Vegetative and Nonvegetative Materials to Control Wind and Water Erosion[1]

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ABSTRACT

Fine, medium, and coarse gravel spread uniformly at rates of 20, 50, and 100 tons per acre, respectively, adequately controlled wind erosion of smooth, bare, Sarpy sandy loam where no traffic was involved.

Resin emulsion sprayed at 600 gallons of concentrate per acre and asphalt emulsion and cutback asphalt sprayed at 1,200 gallons of concentrate per acre adequately controlled wind erosion on level Sarpy sandy loam at estimated respective costs of $213, $247, and $335 per acre on a carload basis, in drums, at Manhattan, Kansas. Under similar conditions, 4,000 pounds of wheat straw mulch per acre anchored with a rolling disk packer was equally effective at an estimated cost of $89 per acre.

Quantities of latex emulsion sprayed at rates up to 225 gallons of concentrate per acre were not sufficient to control wind or water erosion on level or sloping ground. Starch treatments were also ineffective to control wind erosion under the conditions of the experiment.

On a 3:1 construction slope, at least 1,200 gallons of asphalt emulsion per acre sprayed uniformly on the surface were needed to control rill erosion. The treatment cost $335 per acre. In previous experiments on a 3:1 construction slope, prairie hay mulch at 4,000 pounds per acre uniformly spread and anchored with 400 gallons of asphalt emulsion per acre was equally effective at a cost of about $200 per acre.

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Military forces, highway departments, and other agencies continually encounter wind and water erosion on bare soil resulting from various types of ground construction. The problem has been to find materials and methods that could be used to stabilize sloping and flat bare soil quickly and effectively. Information on effective treatments is needed for effective contract specifications.

Several series of experiments were undertaken on contract to the Bureau of Yards and Docks, United States Department of the Navy, to determine materials and methods to stabilize bare soil against erosion by wind. Limited information was also obtained on the relative effectiveness of some of the treatments against erosion by water.

Detailed information obtained on the relative merits of different vegetative mulches and different methods of anchoring the mulches was given in a previous paper.[3] This paper deals primarily with organic and inorganic materials other than vegetative mulches. Limited data on a vegetative mulch as a check treatment are included to compare the relative effectiveness and cost of all types of materials and methods of application.

EXPERIMENTAL PROCEDURE AND MATERIALS

Wind Erosion Control

A series of experiments was initiated in October 1959 (the 1959 series) and another somewhat different series in March 1961 (the 1961 series). The experiments were conducted on level Sarpy sandy loam. Just before initiating the plot experiments, the land was disked and drag harrowed to kill all weeds and to smooth the soil surface. A completely randomized plot design was used with two replications of treatments. All plots were 15 feet by 20 feet except those treated with wheat straw which were 30 feet by 40 feet. A commercial mulch spreader was used for heating the organic liquid materials, if necessary, and for spraying them on the soil surface. A specially designed gravel spreader was used to spread gravel uniformly on the surface.

The materials used were:

1. Gravel and crushed rock of various sizes spread uniformly in different amounts, as shown in table 1.
2. A resin-in-water emulsion (of petroleum origin) heated, or diluted with water, and sprayed in different amounts and dilutions (by volume) with water, as shown in tables 2 and 3.
3. A rapid curing (RC-3) cutback asphalt heated, or diluted with kerosene, and sprayed at various rates, as shown in tables 2 and 3.
4. A rapid and hard setting asphalt-in-water emulsion heated or diluted with various quantities (by volume) of water, and sprayed at various rates, as shown in tables 2 and 3.

Table 1—Natural gravel and crushed limestone for stabilizing Sarpy sandy loam against wind erosion. (Gravel was applied in October 1959, and wind tunnel tests were conducted in April 1960).

Material*	Rate of application, tons/acre	Mean soil loss	
		Quantity,† lb./acre	Statistical significance‡
Medium crushed limestone	100	0	a
Coarse crushed limestone	300	0	a
Medium crushed limestone	50	3	b
Coarse crushed limestone	100	3	b
Fine gravel > 2 mm.	50	9	c
Fine gravel > 2 mm.	20	23	d
Fine natural gravel	50	33	de
Medium crushed limestone	20	66	ef
Fine natural gravel	20	98	fg
Fine gravel > 2 mm.	10	166	gh
Coarse crushed limestone	50	198	gh
Fine natural gravel	10	343	i
Fine natural gravel	5	1,220	j
No gravel or limestone (check)		1,374	j

* Fine natural gravel ranged from about 0.02 to 0.25 inch, medium crushed limestone from about 0.1 to 0.5 inch, and coarse crushed limestone from about 0.25 to 1.5 inches in diameter.
† In a portable wind tunnel under equivalent 85 mile/hour wind.
‡ Means followed by letter "a" are significantly different from those means not having "a"; those followed by "b" are significantly different from those not having "b". For example, treatments with fine gravel > 2 mm. at 50 tons per acre (marked by "c") had significantly greater soil loss than treatments marked by "a" and "b" and significantly smaller soil loss than treatments marked by "d", "e", "f", "g", "h", "i", and "j".

5. A water-soluble or water-dispersible starch compound (hydrolized starch) diluted with different quantities (by volume) of water and sprayed at various rates, as shown in table 2.

6. A latex-in-water emulsion (elastomeric polymer emulsion) diluted in eight times the volume of water and sprayed at different rates, as shown in table 3.

7. Wheat straw (check treatment) spread uniformly on the ground at 4,000 pounds per acre and anchored with a cutaway rolling disk packer with disks spaced 8 inches apart and penetrating the ground about 2½ inches, as shown in table 3. From previous experiments,[3] this type and quantity of mulch and method of anchoring was found adequate to stabilize moderately erodible soil against erosion by strong winds.

A portable wind tunnel described previously[3] was used to determine the relative amounts of wind erosion from different treatments for an equivalent 85-mile-per-hour wind velocity at 50-foot height. The tests were conducted in triplicate on each plot before weed growth occurred. The soil was exposed to wind for a period of 3 minutes. At the end of that period, soil movement had ceased in all tests.

Water Erosion Control

A series of plot experiments was initiated in March 1961 on highway right-of-way with a 3:1 slope. The soil material was a silty clay alluvial subsoil. The surface at the time the plots were laid out and treated was smooth and bare. The plots were as long as the slope which varied from 16 to 20 feet. The area of each plot was 300 square feet. A randomized plot design was used with two replications of treatments.

The plots were first seeded to a brome-alfalfa mixture. Immediately then, organic liquid materials were sprayed on the surface. They were unheated because no heating unit was available at that time. This necessitated diluting the concentrated materials sufficiently to make them sprayable. The materials were as follows:

1. Resin-in-water emulsion (of petroleum origin), one part of which was diluted with four parts by volume of water and sprayed at ⅛, ¼, and ⅜ gallon of concentrate per square yard.

2. A rapid curing (RC-3) cutback asphalt, one part of which was diluted with half volume of kerosene and sprayed at ⅛, ¼, and ⅜ gallon of concentrate per square yard.

3. A rapid and hard setting asphalt-in-water emulsion, one part of which was diluted with one and four parts by volume of water and sprayed at ⅛, ¼, and ⅜ gallon of concentrate per square yard.

4. A latex-in-water emulsion (elastomeric polymer emulsion) diluted in eight times the volume of water and sprayed at 1/64, 1/32, and 3/64 gallon of concentrate per square yard.

The relative effectiveness of treatments on sloping ground was determined from the amount of rill erosion that occurred under natural conditions and from the resulting percentage of brome-alfalfa cover.

RESULTS AND INTERPRETATIONS

Variation in soil losses within the different treatments was proportional to the mean of the treatments; that is, the greater or lesser was the mean, the proportionately greater or lesser was the variation around the mean. For such cases Snedecor[4] recommends that analysis of variance (to determine if differences between treatments are significant) should be based on $\log_{10}$ of the values rather than on the actual values. The analysis was based on the $\log_{10}$ values. In addition, Duncan's[5] multiple range test was used to determine statistical differences between treatments.

Crushed Rock and Gravel

Table 1 indicates that insignificant amounts of wind erosion ($<$ 25 pounds per acre) were obtained in the tunnel when at least 20, 50, or 100 tons of fine, medium, or coarse gravel per acre, respectively, were spread uniformly on a smoothed ground surface. The finer the gravel, the lesser the amount required, but only if the gravel were coarser than about 2 mm. (about 3/32 inch) in diameter. Presence of gravel and sand $<$ 2 mm. in diameter as in fine natural gravel (table 1) made the surface more erodible under an equivalent 85-mile-per-hour wind. However, little or none of this fraction was observed to move under much lower natural winds.

The quantity of gravel needed to control wind erosion was that which was needed to cover the soil surface almost completely. From this, it appears that a complete cover will protect the soil from wind no matter how erodible the soil may be.

Applications of gravel and crushed rock in quantities $>$ 20, 50, or 100 tons of fine, medium, or coarse material per acre, respectively, appeared to be superfluous under the conditions of this experiment in which traffic was not involved.

Organic Surface Films to Control Wind Erosion (1959 Series)

Spraying the soil surface with ¼ gallon of undiluted, heated cutback asphalt per square yard (1,200 gallons per acre) in October 1959 gave (in April 1960) an insignificant amount of erosion of 3 pounds per acre compared with 878 pounds per acre for the untreated soil (table 2). Half that quantity of the asphalt was insufficient to keep soil loss to an insignificant amount of $<$ 25 pounds per acre and more than that was superfluous.

The undiluted, heated asphalt emulsion was nearly as effective in controlling wind erosion as the cutback asphalt, and ¼ gallon of this material per square yard (1,200 gallons per acre) was sufficient to reduce soil loss to an insignificant quantity of $<$ 25 pounds per acre (table 2). The asphalt emulsion film, unlike that of cutback, contracted and cracked considerably after undergoing the influence of the winter season. This behavior was probably due to the asphalt emulsion films being partially dispersible in water. Contraction of the

[4]Snedecor, G. W. Statistical Methods. Iowa State College Press. Ames, Iowa. 534 pp. 1956.

[5]Duncan, D. B. Multiple range and multiple F tests. Biometrics. 11:1-42. 1955.

film was somewhat detrimental from the standpoint of controlling wind erosion but may be beneficial to grass stands by allowing more rainwater to penetrate the film instead of running off.

Excessive dilution of asphalt emulsion with water was detrimental from the wind erosion control standpoint. Thus, the soil loss for the 1/8-gallon-per-square-yard rate of asphalt emulsion diluted with 1/2 gallon of water was 333 pounds per acre compared with only 72 pounds per acre for the same quantity of undiluted emulsion and 67 pounds per acre for the undiluted cutback asphalt (table 2).

The 1/4-gallon-per-square-yard (1,200 gallons per acre) rate of resin emulsion diluted with four parts of water gave a soil loss of 29 pounds per acre (table 2), almost sufficient to reduce it to an insignificant quantity of 25 pounds per acre. Without dilution or with considerably less dilution with water, this quantity likely would have been more than sufficient. This conclusion is based on the fact that, as with asphalt emulsion, dilution of this material with water increased the soil loss by wind, as shown in table 2 for 1:4 and 1:8 dilutions involving the same rates of concentrate.

Table 2—Stability of organic surface films against wind erosion of Sarpy sandy loam (1959 series: films were applied in October 1959 and tested for erosion in April 1960).

Material, dilution with water, if any, and rate of application of concentrate*	Mean soil loss: Quantity, lb./acre†	Mean soil loss: Statistical significance‡	Estimated cost, $/acre§
Cutback asphalt, 1/4 gal./sq. yd.	3	a	247
Cutback asphalt, 1/2 gal./sq. yd.	11	b	292
Asphalt emulsion, 1/4 gal./sq. yd.	15	b	335
Resin emulsion, 1:4, 1/4 gal./sq. yd.	29	c	401
Cutback asphalt, 1/8 gal./sq. yd.	67	d	154
Asphalt emulsion, 1/8 gal./sq. yd.	72	d	182
Resin emulsion, 1:4, 1/8 gal./sq. yd.	116	d	215
Resin emulsion, 1:8, 1/8 gal./sq. yd.	306	e	218
Asphalt emulsion, 1:4, 1/8 gal./sq. yd.	333	e	185
Resin emulsion, 1:4, 1/32 gal./sq. yd.	405	ef	78
Resin emulsion, 1:8, 1/32 gal./sq. yd.	490	efg	80
Asphalt emulsion, 1:4, 1/32 gal./sq. yd.	665	efgh	107
Asphalt emulsion, 1:8 1/64 gal./sq. yd.	750	fghi	51
No film (check)	878	fghij	0
Starch, 1/80 lb. in 1/8 gal. water/sq. yd.	906	ghij	35
Starch, 1/40 lb. in 1/8 gal. water/sq. yd.	1,055	ghij	38
Asphalt emulsion, 1:8, 1/32 gal./sq. yd.	1,022	ghij	70
Resin emulsion, 1:8, 1/64 gal./sq. yd.	1,160	hij	78
Resin emulsion, 1:4, 1/16 gal./sq. yd.	1,433	hij	124
Starch, 1/80 lb. in 1/4 gal. water/sq. yd.	1,428	hij	37
Starch, 1/160 lb. in 1/4 gal. water/sq. yd.	1,727	ij	34
Starch, 1/40 lb. in 1/4 gal. water/sq. yd.	1,945	j	40

* Materials that were undiluted with water had to be heated before they could be sprayed. † Under equivalent 85 mile/hour wind.
‡ Mean followed by letter "a" is significantly different from those means not having "a"; those followed by "b" are significantly different from those not having "b", etc.
§ Costs of material and labor for most of the treatments can be derived from table 3.

Treatments with water-soluble (hydrolized) starch were completely ineffective after going through the winter season. The starch appeared to have decomposed or leached from the surface soil. The darker color of the treated compared with untreated plots indicated that at least some of the starch was decomposed 6 months after application when the tunnel tests were conducted. It is certain that at least some of the starch treatments would have been effective against the equivalent 85-mile-per-hour wind immediately after application and for some weeks or months before the starch was leached or decomposed.

Vegetative Mulch and Organic Surface Films to Control Wind Erosion (1961 Series)

Because some sand was blown onto the 1961 treated plots before wind tunnel tests could be performed, a criterion of insignificant soil loss by wind erosion in the tunnel was taken as < 60 pounds per acre instead of < 25 pounds per acre as for the 1959 series of experiments. Effective treatments in the 1961 series, as shown in table 3, were:

1. Wheat straw applied uniformly over the ground at 4,000 pounds per acre and packed with a disk packer about 2½ inches deep. This treatment was estimated to be the least costly ($89 per acre).

2. Resin emulsion diluted 1:1 with water and sprayed to cover the surface uniformly at the rate of 1/8 gallon of concentrate per square yard (600 gallons per acre). This material was remarkable for wind erosion control—at least on Sarpy sandy loam—for two reasons: *(a)* The resin remained "moist" and sticky for at least 3 months after the applications, and *(b)* Surface roughness and soil clods treated with resin resisted soil slaking by heavy rains, thereby trapping the water during a rainy period and resisting wind erosion during a dry period. The cost of this treatment (in drums on carload basis) at Manhattan, Kansas, was estimated at $213 per acre.

3. Cutback asphalt and asphalt emulsion diluted 1:½ with kerosene and 1:1 with water, respectively, and

Table 3—Stability of surface films against wind erosion of Sarpy sandy loam (1961 series: Films were applied in March 1961, and tested for erosion in April 1961).

Material, dilution with water, if any, and rate of application of concentrate	Mean soil loss: Quantity, lb./acre†	Mean soil loss: Statistical significance‡	Estimated cost per acre, $: Material§	Estimated cost per acre, $: Labor¶	Estimated cost per acre, $: Total
Resin emulsion, 1:1, 1/8 gal./sq.yd.	20	a	183	30	213
Resin emulsion, 1:1, 1/4 gal./sq.yd.	23	ab	366	32	398
Straw, 4,000 lb./acre, anchored with rolling disk packer (check treatment)	25	ab	30	59	89
Resin emulsion, 1:4, 1/4 gal./sq.yd.	33	abc	366	35	401
Cutback asphalt, 1:1/2, 1/4 gal./sq.yd.*	38	bc	144	103	247
Cutback asphalt, 1:1/2, 3/8 gal./sq.yd.*	43	bc	216	122	338
Asphalt emulsion, 1:1, 3/8 gal./sq.yd.	47	c	450	37	487
Resin emulsion, 1:4, 1/8 gal./sq.yd.	49	c	183	32	215
Resin emulsion, 1:1, 3/8 gal./sq.yd.	49	c	549	35	584
Resin emulsion, 1:4, 3/8 gal./sq.yd.	50	cd	549	37	586
Latex emulsion, 1:8, 3/64 gal./sq.yd.	84	de	360	30	390
Latex emulsion, 1:8, 1/32 gal./sq.yd.	88	de	240	30	270
Cutback asphalt, 1:1/2, 1/8 gal./sq.yd*	89	de	72	82	154
Asphalt emulsion, 1:1, 1/4 gal./sq.yd.	125**	ef	300	35	335
Asphalt emulsion, 1:1, 1/8 gal./sq.yd.	132**	ef	150	32	182
Latex emulsion, 1:8, 1/64 gal./sq.yd.	180	f	120	30	150
No film (check)	519	g	0	0	0

* Cutback asphalt was diluted with kerosene because no heating facility was available at that time. † Under equivalent 85 mile/hour wind.
‡ Means followed by letter "a" are significantly different from those not having "a"; those followed by "b" are significantly different from those not having "b", etc.
§ Approximate cost in drums on carload basis, Manhattan, Kans. Baled hay and straw are obtained locally at $15/ton delivered.
¶ Estimated on basis of average contract bids to Kansas Highway Department, 1960, for application of same or similar material.
** More loose sand was deposited by wind on these than on other treatments.

Table 4—Surface films to stabilize silty clay alluvial subsoil (on 3:1 slope) against erosion by water. (Films were applied in March 1961.)

Material, dilution with water, and rate of application of concentrate	Rill erosion on June 20, 1961		Grass cover June 20, 1961, %	Estimated cost per acre, $
	Quantity, tons/acre	Statistical significance		
Asphalt emulsion, 1:1, 3/8 gal./sq. yd.	1.6	a	60	487
Asphalt emulsion, 1:1, 1/4 gal./sq. yd.	4.4	b	72	335
Cutback asphalt, 1:1/2, 3/8 gal./sq. yd.*	12.3	c	45	338
Resin emulsion, 1:1 and 1:4, 3/8 gal./sq. yd.	24.0	d	65	585
Cutback asphalt, 1:1/2, 1/4 gal./sq. yd.*	24.1	de	45	247
Resin emulsion, 1:1 and 1:4, 1/4 gal./sq. yd.	28.3	def	72	400
Asphalt emulsion, 1:1, 1/8 gal./sq. yd.	31.6	defg	58	182
Latex emulsion, 1:8, 3/64 gal./sq. yd.	34.0	defg	50	390
Latex emulsion, 1:8, 1/32 gal./sq. yd.	35.6	defg	65	270
Resin emulsion, 1:1 and 1:4, 1/8 gal./sq. yd.	38.4	defg	78	214
Cutback asphalt, 1:1/2, 1/8 gal./sq. yd.*	43.6	fg	48	154
No film (check)	47.1	g	42	0
Latex emulsion, 1:8, 1/64 gal./sq. yd.	51.7	g	70	150

* Diluted with kerosene.

sprayed uniformly on the surface at the rate of ¼ gallon of concentrate per square yard (1,200 gallons per acre). Dilution with kerosene or water was necessary because a heating unit was not available during this 1961 series of tests, but dilutions probably reduced the effectiveness of the materials for wind erosion control. The cost of the cutback treatment was estimated at $247 per acre and of the asphalt emulsion treatment at $335 per acre.

The latex emulsion sprayed at the rates up to 3/64 gallon of concentrate, diluted with eight parts of water, per square yard was found ineffective to control wind erosion of Sarpy sandy loam (table 3). These rates were apparently too low. It was estimated from results obtained with smaller quantities that from 1/12 to ⅛ gallon of concentrate per square yard (400 to 600 gallons per acre) probably would be needed to control wind erosion effectively on this soil. But this quantity would make the cost of the treatment about $650 to $1,000 per acre.

Organic Surface Films to Control Water Erosion

The asphalt emulsion diluted 1:1 with water and sprayed at rates of ¼ and ⅜ gallon of concentrate per square yard (1,200 and 1,800 gallons per acre) was the only material that was reasonably effective in controlling rill erosion on sloping land (table 4). The cost of the ¼-gallon-per-square-yard rate was estimated at $335 per acre.

The cutback asphalt (RC-3) diluted with half the quantity of kerosene and sprayed at the rate of ⅜ gallon of concentrate per square yard was somewhat less effective than the ¼ gallon of asphalt emulsion per square yard (table 4). The 1959 series of tests to control wind erosion indicated that heated cutback asphalt sprayed in concentrated form had stability (as indicated by the ability of the surface film to go through the winter without disintegrating) at least equal to that of the asphalt emulsion. Dilution with kerosene in these experiments apparently allowed the cutback to penetrate too deeply into the soil and produced a weaker film.

The resin emulsion diluted 1:1 and 1:4 with water and sprayed on the surface with up to ⅜ gallon of concentrate per square yard also failed to control rill erosion adequately (table 4). Much of the resin penetrated the soil surface, thereby weakening the surface film.

The latex emulsion diluted 1:8 with water and sprayed on the surface at rates up to 3/64 gallon of concentrate per square yard also failed to control rill erosion adequately (table 4). The emulsion broke as soon as it hit the surface, producing a pliable latex film. However, the amounts of emulsion used were too small to produce a film that would cover the surface adequately. It was estimated from amounts of rill erosion obtained with these small quantities of material that 1/12 to ⅛ gallon of concentrate per square yard would have been effective, but the cost of such treatment would have been about $650 to $1,000 per acre.

Percent of soil surface covered with brome and alfalfa seedlings 3 months after treatment was highest for resin emulsion treatments (table 4) and lowest where no organic film was applied (check treatment). It was observed that many seeds in the check treatment washed down the slope before they germinated. A stand almost as poor as for the check treatment was obtained where cutback asphalt diluted with half the volume of kerosene was used. The kerosene apparently killed some of the seedlings and weakened the growth of the remaining ones. Both brome and alfalfa seedlings penetrated all films quite readily, although some reduction in the number of seedlings was obtained with greater quantities (up to ⅜ gallon of concentrate per square yard) of materials used.

DISCUSSION AND CONCLUSIONS

None of the nonvegetative materials investigated in these and in previous experiments[3] excelled the well-anchored prairie hay and wheat straw mulches from the standpoint of both cost and effectiveness in controlling wind and water erosion of denuded land. In previous experiments,[3] prairie hay applied uniformly on the surface at 4,000 pounds per acre and anchored with 400 gallons of asphalt emulsion per acre was completely effective in controlling water erosion on a 3:1 construction slope. The estimated cost of the mulch treatment was about $200 per acre. For wind erosion control on flat land, in present experiments, the same quantity of prairie hay and wheat straw, anchored with a disk packer, was effective at a cost of about $89 per acre. The results seem to indicate that all of the organic materials tested in these experiments, if applied in sufficient quantity and concentration, could be made to control wind and water erosion on flat or sloping land, but the cost would be substantially higher than for the well-anchored hay and straw mulches. The costs, of course, are predicted from those existing at Manhattan, Kansas, in 1961.

Excessive dilution of organic emulsions with water was detrimental from the standpoint of erosion control. Spraying without dilution sometimes required heating. Where heating could not be applied, it was best to dilute just enough to make the material sprayable. Cutback asphalt can be diluted with kerosene but kerosene was found detrimental to seedling growth.

The most effective gravel to control wind erosion ranged from about 2 to 6.4 mm. (1/12 to ¼ inch) in diameter; the larger the size, the greater was the quantity required. Where foot or other traffic was not involved, a layer only one gravel diameter thick scattered uniformly to cover the surface was all that was necessary to control wind erosion. Where traffic would be involved, probably deeper layers would be necessary.

[3] Chepil, W. S., et al. *Op. Cit.*