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EROSION CONTROL ON A STEEPLY SLOPED PIPELINE RIGHT-OF-WAY IN SOUTHWESTERN PENNSYLVANIA

Stanley D. Zellmer and Dorland E. Edgar
Energy Systems Division
Argonne National Laboratory

and

H. Ronald Isaacson
Gas Research Institute

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Abstract

The results of precipitation on steeply sloped pipeline rights-of-way (ROWs) during the time between ROW rehabilitation and the establishment of a dense, self-sustaining vegetative ground cover can cause locally severe soil erosion. This erosion results in elevated sediment loads in receiving streams and increases the difficulty and costs of ROW maintenance. A field study was completed that compared the environmental effectiveness of nine treatments (six erosion-control measures and three controls) on a 28% ROW slope in southwestern Pennsylvania. Replicated plots were established immediately after ROW cleanup directly over the pipeline and on the working side of the ROW. The six erosion-control methods investigated in the study, selected to represent a wide range in material type and installation cost, were (1) heavy application of straw mulch, (2) light application of straw mulch, (3) processed wood fiber, (4) chemical soil binder, (5) paper strips in netting, and (6) light straw mulch with a tacking agent. Each of the test plots also received the basic treatment of limestone, fertilizer, and a seed mixture commonly used to rehabilitate ROWs in the region. The basic treatment alone served as a control, as did on-ROW natural vegetation (no erosion-control treatment) and off-ROW undisturbed native vegetation. Precipitation, runoff volumes, and sediment yields were measured on each of 51 plots for 45 precipitation events during the 18-month study. Vegetation data were collected by the point-intercept method four times during the study to determine the amount of plant cover and species composition. Differences in sediment yield were observed among methods and between ROW location, but plant cover development was not influenced by erosion-control method or location. The relationship between environmental and cost data indicated that, of the six erosion-control methods tested, a light application of straw mulch (3.35 metric tons per hectare [1.5 tons/acre]) was the most effective erosion-control treatment.

Introduction

The installation of large-diameter gas transmission pipelines requires the excavation, temporary storage, and replacement of a large quantity of soil. These activities destroy existing vegetation on right-of-ways (ROWs) and can alter the physical and chemical characteristics of excavated and replaced soil materials. The delivery and transport of heavy pipe along a ROW, along with the vehicle traffic required for the bending, welding, and coating of the pipe, can compact soils on the working side of the ROW. All of these construction activities may change surface soil properties and increase ROW susceptibility to potential erosion and may also inhibit the establishment and development of vegetation.

When ROWs pass through cultivated cropland, erosion control after ROW cleanup is generally the responsibility of the farm operator. On uncultivated areas (such as woodlots, pastures, and road ditches), the pipeline company must provide erosion control. On level and gently sloping (<10%) areas, stabilization can be achieved by standard reseeding methods. However, when ROWs traverse steeper slopes, additional and more extensive erosion-control measures are required.

The optimal means of stabilizing ROWs and inhibiting soil erosion on a steep slope is a dense, self-sustaining vegetative ground cover. However, during the time between pipeline installation and the establishment of adequate vegetative ground cover, soil erosion by water can be locally severe and difficult to control. Uncontrolled erosion results in the loss of valuable topsoil, may elevate sediment loads in receiving streams, and increases the difficulty and costs of revegetating and maintaining the ROW. In addition to environmental and economic effects, the visible evidence of accelerated soil erosion degrades the appearance of the ROW, possibly leading to social concerns about the presence of pipeline ROWs. Further, accelerated erosion could contribute to corrosion of the pipeline and lead to a potentially serious safety hazard.

An extensive body of literature discusses the phenomenon of soil erosion and the various factors and conditions that influence the magnitude and rate of soil erosion (for example DeBoodt and Gabriels, 1980; Kirkby and Morgan, 1980; and El-Swaify, Moldenhauer, and Lo, 1985). The relationship between soil erosion by water and modern agriculture also has been examined extensively. Various farming practices, cropping systems, and specific structures (e.g., terraces and grassed waterways) for reducing and controlling erosion have been studied in detail by Stallings (1957), Beasley, Gregory, and McCarty (1984), and by many other scientists and engineers. Procedures have been developed for predicting soil erosion rates (see Foster, 1977) and for determining soil loss tolerances on agricultural lands (Schmidt, 1982). A number of other publications describe engineering approaches and structures designed to control soil erosion and sedimentation during highway construction, mining operations, and similar activities (for example Goldman, Jackson, and Bursztynsky, 1986), and agencies of most state governments have prepared detailed erosion and sediment control guides and manuals for use during inspection and enforcement of soil erosion control regulations.

A common observation throughout the soil erosion literature is that one of the most effective methods for long-term erosion control is a dense vegetative ground cover. Most noncultivated sections of pipeline ROWs in the humid regions of the United States are successfully revegetated in about one or two growing seasons. The time required to establish vegetative cover depends on local conditions (e.g., reclamation practices, season, precipitation, soil physical and chemical characteristics). However, even under ideal conditions, the ROW soil surface is exposed for a time and, if left unprotected, is subject to erosion until the vegetative cover becomes established. To prevent erosion on steep ROW slopes during this critical period, a prevegetation soil erosion control method is required.

An effective prevegetation erosion control method has several functions while vegetation is becoming established. One function is to protect the soil surface from the impact of raindrops to reduce splash erosion and to inhibit the crust formation and surface sealing that reduce infiltration and increase runoff. A second function is to prevent the concentration of rainfall and runoff into channels that may develop into rills or gullies on the ROW. To be effective, the control method should also create seedbed conditions that encourage development of a dense vegetative ground cover for long-term stability. Finally, the control method must be accomplished at a reasonable cost.

Research Objectives

The discussion that follows is based on information and results presented in the final report prepared by Argonne National Laboratory (ANL) for the Gas Research Institute (GRI) on various approaches for the control of erosion on steeply sloped pipelines (Zellmer and Taylor, 1988). The objective of this study was to determine, under field conditions, the environmental and economic effectiveness of various nonvegetative control methods for reducing soil erosion on pipeline ROWs prior to the establishment of a protective vegetative cover. To achieve this overall objective, the study was designed to (1) determine the magnitude of the erosion rate resulting from pipeline installation, (2) measure the effectiveness of several prevegetation methods for reducing soil losses, (3) evaluate the influence of the methods tested on establishing vegetation, (4) estimate the relative economic cost of the methods tested, and (5) provide an environmental and economic comparison of the methods tested.

The investigation was aimed at obtaining information to improve soil erosion control on pipeline ROWs efficiently and cost-effectively. Shorter design times, decreased manpower and equipment needs, and minimal rehabilitation materials will reduce the cost of pipeline construction, and the savings can be passed along to the rate payer. Decreasing erosion and sedimentation on pipeline ROWs has obvious environmental benefits for everyone.

Study Site

Through the efforts of the Gas Research Institute (GRI), discussions between personnel of Argonne National Laboratory (ANL), and the Consolidated Gas Transmission Corporation of Clarksburg, West Virginia, led to the identification of a research site along the ROW of a new pipeline to be constructed during the fall of 1984. This new 61-cm (42-in.) diameter line was to cross Allegheny and Westmoreland Counties in southwestern Pennsylvania and would have a total ROW length of about 55 km (34 mi). The study site is located in southwestern Westmoreland County about 3.2 km (2 mi) west and 0.5 km (0.3 mi) north of West Newton on Pennsylvania Route 136; this site is approximately 45 km (27 mi) southwest of Pittsburgh (Figure 1).

General Characteristics

The study site was in an old field with an established stand of grasses and forbs that had been mowed for the last few years to control weedy growth. The site has a plane slope of about 23% and is approximately 125 m (410 ft) long. The ROW runs directly down the slope. Soil on the experimental slope has been mapped as Westmoreland silt loam, 12-30% slope, moderately eroded (Taylor et al., 1968). These soils (fine-loamy, mixed, mesic Topic Hapludalf) are moderately deep to deep, well-drained, medium-textured soils developed from residuum derived from interbedded gray calcareous shale, sandstone, and limestone. Depth to weathered bedrock ranges from 61 to 152 cm (2 to 5 ft), and shale fragments are common in both the surface and subsoil layers. Permeability of the Westmoreland silt loam is moderate to moderately rapid. Erosion potential is high, and past erosion has removed part of the original surface soil layer, leaving the present topsoil as a mixture of the original surface layer and subsoil material.

Westmoreland County has a humid, temperate continental climate, resulting in warm summers and cold winters. Temperatures in the vicinity of the study site average about 0.5°C (33°F) in January to approximately 24°C (75°F) in July. The average growing season is about 180 days. Precipitation is fairly well distributed throughout the year, with about 50% of the annual average of 102 cm (40 in.) falling between the beginning of May and the end of September (Taylor et al., 1968).

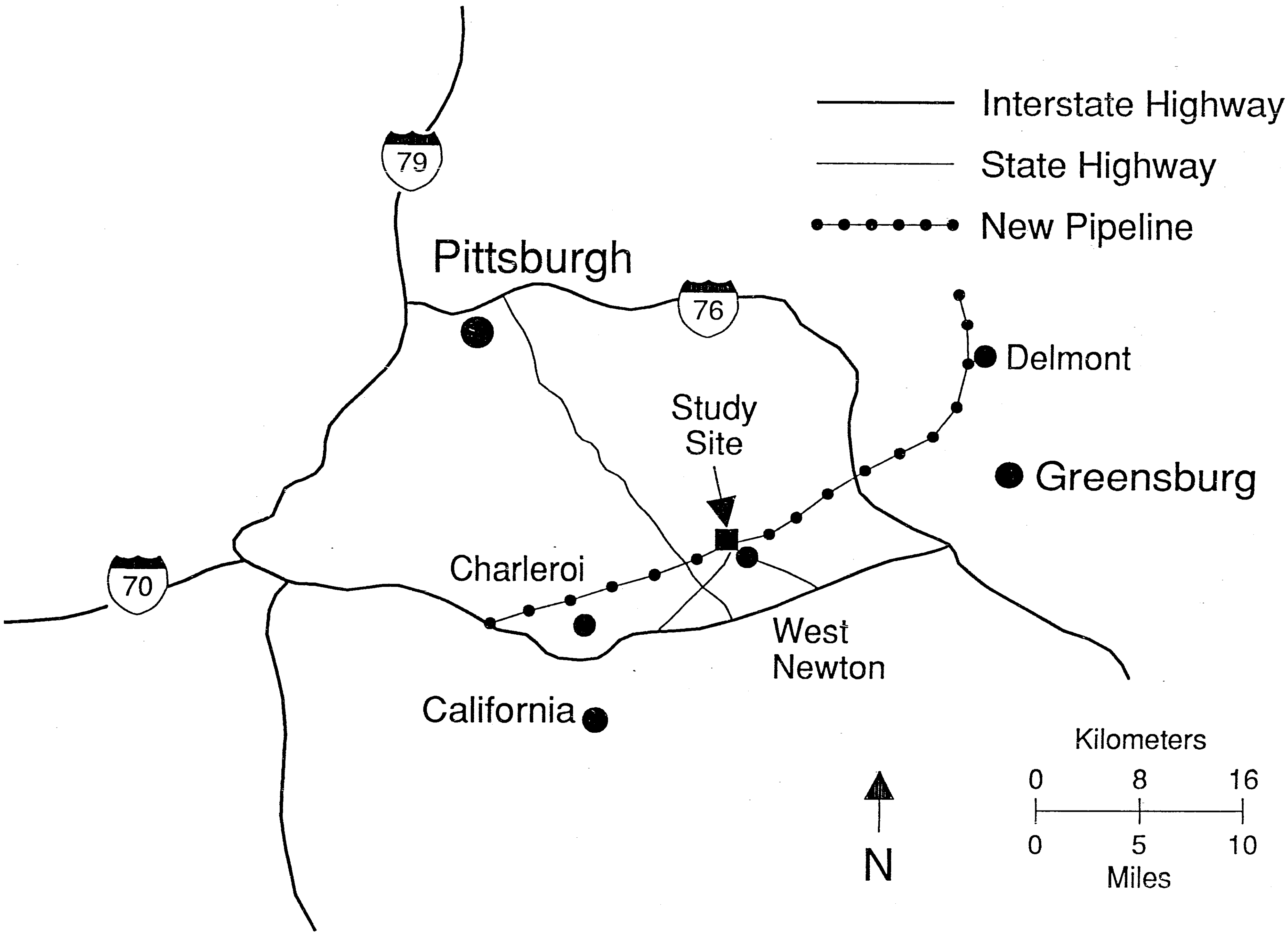
Interstate Highway
State Highway
New Pipeline
79
Pittsburgh
76
Delmont
Study
Site
Greensburg
Charleroi
70
West
Newton
California
Kilometers
0
8
16
0
5
10
Miles
N

Figure 1 Location of the Consolidated Gas Transmission Corporation Pipeline Constructed in 1984 and the Study Site in Westmoreland County, Pennsylvania

Pipeline Installation

The pipeline was constructed during the late fall and early winter of 1984. Pennsylvania regulations require the removal of 20-25 cm (8-10 in.) of surface soil (topsoil) from ROWs in areas with the potential for agricultural crop production. Because the experimental study area was considered agricultural land, surface soil was removed by bulldozer and stockpiled along one side of the 24.4-m (80-ft) wide ROW. Large trucks were used to transport the 18.3-m (60 ft) sections of 61-cm (24 in.) diameter pipe to the ROW, and side-boom tractors were used to unload the pipe. Equipment traffic was limited to the working side of the ROW (e.g., the area stripped of topsoil adjacent to the pipe route).

A wheel trencher was used to dig the pipe ditch about 107 cm (42 in.) wide and about 1.9 m (6.25 ft) deep to provide a minimum of 1.2 m (4.0 ft) of soil cover over the pipe. A backhoe was used in areas where rock was near the soil surface; in these areas, the minimum depth of soil cover over the pipe was reduced to 0.6 m (2.0 ft). Individual pipe sections were welded together, the welds were X-rayed for integrity, and a protective covering was applied to the exposed section of the pipe around the welded area. The welded pipe, some sections of which were more than 0.8 km (0.5 mi) long, was lowered into the ditch by side-boom tractors. Bending, welding, and X-raying of the large diameter pipe, plus lowering long lengths of pipe into the ditch, required a variety of vehicles and heavy construction equipment on the narrow working side of the ROW.

After the pipe was lowered into the ditch, a bulldozer covered it with the soil excavated from the ditch. The graded sections of the ROW were recontoured to the approximate topography, and the stockpiled surface soil was graded back onto the ROW. Waterbars were graded across the ROW on steep slopes after replacement of the surface soil. Because pipeline construction was not completed until mid-December, final cleanup and seeding were delayed until the following spring.

The pipeline at the study site was installed in early November 1984. Installation operations were typical with one exception: a second simulated pipe ditch was excavated and backfilled to provide space for additional test plots. During the experimental design, it became apparent that in order to provide a sufficient number of test plots for the study, a second ditch would be required. The simulated pipe ditch was located parallel to, and about 4.6 m (15 ft) away from, the real pipe ditch. The construction contractor excavated the simulated pipe ditch to the proper depth and width with a large backhoe and then backfilled the ditch with a bulldozer. All other construction at the experimental site was done in the normal manner. During late November, the surface soil was graded back onto the ROW.

Final cleanup and seeding along the entire ROW started in early April 1985. These operations included regrading any erosion damage that had occurred over the winter and removing temporary erosion-control structures (silt fences, stream crossing structures). A seedbed was prepared by disking, and rocks 15 cm (6 in.) or larger (exposed by construction) were removed. Soil amendments and the seed mixture (Table 1) were applied in a single operation by a hydroseeder. The ROW was then mulched with oats (*Avena sativa*) straw at the rate of about 5.6-6.7 t/ha (2.5-3.0 tons/acre) with a power mulching machine.

Experimental Design

Plot Design

A number of factors were considered in determining the size of individual erosion test plots and the design of the runoff collection system. Individual plot size was limited by the 107-cm (42-in) width of the pipe ditch. A second limiting factor for plot size was the length of the pipe ditch on the experimental slope. Plots should be as long as possible for determination of slope length influence, but long, narrow plots would limit the number that could be constructed. An additional consideration was plot surface area: a larger plot would produce a larger runoff volume and increase the potential problems of storage, mixing, and collecting a representative runoff sample. On the basis of information from the literature and the

Table 1 Basic Treatment (soil amendments and seed mixture) Used on Pipeline ROW and Experimental Slope

Material	Application Rate
Agricultural limestone (t/ha)[1]	4.5
Plant nutrients (kg/ha)[2]	
Nitrogen	56.0
Phosphorus	24.5
Potassium	46.5
Seed mixture (kg/ha)	
Tall fescue (*Festuca arundinacea* Schreb.) "Ky 31"	44.8
Birdsfoot trefoil (*Lotus corniculatus* L.) "Viking"	11.2
Birdsfoot trefoil (*Lotus corniculatus* L.) "Empire"	11.2
Redtop (*Agrostis alba* L.)	11.2

[1]To convert t/ha to tons/acre, divide by 2.25.

[2]To convert kg/ha to lb/acre, divide by 1.12.

experiences of other researchers, test plot size was set at 1.5 by 7.6 m (5 by 25 ft), with an area of 11.6 m^2 (125 ft^2). This width was slightly greater than that of the pipe ditch and would provide representative erosion rates over the pipe ditch.

Mutchler (1963) recommended that runoff storage capacity of test plots be designed for a 100-yr, 48-h rain. An event of this frequency and duration in Westmoreland County would result in about 18 cm (7 in.) of precipitation (Miller, 1964). With an area of 11.6 m^2 (125 ft^2), 2,090 L (545 gal) of runoff would occur from each plot during such an event (assuming 100% runoff). This large volume indicated that a simple, dependable runoff divider was required. Such a device, designed to collect and divide the runoff in equal portions, was identified (Brakensiek, Osborne, and Rawls, 1979). With a 10-part divider, the total runoff volume from a maximum storm event could be reduced to about 209 L (55 gal). An advantage to the divider design was that it could be modified to increase the proportion of runoff diverted to the storage drum if site conditions produced mean runoff far below 100%.

The sides of the plots were to be made of 20-gauge galvanized steel 21 cm (8 in.) high, with about one-half of the sheet metal driven into the soil surface. The collector/divider at the downslope end of the plot would also be made of galvanized steel. Runoff water and sediment would be delivered from the collector/divider to the storage drum by 5-cm (2-in.) rigid plastic pipe. The storage container would be a 209-L (55-gal) drum with a plastic liner to simplify emptying and cleaning after large runoff events. A 19-L (5-gal) plastic pail placed inside the drum would simplify the measurement of runoff volumes and sampling from small runoff events.

Site Layout

The number of plots (and therefore the number of treatments) that could be tested at the study site depended on several factors. For statistical evaluation, at least three replicates of each method were required, and several types of control plots were required for meaningful comparisons. Early in the design, it was decided that each erosion-control method was to be tested on the two separate parts of the ROW, that is, the working side and the pipe ditch. This dual evaluation was necessary because of possible differences in erosion rates due to potential compaction on the working side caused by construction traffic and the potential of altered infiltration rates because of the excavation and replacement of soil in the pipe ditch.

The most limiting factor for the number of plots that could be located on the experimental slope was the length of the pipe ditch. The addition of the simulated pipe ditch provided adequate space for 48 plots (24 on the working side and 24 over the pipe ditch). To provide for blocks or replicates in the study, the slope was divided into three equal segments: upper, center, and lower. This division provided space for eight separate treatments on each of the two locations on the ROW. One plot treatment was assigned to each location (working side or pipe ditch) within each block (slope segment). The location of individual plot treatments within locations and blocks was randomly assigned. Figure 2 is a diagram of the experimental slope showing the test plot locations; the numbers represent the eight possible types of individual treatments.

Selection of Erosion-Control Methods

Two of the eight treatment methods were required as controls to provide data for comparison and statistical evaluation. Data from these control plots would be used to determine the erosion rate on the ROW without any managed reclamation practice -- a "worst-case" situation. The first control was not treated, and natural revegetation, if any, was allowed to grow. A second control required application of the basic or minimum treatment of lime, fertilizer, and seed (Table 1). These soil amendments and seed mixtures were used by Consolidated elsewhere on this pipeline project and were used here as a basic treatment to which supplementary procedures were added in the erosion-control methods tested. This second control was necessary to determine erosion rates with minimum reclamation practices and to provide baseline data for the six erosion-control methods tested. An additional set of three control plots was established adjacent to the ROW on an undisturbed area containing native vegetation. These plots provided data on the natural erosion rate from an undisturbed area of the slope.

The first of six supplementary prevegetation erosion-control methods selected for evaluation was one used by Consolidated and many other companies in the region. It consists of applying 6.7 t/ha (3.0 tons/acre) of straw mulch in addition to the basic soil amendments and seed mixture given in Table 1. Data from this method would be used to determine the erosion rate with an accepted erosion-control practice.

The second method was 3.35 t/ha (1.5 tons/acre) of straw mulch plus the basic treatment (Table 1). Biggerstaff, Moore, and Warner (1984) indicated that the effectiveness of straw mulch did not increase appreciably with application rates greater than 2.24 t/ha (1.0 ton/acre). Equivalent erosion protection with a lower mulch rate would yield cost savings for the gas transmission industry and require only minor modification to current reclamation practices.

The third supplementary method was processed wood fiber mulch applied at the rate of 2,240 kg ha^{-1} (2,000 lb $acre^{-1}$) as recommended by the manufacturer. This material is readily available throughout the country under several trade names, but a hydromulcher is required for application. This method was selected because it had been used on many types of disturbed areas in the past. However, a quantitative assessment of the effectiveness of this method has not been made under ROW conditions.

A chemical soil binder was selected as the fourth supplementary erosion-control method. Although several types of chemical soil binders are available, the type selected for evaluation in this study was a latex vinyl acetate resin. The manufacturer recommended a mixture of one part concentrate to 20 parts water, with application at the rate of about 2.26 L m^{-2} (0.5 gal yd^{-2}). This is equivalent to 1,028 L of concentrate to 21,505 L of water per hectare (110 gal of concentrate to 2,300 gal of water per acre). The latex-water mixture can be applied with a sprayer or in combination with hydroseeding or hydromulching.

Chemical soil binders have been available for a number of years but have not been widely tested under field conditions.

The use of 1.6-cm (5/8-in.) width paper strips interwoven in a biodegradable netting was selected as the fifth erosion-control supplement. This material comes in rolls 1.5 or 3 m (5 or 10 ft) wide by 111 m (366 ft) long and is held to the soil with wire staples. Material costs are high for this method, but it was included to determine if the higher cost can be justified by improved erosion control.

The sixth and final supplementary method evaluated was straw mulch applied at 3.35 t ha^{1} (1.5 tons $acre^{-1}$) with a tacking agent to hold the mulch in place. Latex vinyl acetate resin, the material used as a chemical soil binder, was also selected for use as the tacking agent. The recommended dilution of the latex material when used as a tack is one part concentrate with 10 parts water. The resultant solution is applied at about 0.25 L m^{-2} (0.22 qt yd^{-2}), or the equivalent of 2,468 L ha^{-1} (264 gal $acre^{-1}$). In this study, the tack was applied to the mulch with sprayer, but it can also be applied simultaneously with the mulch.

Table 2 lists the eight types of on-ROW erosion test plots and indicates the six supplementary erosion-control methods evaluated in this study. The numerical code listed in this table for each treatment/control corresponds to the numbered plot locations shown in Figure 2.

Table 2 Erosion-Control Treatments and Their Components

Code	Treatment	Components
0	Off-ROW control	Native vegetation
1	On-ROW control	Natural revegetation
2	Basic[1]	Limestone, fertilizer, seed
3	Heavy straw mulch	Basic treatment + 6.7 t/ha straw mulch
4	Light straw mulch	Basic treatment + 3.35 t/ha straw mulch
5	Processed wood fiber	Basic treatment + 2.24 t/ha wood fiber mulch
6	Chemical soil binder	Basic treatment + 1:20 solution @ 21,500 L/ha
7	Paper strips in netting	Basic treatment + single layer of paper
8	Light straw mulch with tack	Basic treatment + 3.35 t/ha straw mulch plus 1:10 tacking solution @ 2,500 L/ha

[1]Materials and application rates are listed in Table 1.

Experimental Installation

The site and seedbed were initially prepared by the pipeline rehabilitation contractor. Locations of the 48 on-ROW runoff plots and three off-ROW control plots were established and all hardware was installed (see Figure 2). Six control plots on the ROW receiving no treatment were covered with plastic sheeting that extended about 0.5 m (18 in.) beyond the plot perimeters to prevent application of soil amendments and seed and to provide a buffer zone around the plot. The contractor applied the basic treatment (see Table 1) to the experimental slope in a single operation with a hydroseeder. This provided the basic treatment for all ROW plots included in the study.

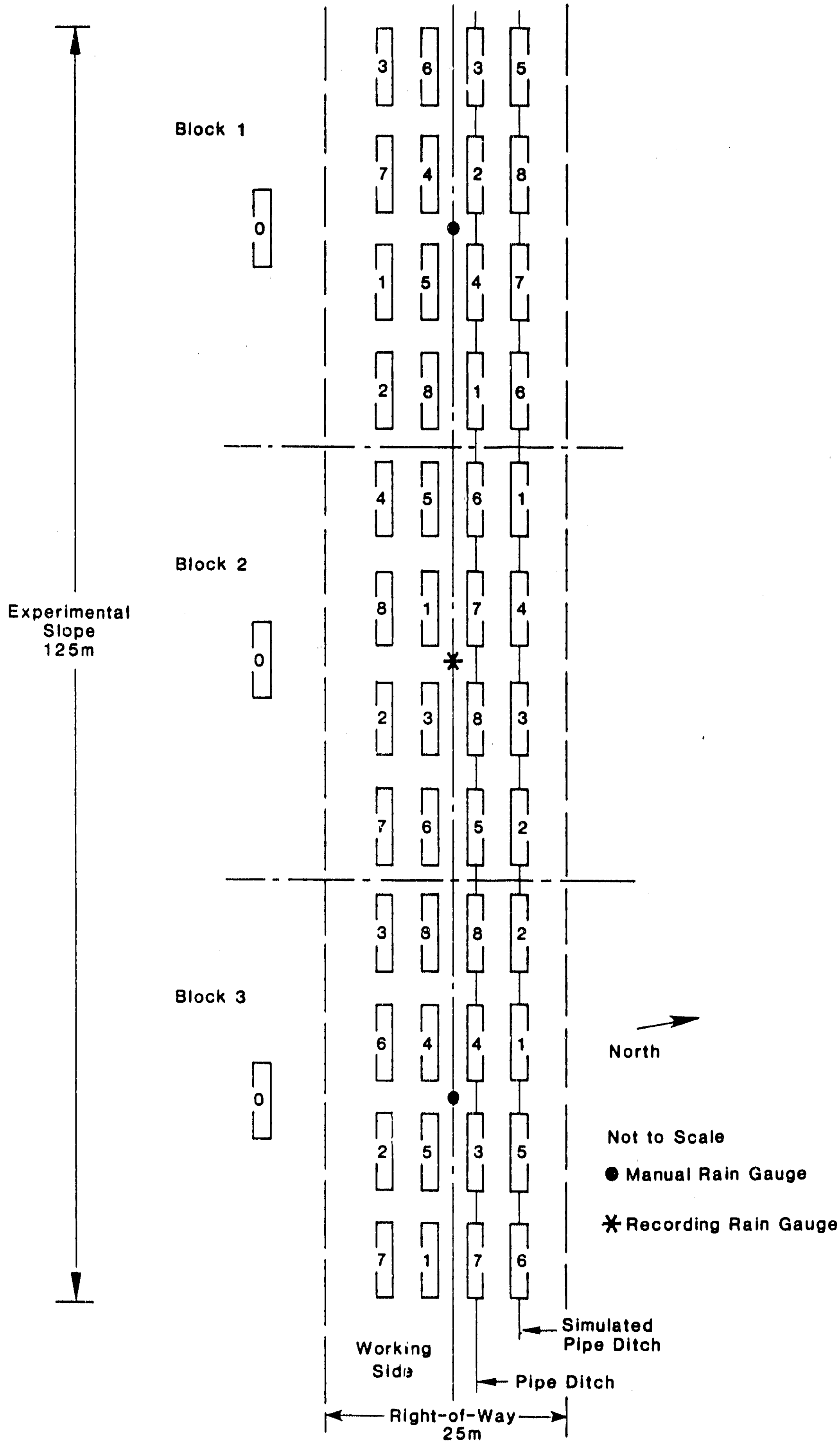
Block 1
Block 2
Block 3
Experimental Slope 125m
North
Not to Scale
Manual Rain Gauge
Recording Rain Gauge
Simulated Pipe Ditch
Working Side
Pipe Ditch
Right-of-Way 25m

Figure 2 Plot Arrangement on Experimental Slope (numbers represent treatments listed in Table 2)

The six supplementary methods were subsequently added over the basic treatment at the application rates noted above. The required oats straw mulch used in three methods was weighed and spread on the assigned plots by hand . Processed wood fiber was applied by a hydromulcher provided by a local landscaping contractor and plastic sheeting was used to cover adjacent areas not receiving this supplement. The chemical soil binder solutions were mixed and applied with a pressurized hand sprayer at prescribed rates for soil binder applications and on appropriate mulched plots scheduled to receive a tacking agent. Finally, a single thickness of the paper strips in netting was installed on the required plots and stapled to the soil surface. All supplementary erosion-control materials were applied to a distance of about 0.5 m (1.6 ft) beyond the perimeter of the plots to provide a buffer zone around each plot.

Two manual rain gauges and one recording gauge were installed at the site concurrently with plot installation. Following the application of all supplementary erosion-control methods and materials, a composite soil sample was collected from each plot based on ten subsamples collected from the upper 15 cm (6 in.) of soil. In addition, three clods were taken from the upper 15 cm (6 in.) of soil for determining bulk density.

Data Collection

Runoff Monitoring

To provide for timely collection and processing of runoff and sediment samples, contractual arrangements were made with the California University of Pennsylvania. Following a precipitation event, university personnel recorded the amount of precipitation received and the depth of runoff in the collection devices. The runoff from each plot was thoroughly mixed and a 1-L sample was taken for processing. If less than 1 L of runoff was produced by an event, the entire volume was collected and processed.

Runoff samples were processed at the university using a method adapted from Guy (1969). Sample volume was measured and filtered, and the oven-dried weight of sediment in each sample was determined. Data on runoff depth in collection containers, process sample volume, and sediment weight were provided to ANL. Subsequently at ANL, total volume of runoff for each plot was computed (L $plot^{-1}$) and the concentration of sediment (g L^{-1}) was calculated. Total sediment yield from each plot (g $plot^{-1}$) was also computed. Such data on runoffs and eroded sediment were obtained for a total of 45 precipitation events from May 29, 1985 thru November 22, 1986.

Vegetation Monitoring

To determine the influence of the prevegetation erosion-control methods on the establishment and development of vegetation, ground cover was measured four times during the 18-month study. Initial ground cover measurements were made in mid-July 1985, and additional measurements were made in mid-October 1985 and in early May and mid-July 1986. The point-intercept method (Chambers and Brown, 1983), using a 10-point frame the same width as each plot, was used to record bare soil, mulch or litter, grass, legume, and other types of plant cover. Data from 10 evenly spaced frame locations at 0.7-m (2.25-ft) intervals were taken in each plot on each date. This method provided 100 data points for each monitoring session.

Soil Analysis

Soil bulk density was determined by the clod method (Blake and Hartge, 1986). Composite soil samples were air-dried and preprocessed for chemical analysis using a method adapted from Sobek et al. (1978, pp. 43-45). Chemical properties determined included organic carbon content determined by the Walkley-Black method (Nelson and Sommers, 1982) and soil pH (1:1) in water (Cahoon, 1974, pp. 16-19). Available phosphorus was obtained by Bray P1 extraction (Cahoon, 1974, pp. 41-45), and potassium, calcium, magnesium, and sodium were determined using the ammonium-acetate extraction method (Cahoon, 1974, pp. 60-65).

Cost Information

Past experience at ANL indicates that the cost of applying experimental treatments to small, replicated test plots is usually 25% to 50% higher per unit area than unit-area costs for similar operations under normal field conditions. The higher costs for the experimental studies are attributed to equipment mobilization and demobilization and the inconvenience of treating small, scattered test plots. For these reasons, the final cost of each method tested in this study was estimated. Costs of materials were calculated for unit areas on the basis of the actual cost of the material used. Application costs for each treatment method were obtained for rehabilitation contracting in the geographic area of the study site. All cost data were calculated at the time of plot installation, and no attempt was made to adjust the cost to current or future dollar values.

Discussion of Results

Erosion Rates

Two objectives of this investigation were to determine the amount of increase in erosion rates caused by pipeline construction and to evaluate the effectiveness of selected nonvegetative erosion-control methods under field conditions. It was also decided early in the experimental design that the question of whether erosion rates over the pipe ditch are different from those on the working side of the ROW should be examined. To evaluate these questions, data on sediment yield from the test plots and precipitation events were examined.

The simplest means of identifying differences between the various treatments and location (off-ROW, pipe ditch, and working side) is to compare the mean annual sediment yield (g $plot^{-1}$ yr^{-1}). These data are shown in Table 3. Total sediment yield was obtained for each plot by summing the individual yields for the 45 precipitation events measured during the course of this study. Mean yield for each treatment at each of the two on-ROW locations was calculated by adding the sums of the individual plot yields from the three replicate blocks on the study slope (see Figure 2) and dividing by three. The combined sediment yield of a treatment representing both pipe ditch and working side was determined by summing the total yields from the six plots and dividing by six. Because monitoring was conducted for 553 days, means were adjusted to an annual rate by multiplying them by 0.66.

Table 3 Adjusted Mean Annual Plot Sediment Yields, by Treatment and Location[1] (g/plot/yr)

Treatment	Off-ROW	Working Side	Pipe Ditch	Combined
Off-ROW control	1.25	--	--	--
On-ROW control	--	589.0	468.0	528.0
Basic	--	478.0	157.0	317.0
Heavy straw mulch	--	21.6	1.6	11.6
Light straw mulch	--	4.9	2.1	3.5
Processed wood fiber	--	176.0	161.0	169.0
Chemical soil binder	--	70.2	7.4	38.8
Paper strips in netting	--	9.8	15.9	12.8
Light straw mulch with tack	--	2.8	0.5	1.7

[1]N = 6 for combined mean; n = 3 for all other means.

The data in Table 3 are useful for making comparisons and determining trends, but limitations exist. The variation between the data from the three replicate blocks was not considered, therefore statistical analysis of these particular data to determine significant differences cannot be made. Furthermore, the obvious limitations of plot size and the inhibiting effects on rill and gully erosion within the test plots preclude the direct extrapolation of these values to larger areas. However, the means within Table 3 do indicate the relative erosion rate of the nine different treatments.

As expected, these data indicate that the off-ROW control plots with undisturbed native vegetation had the lowest sediment yields. Comparison of the off-ROW mean with the on-ROW control with only natural revegetation (no treatment) indicates a 400-fold increase. The application of the basic treatment (soil amendments and seed mixture) reduced the on-ROW erosion by 40%, and even the most ineffective of the six methods tested (processed wood fiber) reduced annual erosion rates by another 50%. Further examination of the data in Table 3 indicates that the means from the plots treated with the three methods involving straw mulch are within an order of magnitude of the off-ROW control. Clearly, pipeline construction increases soil erosion rates, but the increase can be relatively small if effective control measures are taken.

The mean values in Table 3 indicate general trends in the effectiveness of the supplementary erosion-control methods tested. Although the means of all of the methods are considerably lower than those of the basic treatment, the two methods involving light straw mulch applications appear to provide the best erosion control averaged over the locations on the ROW.

To determine if statistically significant differences existed between the six treatments, sediment yield data from the six treatments for all 45 precipitation events were tested with an analysis-of-variance program (Ray, 1982). Location on the ROW (pipe ditch or working side), block number (location on the slope), and the six erosion-control treatments (Table 3) were independent variables in the analysis. The factorial model that was used considered interactions between all independent variables. An analysis was conducted of each precipitation event separately, and results indicated that sediment yields from only six of the 45 precipitation events were significantly different ($P \leq 0.05$). The lack of significant differences among sediment yields for the other 39 events may have been due to absence of sediment yield, similarities in yields, or wide variation between yields within locations, blocks, or treatments. Small precipitation events or events following long dry periods failed to produce runoff or sediment from many treatments, resulting in a large number of zero values.

Data from the six precipitation events that produced significantly different sediment yields were reanalyzed to determine whether interaction between independent variables or a single independent variable was responsible for the differences or whether a single variable was responsible. In all six cases, it was determined that the supplementary erosion-control treatment was the single variable, without interaction, that caused the significant differences. Plots receiving processed wood fiber had significantly higher sediment yields for all six of the precipitation events. For two of the six events, the chemical soil binder treatment had significant higher ($P \leq 0.05$) sediment yields than the remaining four methods. This analysis of variance indicated no significant differences among the sediment yields of the four remaining treatments. On the basis of this analysis, the processed wood fiber and chemical soil binder treatments were judged to be ineffective in controlling erosion. The other four treatments (three with straw mulch and one with paper strips in netting) were statistically equal in controlling erosion. This supports the general trend established by the data in Table 3.

The earliest precipitation event that had a significant difference in sediment yield was almost two months after plot installation, when vegetation was fairly well established on the plots. Although statistical analysis could be used to identify the two less effective methods, it could not provide information of the effectiveness of the four remaining methods. This left unanswered the question as to which method was best for controlling erosion before vegetation is established.

To determine individual treatment effectiveness during the critical period between ROW reclamation and vegetation development, sediment yields from the initial five precipitation events sampled were analyzed (Table 4). Because a direct comparison of the mean data do not reveal obvious relationships, a simple ranking procedure for these data was devised. A rank value of 1 was assigned to the largest mean for each precipitation event with increasing rank values being assigned in the order of decreasing means. Equal means were given equal rank values, as shown in the parentheses within Table 4. The total of the rank values of the sediment yield from each treatment for the five precipitation events is shown as the rank score at the bottom of this table.

Table 4 Influence of Supplementary Erosion-Control Methods on Mean[1] Sediment Yield (g $Plot^{-1}$) for Five Initial Precipitation Events of the Westmoreland County, Pennsylvania Study -- Mean (and rank) of Yield for Each Event and Treatment Method

Precipitation Event Date	Heavy Straw Mulch	Light Straw Mulch	Processed Wood Fiber	Chemical Soil Binder	Paper Strips in Netting	Light Straw Mulch with Tacking Agent
29 May 1985	0.01 (5)	0.00 (6)	8.93 (1)	0.49 (3)	7.11 (2)	0.05 (4)
1 June 1985	0.16 (6)	0.43 (4)	5.62 (1)	2.76 (2)	1.08 (3)	0.21 (5)
23 June 1985	9.26 (2)	1.81 (5)	13.55 (1)	3.02 (4)	4.14 (3)	0.44 (6)
6 July 1985	0.00 (1)	0.00 (1)	0.00 (1)	0.00 (1)	0.00 (1)	0.00 (1)
10 July 1985	6.87 (3)	2.11 (5)	164.27 (1)	27.71 (2)	4.16 (4)	1.11 (6)
	--------------------	-----------------	Rank Score[2]	-----------------	--------------------	
	17	21	5	12	13	22

[1]n = 6

[2]Total of rank values for the five events; higher rank scores indicate lower sediment yields.

The rank scores indicate that processed wood fiber is the least effective of the six methods tested. This poor showing may be due in part to the low application rate of 2,240 kg ha^{-1} (2,000 lb $acre^{-1}$) suggested by the manufacturer. It was noted that following application of the material, a substantial portion of the soil surface was left exposed. The next lowest rank score was associated with the chemical soil binder. This material is designed to bind soil particles and increase infiltration; however, it becomes less effective with time and if the soil surface is disturbed. The relatively low sediment yield for the first precipitation event with increasing yields over time with subsequent events reflects these limitations with this method. The results of the rank-score procedure for the processed wood fiber and chemical soil binder methods agree with the statistical analysis and trends indicated in Table 3.

The third lowest rank score in Table 4 is associated with the method using paper strips in netting. Although this material completely covers the soil surface and prevents splash erosion, precipitation can pass through and between the paper strips and result in sheet erosion beneath the material where it is not in direct contact with the soil. The rank scores of paper strips and chemical soil binder are very similar.

The remaining three methods including straw mulch have nearly equal rank scores (Table 4). Differences in the combined mean sediment yields in Table 3 are larger, but the same ranking order is reflected. The higher rank score and mean annual sediment yield for the heavy straw mulch method indicates that it was less effective in reducing soil erosion than the lighter applications. Although it has been reported that straw mulch application rates in excess of 2.24 t ha^{-1} (1.0 ton $acre^{-1}$) did not improve erosion control, an increase in erosion with increased mulch application has not been reported. No logical explanation for this apparent relationship can be given at this time.

Statistical analysis of the sediment yield from all 45 precipitation events showed no significant differences between locations over the pipe ditch and those on the working side of the ROW. However, the mean sediment yields on the working side are higher than those over the pipe ditch for seven of the eight treatments shown in Table 3. Furthermore, adjusted mean annual runoff volumes were also higher on the working side for six of the eight treatments than over the pipe ditch. These data clearly indicate different runoff and erosion rates for the two ROW locations. These differences may be due to reduced infiltration on the working side from construction traffic compacting the soil or to increased infiltration rates and potentially lower soil bulk densities from working the pipe ditch soils.

Vegetation

Vegetation data were statistically analyzed. No significant differences in the data were indicated to be due to location on the ROW, to block number (position on the slope), or to interaction between variables for any of the four monitoring periods. Significant differences due to supplementary erosion control methods were observed only for the initial monitoring date. A summary of these data, expressed as percentages, is contained in Table 5. Mean percentages, followed by the same letter for a given parameter, are not significantly different ($P \leq 0.05$); only the six supplementary methods were included in the analysis.

Bare soil was recorded for any point that was not covered by vegetation, mulch, or litter. The significantly higher mean sediment yield and large mean percentage of bare soil for the wood fiber material was due to the disappearance of the material before the monitoring date, less than two months after application. The higher mean percentage of bare soil for the chemical soil binder reflects the fact that no mulch was applied. As would be expected, methods that include straw mulches had a low amount of exposed soil. The expected relationship of generally increased soil erosion with increased percentages of bare soil can be seen by comparing the data in Tables 3 and 5.

The vegetative cover represents planted grasses and legumes, volunteer (from topsoil), and invading weedy species. Comparing the on-ROW control (representing natural revegetation) with the data for the basic treatment (Table 5) indicates the value of providing a seed source for revegetation. The lower mean for total vegetation cover for the paper strips in netting suggests this method may inhibit early plant growth, because vegetation had to push its way through the covering material. This same influence may be reflected in the value for heavy straw mulch. The increase in cover associated with the chemical soil binder and light straw with tack may have been due to improved seedbed conditions (improved temperature and moisture) by these two treatments. However, the small differences between the basic treatment and all six of the supplementary treatments indicates minimum influence of treatments on the degree of vegetation development.

Soils

Composite soil samples were collected from each plot immediately following treatment application and were analyzed to determine whether soil properties influenced vegetation establishment and growth. Soil bulk densities were significantly lower on the off-ROW control plots than on all on-ROW plots. Conversely, organic matter was significantly higher on the off-ROW controls. However, values for both parameters on the ROW are well within the acceptable range for plant growth and would be expected to influence vegetation results in this study.

Soil pH was significantly higher on limed plots when compared with both on- and off-ROW control plots. As expected, the same relationship was seen in soil calcium and magnesium data. Differences between the two types of controls, locations on the ROW, replicate blocks, or erosion-control method were not statistically significant for these parameters. Mean levels of extractable soil potassium of the fertilized plots were significantly higher than those of unfertilized control plots, but this relationship was not observed in available phosphorous data. This suggests that there may have been some minor variations in fertilizer application on the experimental slope. However, because all soil fertility parameters on plots were within acceptable levels for plant growth, soil fertility was not a factor in vegetation growth nor did it influence the outcome of the experiments.

Table 5 Mean[1] Percent of Surface Cover by Type and Plot Treatments, July 22, 1985, for the Westmoreland County, Pennsylvania, Erosion-Control Study

Treatment	Bare Soil	Total Vegetation	Grass	Legume
Control				
Off-ROW Control (Native Vegetation)	0.0	100.0	19.0	0.3
On-ROW Control (Natural Revegetation)	33.7	69.0	22.7	2.0
Basic Treatment[2]	15.8	84.2	46.8	9.8
Supplementary[3]				
Heavy Straw Mulch	0.2[c4]	79.7[ab]	46.5[a]	5.7[ab]
Light Straw Mulch	5.7[bc]	83.3[ab]	50.8[a]	5.7[b]
Processed Wood Fiber	17.3[a]	82.7[ab]	45.2[a]	12.3[a]
Chemical Soil Binder	11.7[bc]	88.3[a]	41.7[a]	9.7[ab]
Paper Strips in Netting	0.2[c]	74.8[b]	53.0[a]	6.5[ab]
Light Straw Mulch with Tacking Agent	1.0[c]	89.0[a]	62.0[a]	4.5[b]

[1]n = 3 for off-ROW control, n = 6 in all other treatments.

[2]Table 1 gives types and application rates of soil amendments and species and seeding rate of seed mixture.

[3]Added to basic treatment (supplementary methods listed in Table 2).

[4]Means in the same column followed by the same letter are not significantly different (Sidak's parwise t test for inequality).

Cost

Because of wide variations in rehabilitation costs caused by topography and ROW conditions, local availability of materials and services, and other factors, economic data reported herein should be used for comparison only, not as reflections of actual costs. A summary of estimated costs of the rehabilitation and erosion-control treatments examined in this study is presented in Table 6.

No rehabilitation costs were involved in the on-ROW control plots because no treatments or operations were involved. Erosion control on these plots was unacceptable. Costs associated with the basic treatment were for agricultural limestone, fertilizer, seed, transportation, and combined application by hydroseeder. Costs were low, but erosion control resulting from this method was also judged to be ineffective.

Further review of the data in Table 6 indicates that material costs are generally, and often considerably, less than the cost of labor required to apply the materials. The one exception to this is the paper strips in netting, which also has the greatest per unit area cost of all the methods evaluated. This higher cost was clearly not reflected in improved erosion control. The two lowest-cost control methods were the chemical soil binder and processed wood fiber, but both of these methods provided poor initial and annual erosion control results.

Table 6 Estimated Cost Per Unit Area by Components and Plot Treatment Used in the Westmoreland County, Pennsylvania, Erosion-Control Study

Treatment	Basic Treatment ($\$$ ha^{-1})	Materials ($\$$ ha^{-1})	Application ($\$$ ha^{-1})	Total ($\$$ ha^{-1})	Total ($\$$ acre^{-1})
Control					
On-ROW control (natural revegetation)	0	0	0	0	0
Basic treatment[1]	1,186	0	0	0	480
Supplementary					
Heavy straw mulch	1,186	556	2,409	4,151	1,680
Light straw mulch	1,186	278	1,545	3,009	1,218
Processed wood fiber	1,186	741	988	2,915	1,180
Chemical soil binder	1,186	531	988	2,705	1,095
Paper strips in netting	1,186	6,177	1,235	8,598	3,479
Light straw mulch with tacking agent	1,186	556	2,545[2]	4,287	1,735

[1]Includes cost of limestone, fertilizer, seed, transport to ROW, and combined application by hydroseeder.

[2]Separate application of straw mulch and tacking agent.

Erosion rates from the three methods that used straw mulch were similar to the rate of the off-ROW control on an annual basis (Table 3) and within the same general range for the initial two months of the study (Table 4). Although there was some environmental advantage to the methods with lighter mulch applications compared with the heavier application, differences in measured sediment yields and rank score were small. The selection of the best of the methods using light applications of straw mulch can be made on the basis of a cost comparison. The results of this study indicate the straw mulch applied at a rate of 3.35 t ha^{-1} (1.5 ton acre^{-1}) is the most environmentally and economically effective of the methods that were evaluated.

Summary and Conclusions

Comparison of the adjusted mean annual sediment yield of the off-ROW control plots with that of the on-ROW control plots shows that the potential 400-fold increase in erosion rate following pipeline construction. Furthermore, data show that natural revegetation did not stabilize the ROW after two growing seasons, thus indicating that an effective erosion-control method is required. Differences between the mean sediment yields of the on-ROW control plots and the yield of the basic treatment plots (adjusted annual sediment yield reduced by 40%) demonstrate the importance of revegetation in controlling erosion. However, large differences between the erosion rates on the basic treatment areas and the off-ROW controls indicates that applying soil amendments and a seed source is insufficient, by itself, to control erosion effectively.

Plots receiving processed wood fiber mulch had the highest sediment yield of the six supplementary erosion-control methods that were tested, followed by the chemical soil binder, paper strips in netting, and the three methods using straw mulch. Statistical analyses indicated only six of the 45 precipitation events produced significant differences in sediment yields. Analysis of data from these six events show significantly higher sediment yields from processed wood fiber and chemical soil binder methods. This reflects the relative ineffectiveness of these two methods.

Sediment yields from the five initial precipitation events monitored following plot installation were evaluated using a ranking system. This evaluation confirmed the data trends observed in the adjusted mean annual sediment yield data and results of the statistical analysis. Additionally, this ranking evaluation suggested the method using paper strips in netting is less effective at controlling erosion than the three methods using straw mulch. Of the three methods, the light application of mulch with tacking agent was judged to be slightly more effective than untacked mulch applied at the same rate.

An evaluation of adjusted mean annual sediment yield and runoff volume showed that erosion and runoff rates are generally less over the pipe ditch than on the working side of the ROW. This difference is probably due to increased compaction on the working side due to construction traffic and increased infiltration over the pipe ditch due to soil removal and replacement.

Analyses of vegetation cover data indicated significant differences only during the initial phase of the study. Differences in exposed soil between the six treatments can be accounted for by the presence of paper strips or straw mulch used in the methods. Higher total vegetative cover on plots with chemical soil binder and light straw mulch with tack may be due to improved seedbed and growth conditions. Grass cover was not influenced by erosion-control method, but legume cover did vary between certain treatments. Generally, however, small data differences indicated that erosion-control methods did not influence plant growth and development. Similarly, although results of soil tests indicate the benefits of fertilization and liming, soil fertility was not a factor in vegetation growth nor did it influence the outcome of the experiments.

Relative costs of the materials and installation were c llected and evaluated. These data indicate that paper strips in netting was the most expensive of the six methods tested, but the method was judged to be ineffective in controlling erosion in this study. For the remaining five methods, the cost of materials was consistently less than application cost. The two lowest-cost methods were processed wood fiber and chemical soil binder, but both of these methods were judged to be ineffective in controlling erosion on the experimental plots. The three remaining treatments with straw mulch were determined to be about equal in controlling erosion. The combined cost and erosion-control data indicate that straw mulch applied at a rate of 3.35 t ha^{-1} (1.5 tons $acre^{-1}$) is the most economical and environmentally effective of the eight methods examined in this study.

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