Effectiveness of Various Soil Additives for Erosion Control

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THIS paper summarizes an extensive search for soil additives that can reduce the damaging effects of rainfall on steep slopes and thereby curb erosion. Described are laboratory testing procedures developed for hydromechanical studies of soil erosion and for evaluating the soil additives studied. As a check on the laboratory work, field slopes have been set up in several sections of the country and observations on these have been quite encouraging.

Although no entirely successful material was found during these investigations, one has proved to be quite effective on certain soil types. Several other additives have shown good possibilities on one or two soil types. In order of their effectiveness based on current test data these are: (1) Monsanto CRD-189; (2) Monsanto CRD-186; (3) soil-cement aggregates; (4) Dupont Orchem DV-71; (5) Aerotil; and (6) Dupont Elchem-1089.

As a result of this study, two practical methods of application were evolved: (1) spread additive on surface uniformly and wet down and (2) bake in additive to a depth of about ½ in. and wet down.

● EROSION is one of the more-serious problems encountered by engineers and soil conservationists. Highway cut and fill sections, upstream faces of earth dams, and other types of earth slopes must be protected against erosion. Current control methods are either too expensive or detrimental to vegetation, which is the simplest means for protection of most slopes. Many fine-grained soils, which are not conducive to vegetation, are highly susceptible to erosional damage.

Navy interest in soil-erosion studies results from its control of nearly 4,500,000 acres of land in this country, ranging from barren desert to heavily timbered areas. Erosion is a particular problem at ammunition depots and airfields. Consequently, late in 1950 the current research project was inaugurated by the Bureau of Yards and Docks, U.S. Navy Department, to make hydromechanical studies of soil erosion and explore techniques for controlling construction of slopes. Important parts of the over-all objectives include: (1) design and construction of a device for simulating rainfall in the laboratory; (2) location of additives that would reduce drastically the effects of rainfall on steep slopes and be conducive to plant life; (3) determination of the practicality of promising additives for field use; and (4) establishment of a mathematical relationship between the energy of raindrops and soil loss.

Since the texture and chemical composition of soils vary over such a wide range, and since even slight changes in these properties greatly influence the susceptibility of soils to the erosional processes, the problem of curbing erosion by soil additives is extremely complex and one unlikely to be solved by a single, simple method.

It is the purpose of this paper to summarize the progress made to date and to stimulate more interest in this urgent problem.

MATERIALS TESTED

Soils

In order to test the effectiveness of prospective soil additives upon a wide range of fine-grained soils, samples

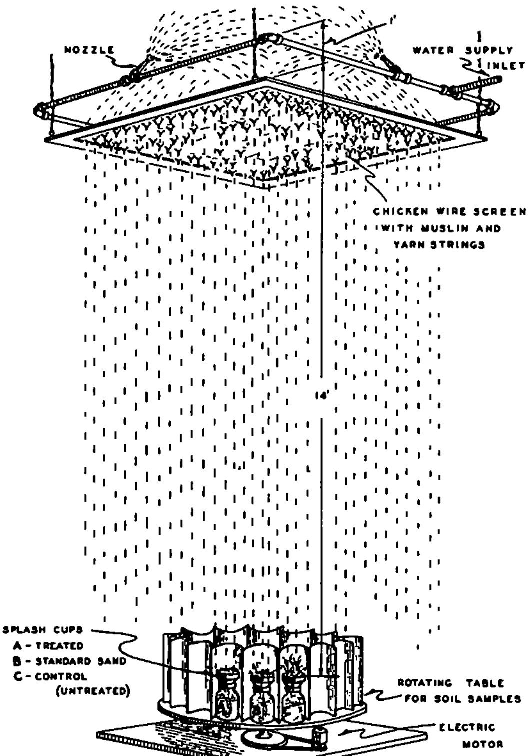

Figure 1. Artifical-rainfall applicator.

were obtained from various parts of the country. The characteristics of the soils used to date are shown in Table 1.

Additives

Six additives have been investigated as to effectiveness in curbing soil erosion at the time of this writing. A brief description and source of each additive is given in Table 2.

TESTING PROCEDURES

Since soil erosion is "a process of detachment and transportation of soil materials by erosive agents,"[1] it was believed that the primary solution to the erosion problem on steep slopes must lie in the prevention of the detachment of particles of soil. Realizing that the principal detaching agent is the raindrop, it was decided to run a sufficiently large number of splash tests to determine the effectiveness of various additives in reducing the splash loss of soils subjected to high erosional damage.[2]

For determining the splash loss of a given soil, an artifical-rainfall applicator was designed and constructed. Figure 1 shows three splash cups in place on a rotating table under the rainfall applicator. Model slopes of varying degree were also investigated under this applicator. Photographs of two typical model slopes after a splash test are shown in Figure 2. The use of a rotating table and the practice of oscillating the screen ensures identical rainfall treatment on all soil samples. A complete description of the equipment used in the splash-loss analyses and its function will be found in a previous paper[3] written by the author.

At the outset of the investigation it was realized that a simple, yet effective, method for screening the various additives must be found. Initially, to establish a trend on the effectiveness of an additive, gradation analyses were run on soil samples treated with an economical concentration of the additive (0. 2 percent of dry weight). These results were then compared to mechanical analyses on the untreated soil samples, and if the percentage of treated soil passing the No. 200 sieve was reduced by one half or more, the additive was considered promising. Due to the shortcomings of this method, it was later decided to evaluate additives in the following manner:

1. Sprinkle an economical concentration of the additive in question into a slurry of water and fine-grained soil. In most cases, if the water is taken up and the fine grains of the soil form into aggregations or clumps, the additive will be effective in curbing erosion.

2. Then, as a check on Step 1, treated soil crumbs are placed in a beaker of water. If the treated crumbs maintain their shapes indefinitely (untreated crumbs will disintegrate immediately), it is felt that the additive should be investi-

[1]W D Ellison, "Soil Detachment and Transportation," published in U S Soil Conservation Service "Soil Conservation", February 1936, Volume II, No 8

[2]These soils are principally fine sands, silts, and clays

[3]L J Goodman, "Erosion Control in Engineering Works", Agricultural Engineering (March, 1952)

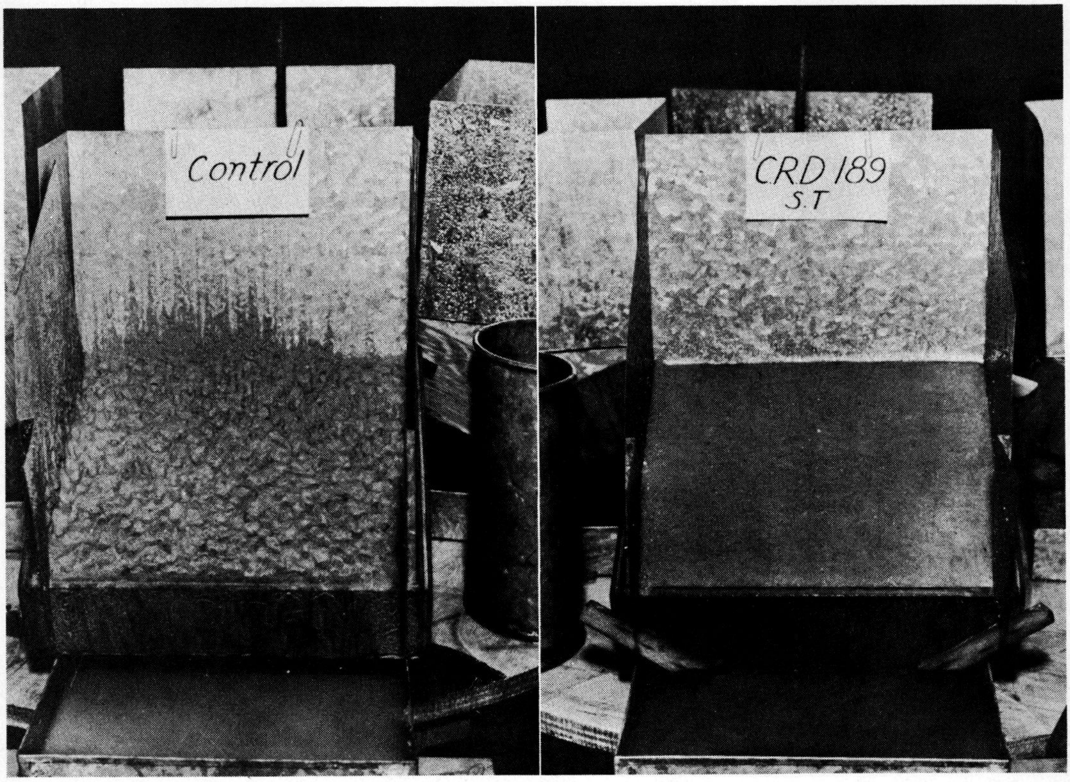

Figure 2. An untreated model slope (at left) is compared with a CRD-189 surface-treated slope (at right) after a 15-min. splash test.

TABLE 1

CHARACTERISTICS OF SOILS INVESTIGATED

	Soil	Gravel %	Sand %	Silt %	Clay %	Uniformity* Coeff.	Liquid Limit	Plasticity Index	Specific Gravity	pH	Description
A.	Shade River	0.0	81.25	16.25	2.50	6.3	(Not plastic)		2.63	6.1	Silty Sand
B.	Delaware Sand	0.0	71.1	28.9	0.0	7.8	(Not plastic)		2.73	9.4	Silty sand
C.	Boston Blue Clay	0.0	0.0	36.0	64.0	29.0	39.2	16.7	2.74	8.0	Very silty clay
D.	Mechanicsburg, Pa.	3.0	14.5	46.0	36.5	9.1	31.2	10.3	2.75	7.2	Clayey silt w/sand
E.	University Farm	2.0	50.5	22.5	25.0	29.9	39.5	15.9	2.71	7.3	Clayey silty sand
F.	Blendon Woods (Cut)	3.0	22.0	44.0	31.0	-	33.7	15.5	2.73	-	Clayey silt with appreciable sand
G.	Olentangy Sand	0.0	81.0	17.0	2.0	12.0	(Not plastic)		2.65	-	Silty sand
H.	Muskingum Sand	23.08	69.23	5.23	2.46	7.1	(Not plastic)		2.68	8.4	Gravelly sand w/ some fines
J.	Blendon Woods (Fill)	8.62	9.96	39.95	41.47	11.7	36.0	19.95	2.72	7.2	Silty clay w/ sand sizes
K.	Delaware silt	10.25	46.06	41.9	1.79	9.1	(Not plastic)		2.70	9.0	Sandy silt w/ some gravel
L.	Olentangy (East Bank)	6.60	7.96	54.25	30.74	51.1	43.1	17.27	2.76	6.8	Clayey silt w/ sand sizes
M.	New Jersey P. S. (Yellow)	0.41	84.09	13.31	2.19	5.6	(Not plastic)		2.69	5.7	Silty sand
N.	New Jersey G. S. (Red)	0.5	83.5	7.6	8.4	67.5	(Not plastic)		2.72	5.3	Sand with some fines
O.	Stonelick	5.5	8.5	66.5	19.5	7.6	33.0	6.4	2.67	5.8	Clayey silt
P.	Tusca-Meigs	0.0	3.2	37.5	59.3	0.0	51.3	24.07	2.77	-	Very silty clay
Q.	Crane Ind.	0.0	18.6	47.6	34.8	23.6	30.7	21.8	2.70	5.8	Clayey silt w/ sand
R.	New Jersey (Pier Area No. 1)	0	50.2	31.4	18.4	2.7	(Not plastic)		2.57	4.2	Silty sand w/ clay
S.	New Jersey (Pier Area No. 2)	0	51.0	26.6	22.4	14.2	(Not plastic)		2.58	3.8	Silty sand w/ clay

*Uniformity coefficient is defined by Hazen as the ratio of diameter of 60-percent size to diameter of 10-percent size.

gated in a splash-loss analysis.

In preparing for a splash test, the soil samples were compacted into the splash cups in three layers and struck off. The compactive effort was predetermined to give a density comparable to the in situ, or natural, density for each soil. The soil samples were brought to a standard condition of moisture before the test by putting water in the jars and allowing saturation to take place via cotton wicks over night (see Fig. 1). The jar served another function in collecting the water that would seep down through the soil during the test, giving a relative measure of infiltration.

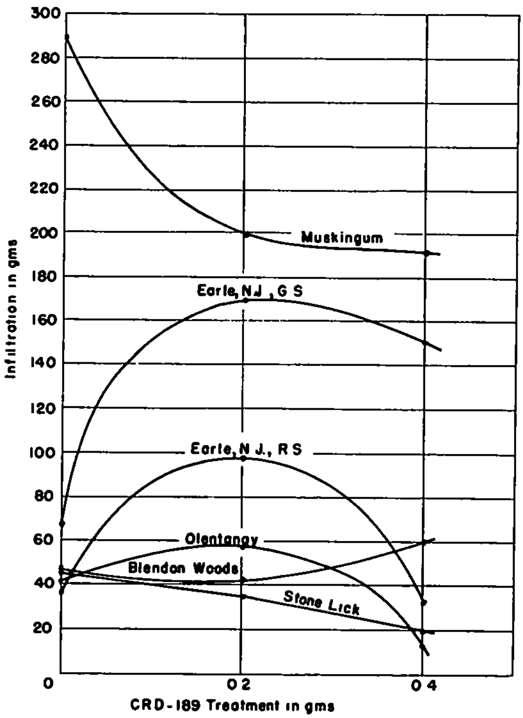

Figure 3. Treatment versus infiltration curves for various soils.

For the treated samples, the soil additives were applied either as a surface or rake-in treatment at a concentration comparable to 1 lb. per 100 sq. ft. Then both treated and untreated soil samples were surface moistened. The surface moistening served a dual purpose: (1) water soluble additives such as Monsanto's materials must be put into solution to cause the aggregation to take place. (2) All soil samples should be

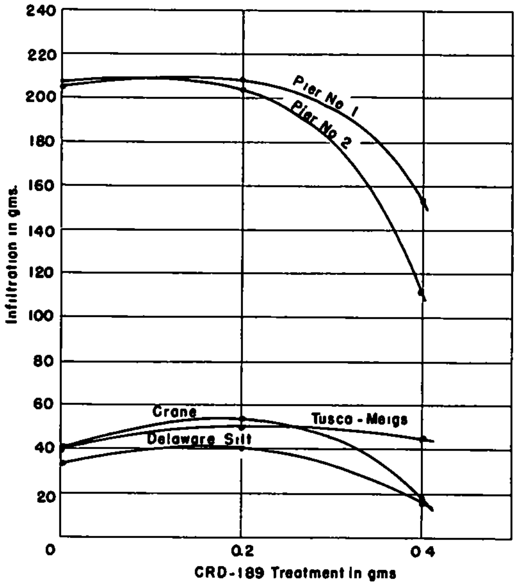

Figure 4. Treatment versus infiltration curves for various soils.

kept in a standard condition of moisture before the test.

It was found desirable to use an oil cloth large enough to cover all the samples until the rainfall applicator was functioning properly. Also, upon com-

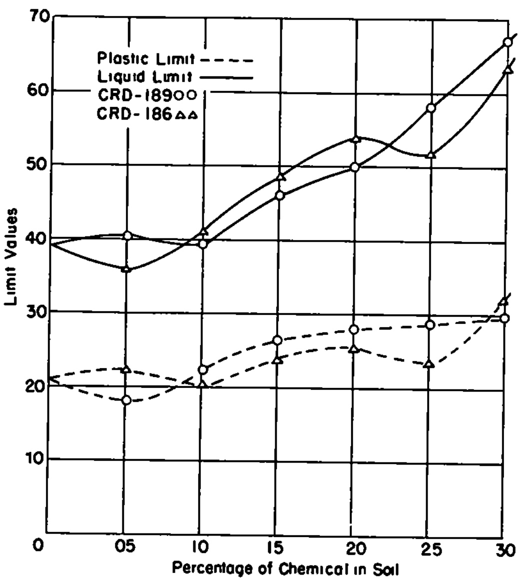

Figure 5. Liquid and plastic limits versus concentration of chemical for Boston Blue Clay.

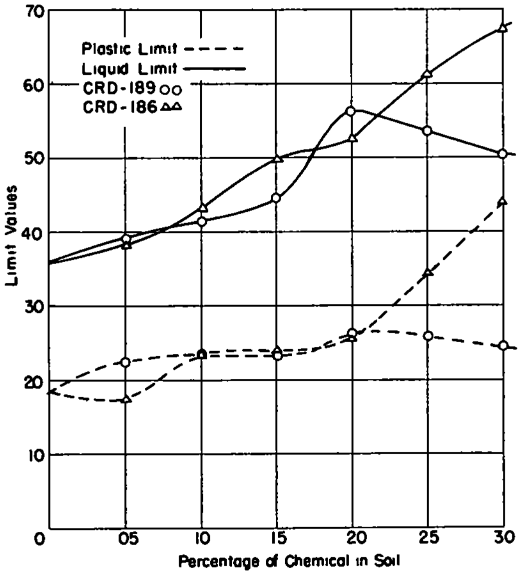

Figure 6. Liquid and plastic limits versus concentration of chemical for Blendon Woods Fill.

pletion of a test, the samples were again covered quickly until all dripping had ceased.

Rainfall intensity was measured by placing two water containers diametrically opposite each other on the turntable.

In tests to date, a raindrop diameter of 5.04 mm., which compares favorably with the size of drop encountered in erosive rainstorms, has been used. This was accomplished by employing a 3/16-in.-diameter cotton yarn with a 2-in.-mesh wire screen.

Duplicate samples of a well-rounded standard sand (60 to 70 gradation) were also investigated in each splash test to compile data for the mathematical analyses of detachability.

Splash loss is determined by obtaining the differences in oven-dry weights of each sample before and after the test.

Infiltration data were obtained with different concentrations of CRD-189. In this phase of the investigation the drip screen was lowered several inches above the splash cups to eliminate impact effects on the soil surface.

The effects of the additives on the plastic and liquid limits of certain of the soil samples were also investigated.

TEST RESULTS

The laboratory splash-loss analyses are summarized in Table 3. In studying these test results, it should be realized that most of the materials investigated were not developed primarily for erosion control and that the results obtained in this connection do not necessarily reflect the effectiveness of these materials when used for other purposes.

Infiltration data to date have been compiled on CRD-189, one of the most promising additives for erosion control used to date. The results of this study are shown in Figures 3 and 4.

The effect of various concentrations of CRD's 186 and 189 on the liquid and plastic limits of soils C and J are shown in Figures 5 and 6.

Discussion of Results

CRD-189, when applied as a surface treatment, ranged from excellent to fair in effectiveness in reducing the splash loss on all soils investigated with the exception of Soil B. As can be noted from Table 3, this resin was very effective on half of the soils on which it was tested, reducing splash loss by as much as 24 times on Soil O, a silt containing appreciable clay. It might be well to mention here that Monsanto's CRD's have remarkable effects in altering the struc-

TABLE 2

Material	Description	Source
1 Monsanto CRD-189	Sodium salt of hydrolyzed polyacrylonitrile - - powder form - known commercially as "Krilium"	Monsanto Chemical Company
2 Monsanto CRD-186	Calcium carboxylate polymer - powder form	Monsanto Chemical Company
3 Soil-cement aggregates	Aggregates made from a workable mortar of one part cement to eight parts natural soil (by wt.) Aggregates passing a 3/8-inch screen and retained on a number 8 screen used.	Ohio State University concrete laboratory
4 Dupont Orchem DV-71	-	Dupont Chemical Company
5 Aerotil	Hydrolyzed polymer of acrylonitrile - wettable flakes	American Cyanamide Company
6 Dupont Elchem 1089	Acidic vinyl polymer - powder form	Dupont Chemical Company

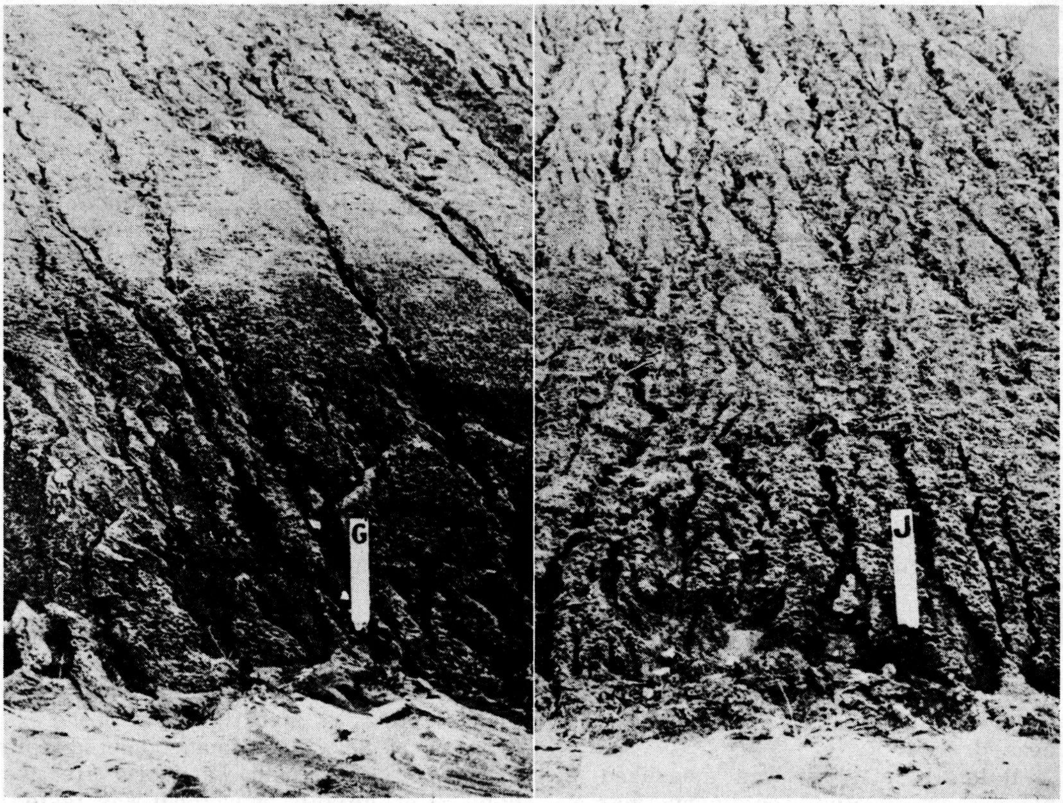

Figure 7. A CRD-189 surface-treated slope (at left) and a control slope (at right) illustrate effects of frost action on erosion.

ture of many soils containing clay particles, increasing aggregation. It can also be noted from Table 3 that CRD-189, when applied as a rake-in treatment, actually increased the splash loss. This appears to be due to the swelling effect the additive has when raked into the soil.

It can be seen in Table 2 that CRD-186 ranged from excellent to fair in effectiveness in reducing splash loss, both as a surface and a rake-in treatment, on nearly all soils investigated. Generally speaking, better results were obtained from the surface treatments, but the splash loss was reduced by approximately 16 times when this polymer was raked into Soil A, a silty sand.

Soil-cement aggregates showed good results on the silty sand from Earle, New Jersey, but a large concentration was needed. Crushing the mortar into aggregate sizes that will be effective in reducing splash loss and yet not reduce percolation has posed a problem. Adequate coverage for preventing the blasting effect of the raindrop is necessary, but the coverage must not be detrimental to vegetation.

To date, DV-71 has been investigated on several soil types. From these inconclusive results, it appears that this new additive will be quite effective in curbing soil erosion on both clayey and sandy soils.

Aerotil had no effect in reducing splash loss of clayey soils but was quite effective on a silty sand. This is a new additive and more test data are required.

Finally, it can be noted from Table 2 that Elchem 1089 showed only fair results. In some of the tests not summarized here this chemical appeared to be quite erratic, and at present it does not hold much promise as a controller of soil erosion.

It was hoped to establish a correlation

between infiltration and splash loss on the soils investigated with a CRD-189 surface treatment. On the basis of the data compiled at this writing, the results appear to be quite erratic in that splash loss reduction was effective on soils with both increased and decreased infiltration. However, it can be noted from Figures 3 and 4 that the infiltration shows a decreasing trend at the 0.4-gram concentration of CRD-189 for all soils except Soil J. This concentration is comparable to 1 lb. per 100 sq. ft. A more rigorous analysis of water percolation will be conducted at a later date in the form of falling-head permeability tests.

It is interesting to note from Figures 5 and 6 that both the liquid and plastic limits were increased at the 0.2-percent concentration of CRD-189 and CRD-186, a concentration comparable to the 1 lb. per 100 sq. ft. used in the splash-loss analyses. This increase in liquid and plastic limits indicates an increase of the strength of the soils. Since the splash loss of Soils C and J was reduced by these two chemicals, it appears that the plasticity tests might well be used in screening additives for erosion control of cohesive soils. This trend has been observed on other clayey soils and will be investigated in detail.

FIELD INVESTIGATIONS

Experimental plots have been established in several sections of the country to obtain field correlations with laboratory results. To date the only additives used in the field have been Monsanto's CRD's, but additional experimental slopes will be established in the immediate future with other promising additives, especially Dupont DV-71. The concentration of chemicals used in the field has been similar to laboratory concentrations.

At the U. S. Naval Ammunition Depot

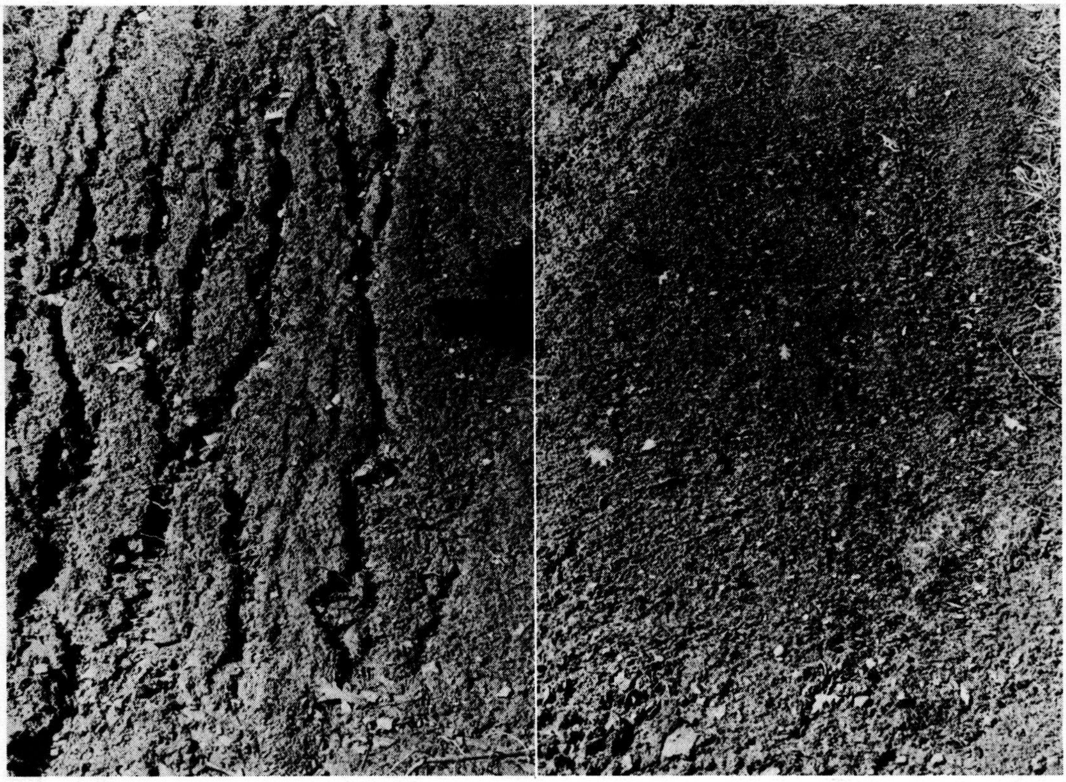

Figure 8. An untreated slope (left) and a CRD-189 surface-treated slope (right) are compared after several highly erosive rainstorms.

TABLE 3

Soil	How Investigated	Treatment	Concentration of Additive	Rainfall Intensity iph.	Duration of Test min.	Free Fall of Raindrop ft.	Average Splash Loss grams
A	Splash Cups	Control (Untreated)	1 lb/100 sq ft.	6 15/16	20	14	79 8
		CRD-186 (Rake-in)	"				4. 8
		186 (Surface)	"				12. 0
		189 (S)*	"				47. 7
		189 (R)*	"				101 3
B	Splash Cups	Control	1 lb/100 sq. ft.	8	20	14	75. 3
		CRD-186 (S)					21. 0
		186 (R)					58. 9
		189 (S)					86. 2
		189 (R)					124. 1
C	Splash Cups	Control		7 5/16	20	14	62. 2
		CRD-186 (R)	1 lb/100 sq ft.				39. 5
		186 (S)	"				40. 0
		189 (S)	"				46. 4
		Control		3	30	6	13. 6
		Aerotil (S)	"				14. 6
D	Splash Cups	Control		6 15/16	20	14	67 9
		CRD-189 (S)	"				6. 8
		186 (S)					15. 1
		186 (R)					35. 3
		189 (R)					13. 1
E	Splash Cups	Control		9	20	14	81. 6
		CRD-186 (R)	1 lb/100 sq ft.				47. 9
		186 (S)	"				68. 3
		189 (S)	"				73. 0
		189 (R)	"				123 4
F	Splash Cups	Control		8 1/4	20	14	86. 9
		CRD-186 (R)	1 lb/100 sq ft.				17. 1
		186 (S)	"				59. 0
		189 (S)	"				59 7
		Control		2 3/4	30	6	14. 0
		Aerotil (S)	"				13. 5
G	Splash Cups	Control		10	20	14	98. 7
		CRD-189 (S)	1 lb/100 sq ft				21. 3
		186 (R)					91. 9
H	Model Slopes	Control		3	20	9	71. 5
		CRD-189 (S)	1 lb/100 sq. ft.				64. 4
J	Splash Cups	Control		3	30	6	12. 5
		Aerotil (R)	1 lb/100 sq ft.				19 5
		Control		1 3/8	60	6	18. 6
		Elchem 1089 (S)	2 lb/100 sq ft				15. 2
		Control		1 7/8	60	6	15 7
		DV-71 (S)	15 lb/100 sq ft.				7 6
	Model Slopes	Control		3 3/4	15	9	170. 5
		CRD-186 (S)	1 lb/100 sq. ft.				16. 4
		189 (S)	"				18. 0
K	Model Slopes	Control		4 1/3	20	9	75. 9
		CRD-189 (S)	1 lb/100 sq ft.				11. 3
		186 (S)	"				12. 9
L	Splash Cups	Control		2 3/8	60	6	26. 0
		CRD-189 (S)	1 lb/100 sq. ft.				13 3
		Elchem 1089	2 " "				24. 4
		Control		3			11. 5
		Aerotil (S)	1 lb/100 sq. ft.				13. 0
		Control		2 1/16	60	6	22 0
		CRD-189 (S)	1 lb/100 sq. ft.				10. 0
		DV-71 (S)	15 lb/100 sq. ft.				15. 2
	Model Slopes	Control		3 3/4	20	9	217 0
		CRD-189 (S)	1 lb/100 sq. ft.				97. 8
M	Splash Cups	Control		3 2/3	30	9	37. 8
		CRD-189 (S)	1 lb/100 sq ft.				3. 6
		186 (S)	"				7. 3
		Control		2 1/2	15	9	18. 1
		Soil-Cement (1 4)	35 lb/100 sq. ft.				10. 0
	Model Slopes	Control		4 1/2	20	9	272 6
		Soil Cement (1. 8)	3/4 inch depth				9 9
		Control		3 3/8	20	9	225 3
		CRD-189 (S)	1 lb/100 sq ft.				17 3
		Elchem 1089	2 lb/100 sq ft.				190 8

TABLE 3 (continued)

Soil	How Investigated	Treatment	Concentration of Additive	Rainfall Intensity iph.	Duration of Test min.	Free Fall of Raindrop ft.	Average Splash Loss grams
N	Splash Cups	Control		$1\frac{3}{4}$	30	6	14.9
		Aerotil (S)	1 lb/100 sq. ft.				8.9
		Control		$2\frac{3}{8}$	60	6	36.9
		DV-71 (S)	15 lb/100 sq. ft.				10.9
		Control		$2\frac{1}{16}$	60	6	28.4
		CRD-186 (S)	1 lb/100 sq. ft.				8.6
		Elchem 1089 (S)	2 " "				16 2
O	Splash Cups	Control		$2\frac{3}{4}$	30	6	39 2
		Aerotil (S)	1 lb/100 sq ft.				35.6
	Model Slopes	Control		$4\frac{3}{4}$	20	9	213.3
		CRD-189 (S)	1 lb/100 sq ft.				8.7
		186 (S)	"				92.6
P	Splash Cups	Control		$2\frac{3}{4}$	30	6	39 2
		Aerotil (S)	1 lb/100 sq ft.				35.6
	Model Slopes	Control		5	20	9	224.0
		CRD-189 (S)	1 lb/100 sq ft.				27 1
		186 (S)	"				55.2
Q	Splash Cups	Control		$4\frac{1}{8}$	30	6	29 1
		DV-71 (S)	15 lb/100 sq ft.				10.8

* S denotes surface application
R denotes rake-in application

in Earle, New Jersey, slopes of 1 on 2 (1 vertical to 2 horizontal) and from 60 to 78 ft. long were selected for field-testing the chemicals. Generally speaking, results have been quite encouraging in this area. However, one group of plots was established in the late fall of 1951 to determine the field effects of frost action on treated slopes with no vegetation present. The results of this investigation after an average winter are shown in Figure 7. It can be seen that a surface treatment of CRD-189 at a concentration of 1 lb. per 100 sq. ft. was not effective in controlling erosion due to frost action. This may be due to soil, which is very acid (pH = 4.0), or due to the ineffectiveness of this particular chemical in controlling frost action. This matter will be investigated in detail.

Fairly steep slopes were also established on a highway fill section in the Blendon Woods Metropolitan Park area, Columbus, Ohio, (Soil J). Results from this section have been excellent. Figure 8 shows a control (untreated) slope and a CRD-189 surface-treated slope after several highly erosive rainstorms. The control slope was severely eroded, whereas the treated slope shows no sign of erosion.

Figure 9 is a photograph taken recently of the fill section at the Blendon Woods Metropolitan Park area. The slope on the right is untreated while that on the left has a CRD-189 surface treatment at a concentration of 1 lb. per 100 sq. ft. Both plots were seeded and fertilized simultaneously. Note the heavy growth of grass on the treated plot.

MATHEMATICAL RELATIONSHIPS

An attempt has been made to establish a mathematical relationship between soil loss and the energy of raindrops. The practicality of the relationship has not yet been determined, and the following discussion will concern itself solely with theoretical considerations.

The loss of soil from laboratory splash cups is in some way related to total rainfall, raindrop diameter, and the velocity of the rain. The splash-cup data for tests run on the standard sand (60 to 70 gradation) and the New Jersey yellow soil were analyzed for the mathematical relationships. Plotting of the data showed the general equation of exponential form to be satisfactory. Accordingly the following equation was used:

$$L = KV^a I^b T^c D^e$$

Where, L = Loss of soil or sand due to raindrop splash, in grams.

K = A constant of proportionality to be calculated.

Figure 9. A CRD-189 surface-treated slope (at left) and an untreated control slope are studied several months after being established.

V = The corrected velocity of a water drop falling in stagnant air, in feet per second.
I = The rainfall intensity, in inches per hour.
T = The time in minutes at which a given loss occurs.
D = Raindrop diameter in mm.
a, b, c, e = Exponents which must be calculated.

In the mathematical data compiled to date a constant raindrop diameter of 5.04 mm. has been used, thereby eliminating this variable temporarily. The splash loss equation then becomes

$$L = K\,V^a I^b T^c$$

The coefficients and exponents were calculated by the method of least squares. Velocities of impact for raindrops were introduced as 25.5 ft. per sec. for a free fall of 14 ft. and 21.6 ft. per sec. for a free fall of 9 ft. The standard sand data were obtained over a relatively wide range of intensities and times and should be fairly reliable. Intensities ranged from 2 ½ to 10 in. per hr. and times from 0 to 60 min. However, mathematical data from tests on the New Jersey yellow soil was relatively limited, rendering the results inconclusive as of this writing.

For standard sand the following relationship resulted:

$$L = \frac{V^{0.619} I^{1.204} T^{0.891}}{10}$$

It must be emphasized here that much more data on both untreated and treated soil samples is needed for reliable mathematical relationships. It is advisable to have a minimum of three points on the velocity curve, and this is currently being accomplished by using a range of free falls from 6 to 2 ft. to supplement data and results obtained with the free falls of 14 and 9 ft. Also, varying raindrop diameters will be employed.

CONCLUSIONS

From the results presented in this paper, it is apparent that no entirely satisfactory soil additive for curbing erosion has been found. Although several materials are effective with certain soils, none has proved to be universally suitable. Based upon the data and results compiled to date, the following conclusions can be stated:

1. The testing procedures developed in this investigation, from evaluating potential effectiveness of proposed erosion control additives to conducting a splash loss analysis, appear to be satisfactory.
2. Proposed soil additives for curbing erosion should be tested with a large number of soils because the effectiveness of a particular treatment varies with the soil used. The characteristics of the natural soils are the greatest variables encountered in erosion control.
3. The surface-treatment method of applying the soil additives to soil plots appears to be the more effective and practical.
4. Based on laboratory and field results, Monsanto's CRD-189, when applied as a surface treatment, has been the most effective in curbing erosion. However, it must be cautioned here that a rake-in treatment of CRD-189 is not effective.
5. Monsanto CRD-186 has been quite effective in reducing splash loss in the laboratory, but field results using this polymer have not been too encouraging. It appears that more field data on this chemical are needed.
6. More test data on soil-cement aggregates are needed. However, it does not appear that this soil additive will be practical, since extremely heavy concentrations are necessary for effectiveness in reducing the splash loss.
7. Dupont's Orchem DV-71 has shown good promise in the laboratory investigations and will be field tested at more economical concentrations in the near future.
8. Field results show conclusively that the CRD's at economical concentrations (1 ± lb. per 100 sq. ft.) do not inhibit the growth of vegetation, the simplest means for protection of most slopes (see Fig. 9).
9. Cut and fill sections will tolerate steeper slopes when treated with effective soil additives. This may represent an important technique for reducing construction and maintenance on many miles of highway slopes.
10. It appears that there is a definite correlation between the effect of the soil additives on the liquid and plastic limits of cohesive soils and their effectiveness in curbing soil erosion. It is planned to conduct a detailed investigation of this matter.
11. Finally, it appears advisable to study the effects of the various soil additives in controlling frost action.

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