which prevented the mulch from falling onto the conveyor belt that feeds the thrower assembly. Average discharge time was 0.95 yd³/min. The slow and erratic discharge times increased loader idle time and allowed only 3.8 acres/day to be mulched when the area was within a 0.5-mile radius of the loading point. The risk of large foreign materials that could damage the thrower unit was a constant threat. Seed mixtures were metered directly from a storage bin mounted above the thrower assembly and applied with the mulch. Fertilizer was mixed prior to loading or added during the loading operation. Itemized cost per acre for equipment, labor, and transportation for unprocessed bark totaled $110.35 (see Table 2).

Processing mill residues to increase production time and reduce equipment down time was investigated. Processing can be accomplished with a unit such as a hog or hammer mill at the sawmill site or with a portable unit transported from location to location. Interviews with sawmill operators in eastern Kentucky indicated a willingness to install the necessary processing units, but only if a firm could be contracted to purchase the residue at a price that was sufficient to cover its investment, expenses, maintenance, and management of such equipment.

A Farmhand 900B tub-grinder was evaluated for its potential use as a portable processing unit. A self-contained tub-grinder, powered by a 220-hp diesel engine, is commercially available, but the unit evaluated in this study was powered by an 8700 Ford, 115-hp farm tractor. A Michigan 45B front loader with a 2-yd³ bucket loader was used to feed the grinder unit. Particle size reduction decreased the input-to-output volume by 50 percent. An average output of bark at 1.52 yd³/min, or 91.36 yd³/h, was processed by the grinder. The processed bark mulch increased the Estes thrower capacity to 2.14 yd³/min with an SD of 0.86 yd³/min. Operation of the two units increased the area that could be mulched from 3.8 to 8.5 acres/day. With a stock pile of processed mulch within a 0.5-mile radius of the reclamation area, the itemized cost per acre was reduced to $83.12 (see Table 3).

Composted Municipal Waste

Disposal of solid and sewage waste is an increasingly serious problem in our cities. Although the idea of composting these wastes to yield a usable mulch through rapid action of thermophilic aerobic bacteria is not new, the application of these composts as mulches to surface mines is a recent development. The need to establish such uses to eliminate the problems associated with land fill and waste-incineration operations has led to the application of a composted mulch that consists of 67 percent solid waste and 33 percent raw sewage or water and sewage sludge on Kentucky surface mine areas. The material was composted by the Real Earth Naturizer plant in Norman, Oklahoma.

Composted municipal waste is of a sufficient texture that grinding or further processing is not required for application with the Estes Aero-Spreader. Recommended rates for application to disturbed sites have not yet been established by the Kentucky Bureau of Reclamation and Surface Mining. Preliminary data indicate that approximately 20 tons/acre is sufficient for good erosion control and vegetative response (5). At a volume of approximately 2.4 yd³/ton, this represents about 48 yd³/acre, or a mulch depth of 0.34 in.

Application time with the Estes Aero-Spreader was 2.24 yd³/min (SD = 0.80) when discharged through the thrower unit. This system could apply 20 tons/acre of Real Earth Naturizer to 8.5 acres/day when within a 0.5-mile radius of the loading point. Thrower discharge capacity was slightly lower for processed bark, but the additional 3-yd³/acre requirement made the area mulched per day the same as processed bark.

Application costs were $671.15/acre (see Table 4). Increased transportation cost and the $28.50/ton FOB plant were the inflating factors. Transportation cost was assessed by assuming that a composting plant was located within an 80-mile radius of the treatment site. Transportation cost was found by soliciting bid quotes from trucking firms. Plant locations that are farther away may require cost adjustments.

Straw and Hay with Asphalt Binder

The suggested rate of application of hay or straw with binder as a mulch in Kentucky is 1.5 tons/acre. However, competing uses of straw and hay within the Bluegrass areas of Kentucky have limited the amounts available as a mulch in the mountainous eastern Kentucky regions.

The application rates and other data were compiled from interviews with mining and contracting firms that use this mulching system. Results indicate that an average of 7.5 acres/day can be mulched at the 1.5-ton rate. Some 100 gal of an emulsion-

Table 2. Equipment, depreciation schedule, and calculated cost of applying unprocessed bark at 45 yd^3/acre.

Item	Equipment Cost ($)	Straight-Line Depreciation Schedule (years)	Yearly Charge ($)	180-Day Operating Year ($/day)	Cost per Acre[a] ($)
Two-yard front loader (Michigan 45B)	42 000	10	4200	23.33	6.14
Estes Aero-Spreader[b]	28 000	7	4000	22.22	5.84
Bark transportation cost[c]					56.25
Two operators (each at $10/h)					42.11
Total	70 000				110.35

[a]Cost calculated by using the 3.8 mulched acres/day derived through time and motion studies.
[b]Single-axle Ford truck with thrower unit powered by a 300-in^3 Ford gasoline engine.
[c]From actual spring 1978 total transportation cost of $1.25/yd^3 for transportation not farther than 25 miles (one way).

Table 3. Equipment, depreciation schedule, and calculated cost of applying processed bark at 45 yd^3/acre.

Item	Equipment Cost ($)	Straight-Line Depreciation Schedule (years)	Yearly Charge ($)	180-Day Operating Year ($/day)	Cost per Acre[a] ($)
Two-yard front loader (Michigan 45B)	42 000	10	4200	23.33	2.92
Estes Aero-Spreader[b]	28 000	7	4000	22.22	2.61
Farmhand tub-grinder[c]	27 000	7	3857	21.43	2.52
Bark transportation cost[d]					56.25
Two operators (each at $10/h)					18.82
Total	127 000				83.12

[a]Cost calculated by using the 8.5 mulched acres/day derived through time and motion studies.
[b]Single-axle Ford truck with thrower unit powered by a 300-in^3 Ford gasoline engine.
[c]Farmhand 900B tub-grinder powered by a self-contained 200-hp diesel engine.
[d]From actual spring 1978 total transportation cost of $1.25/yd^3 for transportation not farther than 25 miles (one way).

type binder must also be applied per ton of hay or straw to prevent it from blowing away from the site. Equipment requirements and costs per acre were $227.37 (see Table 5).

Twenty-five percent of the daily operating costs of a hydroseeder and crew were charged to the per acre cost for this system. This was necessary because mining firms that were interviewed used hydroseeders to apply seed and fertilizer rather than applying it manually.

CONCLUSIONS AND RECOMMENDATIONS

The cost of equipment was minor in all of the systems evaluated when it was reduced to cost per acre for application. The factors that had the greatest effect on overall cost were prices of the mulching material, transportation, and labor. Cost data for fuel, lubricants, or maintenance were not calculated for any of the systems.

A summary of equipment costs and application cost per acre for each mulching system investigated is given below:

Mulching System	Equipment Cost ($)	Mulch Application and Material Cost per Acre ($)
Hydromulching	58 600	208.02
Unprocessed bark	70 000	110.35
Processed bark	127 000	83.12

Table 4. Equipment, depreciation schedule, and calculated cost of applying composted solid municipal waste at 20 tons/acre.

Item	Equipment Cost ($)	Straight-Line Depreciation Schedule (years)	Yearly Charge ($)	180-Day Operating Year ($/day)	Cost per Acre[a] ($)
Two-yard front loader (Michigan 45B)	42 000	10	4200	23.33	2.92
Estes Aero-Spreader[b]	28 000	7	4000	22.22	2.61
Composted municipal waste[c]					570.00
Transportation cost[d]					76.80
Two operators (each at $10/h)					18.82
Total	70 000				671.15

[a]Cost calculated by using the 8.5 mulched acres/day derived through time and motion studies.
[b]Single-axle Ford truck with thrower unit powered by a 300-in^3 Ford gasoline engine.
[c]Based on Real Earth, Ltd., quoted price of $28.50/ton free-on-board (FOB) price at the plant in Versailles, Kentucky.
[d]Cost from low bid quote of $1.60/yd^3 for maximum one-way trip of 80 miles and assuming 2.4 yd^3/ton.

Mulching System	Equipment Cost ($)	Mulch Application and Material Cost per Acre ($)
Composted municipal waste	70 000	671.15
Straw or hay	57 650	227.37

The expansion of these data, which include varying rates of mulching, is given in Table 6.

Mulching with a hydroseeder was found to be very versatile and exhibited an effective range of coverage of up to 200 ft. The 2500-gal unit could lightly mulch, seed, and fertilize 4-5 acres/trip, depending on terrain and crew experience. On sites that did not require a specified mulching rate, a two-man crew could cover 32-40 acres/day. Poor sites that required 1500-lb WFM/acre reduced the capacity to 4.8 acres/day (see Table 7).

Processed and unprocessed bark could be applied at Kentucky's recommended rates for the lowest cost per acre. The aero-spread truck was also capable of effectively reaching a coverage range of up to 200 ft with processed bark. The decreased risk of damage to the thrower unit and the increased production rates with processed residues indicate that sawmill residues should be processed prior to application.

The Farmhand 900B tub-grinder processed the mill residues in sufficient quantities to keep a ready supply for the aero-spread truck. The tub-grinder also processed hay, sugarcane stalks, partially composted trash, and a mixture of chicken manure and bark. With proper screens it can also process a multitude of dry organic-waste materials.

Sawmills annually generate enough residue to mulch 2956 acres at the recommended rate of 45 yd^3/acre in the two most heavily mined forest service survey units of eastern Kentucky (6). This material, which has been considered a problem in waste disposal, may begin to increase in value with its development as a mulching agent. Holding all other costs constant, the price per cubic yard that may be paid at sawmills within a 25-mile radius, and not exceed the cost of hydromulch application, is $2.78.

The cost of composted municipal waste ($28.50/ton FOB plant), including its transportation and availability, is currently more expensive than alternative mulches. However, the concept is good and some type of federal subsidy for firms that use processed waste from surrounding cities in their reclamation effort may be a possible answer to some of the envi-

Table 5. Equipment, depreciation schedule, and calculated cost of applying straw and hay at 1.5 tons/acre.

Item	Equipment Cost ($)	Straight-Line Depreciation Schedule (years)	Yearly Charge ($)	180-Day Operating Year ($/day)	Cost per Acre[a] ($)
15-ton/h power mulcher[b]	13 000	5	2600	14.44	1.44
Dual-axle flat-bed truck	30 000	7	4286	23.81	2.38
2500-gal hydroseeder[c]	3 400	7	486	2.70	0.36
Dual-axle truck[c]	11 250	7	1607	8.93	1.19
Two operators[c]					5.33
Hay or straw mulch[d]					120.00
Binder (asphalt)[e]					54.00
Four operators (each at $10/h)					42.67
Total	57 650				227.37

[a]Cost calculated by using the 7.5 mulched acres/day derived through time and motion studies.
[b]Includes a Finn, Eagle model, 15-ton/h, and 50-gal/min asphalt-binder system.
[c]Charges of 25 percent of a Finn 25 000-gal hydroseeder to be used for the application of seed and fertilizer.
[d]Average cost of $80.00/ton for hay or straw delivered.
[e]Binder is applied at the rate of 100 gal/ton and cost $0.36/gal.

Table 6. Expanded cost per acre for applying varying rates of mulches.

Mulching System and Rate	Cost per Acre[a] ($)	Mulching System and Rate	Cost per Acre[a] ($)
Apply seed and fertilizer only	43.02	Hydromulch at	
		250 lb/acre	70.52
Processed bark at		500 lb/acre	98.02
45 yd^3/acre	83.12	750 lb/acre	125.52
70 yd^3/acre	129.30	1000 lb/acre	153.02
140 yd^3/acre	258.60	1500 lb/acre	208.02
Composted municipal waste at		Hay or straw at	
		1.5 tons/acre	227.37
20 tons/acre	671.15	3.0 tons/acre	454.74
40 tons/acre	1342.30		

[a]Price includes cost of mulch, transportation, straight-line depreciation of equipment, and cost of labor per acre of mulch application.

Table 7. Average daily acres of mulch applied for each mulching system.

Mulching System	Acres Mulched Daily (8 h)
Hydroseeder applying 1500 lb/acre of hydromulch	4.8
Estes spreader applying	
Unprocessed bark at 45 yd^3/acre	3.8
Processed bark at 45 yd^3/acre	8.5
Composted municipal waste at 20 tons/acre	8.5
Straw or hay applied at 1.5 tons/acre	7.5

ronmental problems of disposal of municipal waste.

The potential of hay and straw mulching systems is limited on surface mines in eastern Kentucky. Backing into or out of hollow fills presents a safety hazard to revegetation crews in mountainous terrain. Supplies of hay and straw are usually some distance from mining activity and multiple handling of each bale makes mulching with this system very strenuous.

No single mulch material exists in quantities great enough to satisfy the industry's needs except WFM. It is capable of producing acceptable levels of vegetation on many sites. However, it is not suitable in all cases. This necessitates consideration of revegetation systems that are capable of applying various mulching mediums so that the one best-suited for a particular situation can be used.

It may be necessary to consider blending mulches to attain specific chemical and physical properties and equalize cost structures. Research in this area has already begun in Kentucky. Combinations of bark or whole tree chips, industrial waste, and poultry manure are being evaluated. Other possible materials that should be tested include hay, straw, or leaves that are processed through grinder systems because of their rapid use and blending capabilities.

The objective of future research will be to meet mining-area needs for mulching mediums for revegetation while also solving the waste-disposal problems of surrounding communities. Mining firms should not consider a single mulching system as the solution to their complete revegetation needs. Combinations of mulches and mulching systems should be considered for cost of investment, cost per acre of application, revegetation achieved, and the overall environmental qualities produced by each.

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