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UTILIZATION OF SEWAGE SLUDGE FOR TERRAIN STABILIZATION IN COLD REGIONS: PART III

S.D. Rindge, D.A. Gaskin and A.J. Pařazzo

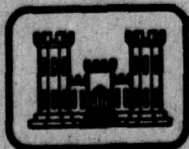
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or all three nutrients. The seed mixture in the treatments contained four grasses and one legume. The effects of the various treatments were determined through soil loss yields, visual grass ratings and plant yields. Results show that average soil loss from all treatments was within the acceptable limit of one ton/acre per year and was significantly less than that from the untreated controls. Supplementary fertilizers rich in N, P and K or in P and K appear to be slightly more beneficial than those with N alone in the reduction of soil loss. Greater plant yields during the first year were from the treatments with the lower sludge rate and supplemental fertilizer. During the second year, treatments with the high sludge rate were the better producers. Tall fescue and red fescue were the plant species that performed well in all treatments, while birdsfoot trefoil was the dominant species in treatments which did not receive nitrogen fertilizer. Total cost of installation for the treatments (including overhead and profit) ranged from \$2,850 to \$4,735/acre. More expensive treatments were those with higher rates of sludge and fertilizer.

PREFACE

This report was prepared by Susan D. Rindge, Physical Scientist, and David A. Gaskin, Geologist, of the Geotechnical Research Branch, Experimental Engineering Division, and by Antonio J. Palazzo, Agronomist, of the Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. The work was performed under DA Project 4A762720A896, Environmental Quality for Construction and Operation of Military Facilities, Task 04, Land Use Planning, Work Unit 003, Revegetation of Terrain After Construction in Cold Regions.

Roy Bates of CRREL and Dr. Frederick Erbisch of the Keweenaw Research Center, Houghton, Michigan, reviewed the technical content of this report.

The authors acknowledge the contributions made by John Bayer, Robert Essex, David Fisk, John Graham, Richard Parrot, William Seamans, and Roger Winn in the installation of revegetation treatments and/or the collection of the vegetation harvests. The Hanover Detachment of the Maynard, Massachusetts, Meteorological Team, U.S. Army Atmospheric Sciences Laboratory, measured and reduced the meteorological data.

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gallon	0.00379	meter ³
pound	0.4536	kilogram
pound/acre	1.121	kilogram/hectare
ton/acre	2.240	megagram/hectare
dollar/acre	2.471	dollars/hectare

*Exact

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SUMMARY

Objectives

We have studied revegetation treatments involving anaerobically digested sewage sludge with or without supplemental fertilizers for two years. Our objective was to determine which of the treatments were the most successful by assessing their ability to promote grass growth and stabilize soils on a west-facing 16° slope. We were interested in the differences between two application rates of sludge (20 and 40 tons/acre) and in the use of sludge alone or sludge with fertilizer.

Of the two supplemental fertilizers included, one was rich in nitrogen (N) and the other was rich in phosphorus (P) and potassium (K). We added these to the sludge both alone and together to check their separate and combined effects.

A treatment which included no sludge or fertilizer served as the control.

Conclusions

Sewage sludge application appears to be successful as a revegetation technique. Treatments with both rates of sludge application, alone and with fertilizers, retarded erosion significantly more than the untreated control. All treatments, excluding the control, had an average soil loss within the acceptable limit of one ton/acre per year set by the U.S. General Accounting Office (1977). Differences between the two sludge rates were inconclusive, with the higher rate perhaps slightly more effective. Fertilizer additions rich in N, P and K or P and K appear to be slightly better in retarding erosion than N alone.

Plant growth was variable from one year to the next. During the first year, greater plant yields resulted from the treatments with sludge at the lower rate and supplemented with fertilizers. Without the addition of fertilizer, the higher sludge rate, 40 tons/acre, produced greater plant growth than the 20-ton/acre application rate. During the second year, however, the effect of supplemental fertilizer was not evident. All treatments at the high sludge rate were the better producers.

Of the plant species sown, tall fescue and red fescue performed well in all treatments. Birdsfoot trefoil, a legume, was more prominent in treatments which did not receive nitrogen fertilizers. Total installation cost of the treatments, including overhead and profit, ranged from \$2,850/acre for sludge at 20 tons/acre and seed to \$4,735/acre for sludge at 40 tons/acre with both fertilizers and seed. Obviously, higher rates of sludge and addition of fertilizer increase the cost.

UTILIZATION OF SEWAGE SLUDGE FOR TERRAIN
STABILIZATION IN COLD REGIONS: PART III

By

Susan D. Rindge
David A. Gaskin
Antonio J. Palazzo

Introduction

This study is a continuation of revegetation research that we have conducted at CRREL, Hanover, New Hampshire, since 1974. The studies have involved the application of treatments to a sloping surface, followed by assessment of the vegetation growth and measurement of soil loss at the base of the slope (Gaskin et al. 1974, 1977, 1979; Hannel et al. 1976).

In 1974 (Gaskin et al. 1974, 1977) we tested these variables with a constant grass mixture:

Nutrient source

1. Fertilizer
2. Sewage sludge (23 tons/acre)
3. Primary wastewater

Moisture

1. Irrigated with water
2. Irrigated with primary wastewater
3. Nonirrigated

Erosion control material

1. Jute netting
2. Straw tacked with Terra Tack I
3. No erosion control material

Sewage sludge treatments allowed the least soil loss of the nutrient sources tested in 1974. However, all treatments except wastewater alone were adequately effective in reducing soil loss.

Of the erosion control materials, straw with Terra Tack I appeared to be more effective than jute netting or no erosion control material.

No correlation existed between vegetation production and soil loss. Vegetation was generally highest on plots which received fertilizer as a nutrient source.

During 1975-1976 (Gaskin et al. 1979, Hannel et al. 1976) we tried a different grass mixture and changed the variables to:

Surface preparation

1. Tracked
2. Compacted
3. Tilled

Nutrient source

1. Fertilizer or
2. Sewage sludge (22 tons/acre)

Mulch

1. Wood fiber mulch
2. Peat moss
3. No mulch

Tacking agent

1. Terra Tack III
2. Curasol
3. No tacking agent

The study was established in the spring of 1975, but half of the plots had to be reestablished in the fall of 1975 because of washouts.

All three of the surface preparations tested were quite effective in retarding erosion (91-94% effective compared to the stripped control).

Fertilizer and sewage sludge treatments had about the same amount of soil loss (93 and 91% effective compared to the control, respectively).

Vegetation response to sludge and fertilizer was variable. Among the spring-seeded plots, those with fertilizer produced greater yields at the first cutting, but thereafter the sludge-treated plots had the highest yields. On the fall-seeded plots, the sludge-treated plots were consistently the higher yielders.

Two treatments - 1) no mulch or tacking agent and 2) wood fiber mulch with no tacking agent - were the most effective combination of these two variables in reducing soil loss.

Because of the continued success of the sludge treatments in the 1975-1976 study, we designed the present study to test the effects of a higher rate of application and combination of sludge with fertilizers.

SITE CHARACTERIZATION

The research/demonstration site (Fig. 1) is located at CRREL, Hanover, New Hampshire. The test area is a west facing, 16° slope consisting of fine sediments deposited into glacial Lake Hitchcock during the Pleistocene epoch. However, sand and gravel fill has been mixed with the surficial soil on most of the plots over the last four years.

Hanover has a subcontinental climate involving cold winters and moderately warm summers with a vegetation growth period of 160-210 days. Landsberg et al. (1965) classified the climate as the Woodland type of the Cool Temperate zone. Yearly total precipitation for the area averages 37.3 in. with the maximum occurring in July (4.8 in.) (based on the 30-year period from 1941-1970, U.S. Dept. of Commerce 1973). The normal mean temperature is 44.8°F, with recorded temperature extremes of 101°F and -40°F. Bilello and Bates (1978) further discuss the climate at the CRREL test site.

METHODOLOGY

Test Plot Design

There were a total of 27 test plots of two sizes. Plots 1-14 measured 10 x 40 ft and plots 15-27 measured 8 x 40 ft (Fig. 1).

Each plot had a sediment collection tank at its base for measurement of soil loss. Plots 1-14 had 350-gal. tanks, plots 15-26 had 110-gal. tanks, and plot 27 had a 320-gal. tank. A CRREL Technical Note (Hannel et al. 1976) describes the tank installation procedures.

Treatment Variables

We applied three replicates of eight treatments to 24 of the plots. Treatments included a uniform seed mixture and combinations of 1) sewage sludge and 2) two fertilizers, one rich in N and the other rich in P and K (Table 1). Sludge and fertilizer combinations varied in the following pattern: sludge with both fertilizers, sludge with each fertilizer alone, and sludge alone. The three remaining plots were controls and received neither sludge nor fertilizer. Of these, two had a bare surface and one was seeded.

The seed mixture consisted of one legume and four grasses applied at a total rate of 100 lb/acre (Table 2). The mix included species for rapid germination and good growth in a climate with a limited growing season and cool temperatures. Birdsfoot trefoil, the legume, has a tolerance to cold temperatures and an ability to grow in less fertile

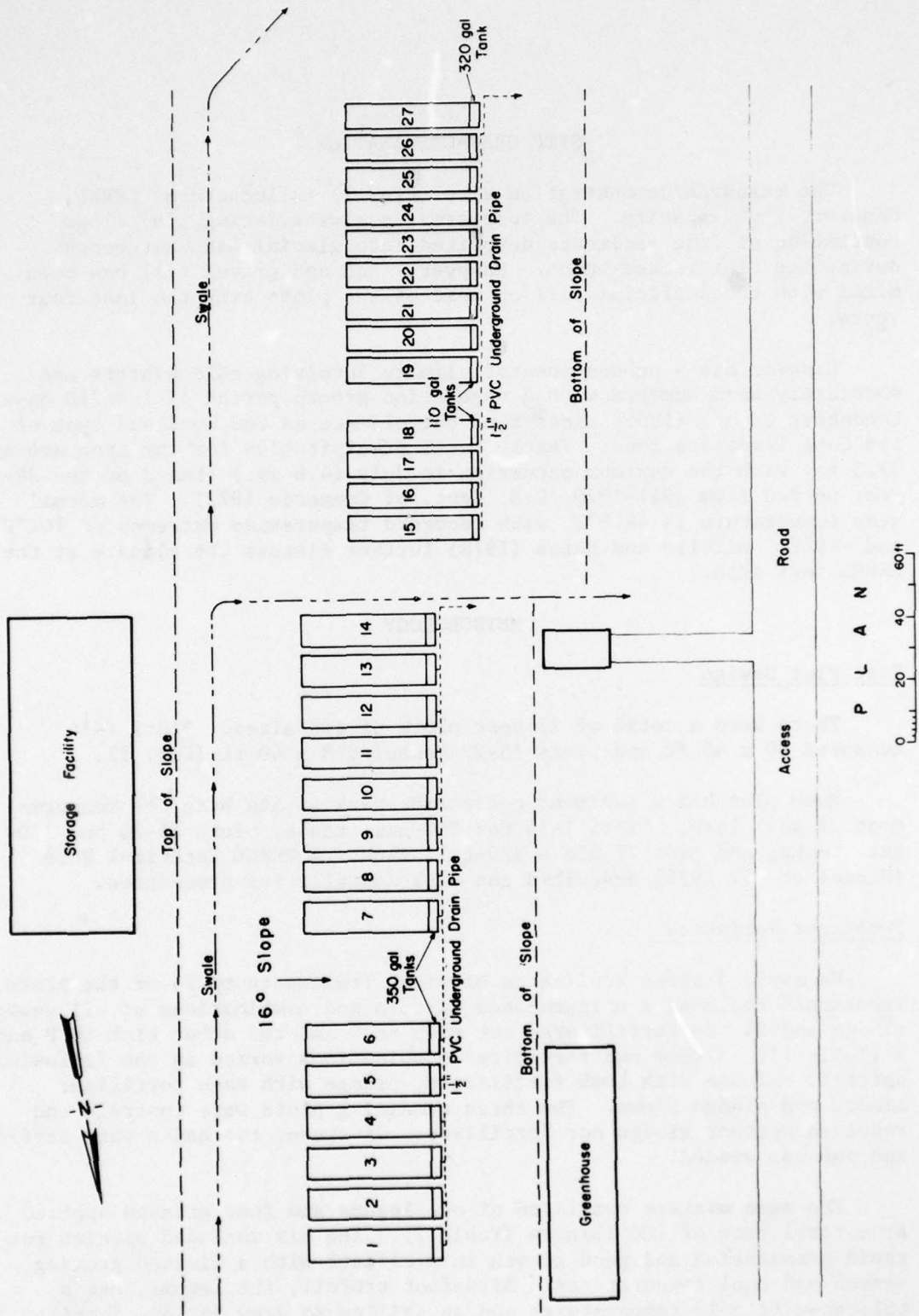


Figure 1. Plan of the 1977-78 stabilization study.

Table 1. Experimental design.

<u>Treatments</u>	<u>Plots</u>	<u>Seeded</u>	<u>Sludge</u> (tons/acre)	<u>Fertilizer*</u>
1	1, 10, 20	Yes	20	F1 F2
2	2, 11, 21	Yes	20	F2
3	3, 12, 22	Yes	20	F1
4	4, 14, 23	Yes	20	-
5	5, 15, 24	Yes	40	F1 F2
6	7, 16, 25	Yes	40	F2
7	8, 18, 26	Yes	40	F1
8	9, 19, 27	Yes	40	-
9	13, 17	No	-	-
10	6	Yes	-	-

*F1(N) = 99, 27 and 36 lb/acre of N, P₂O₅ and K₂O, respectively

F2(P+K) = 100 lb/acre each of P₂O₅ and K₂O

F1F2 (N+P+K) = 99, 127 and 136 lb/acre of N, P₂O₅ and K₂O, respectively

Table 2. Seed mixture.

<u>Seed mixture</u>	<u>Rate</u> (lb/acre)
Pennlawn red fescue	40
Kentucky-31 tall fescue	40
Birdsfoot trefoil	10
Colonial Highland bentgrass	5
Annual ryegrass	<u>5</u>
Total	100

Table 3. Sludge analyses*.

<u>Sample</u>	<u>N</u>	<u>P</u>	<u>K</u>	<u>Ca</u>	<u>Mg</u>	<u>Na</u>
	----- % -----					
1	0.60	0.84	0.5	1.79	0.143	0.283
2	0.60	0.80	<0.4	1.63	0.128	0.238

<u>Sample</u>	<u>Al</u>	<u>Ba</u>	<u>Fe</u>	<u>Sr</u>	<u>B</u>	<u>Cu</u>	<u>Zn</u>	<u>Mn</u>	<u>Cr</u>
	----- ppm -----								
1	8,108	132	6,726	37.6	31.9	178	284	98	37.8
2	7,365	118	6,395	36.6	29.4	197	231	87	29.5

<u>Sample</u>	<u>pH</u>	<u>Solids (%)</u>
1	7.5	46.07
2	7.5	44.10

*Determined on a wet weight basis.

and low pH soils. Annual ryegrass germinates rapidly so that it provides initial soil stability. The other grasses - Pennlawn red fescue, Kentucky-31 tall fescue, and Colonial Highland bentgrass - all tolerate a wide pH and temperature range.

The sewage sludge in this study was a dewatered, anaerobically digested sludge obtained from the primary sewage treatment plant in Hanover. We applied it to the soil surface at rates of 20 or 40 tons/acre.

Two grab samples of the sludge were analyzed on a wet weight basis at the University of Wisconsin following the procedures of Liegel and Schulte (1977) (Table 3). Its nitrogen, phosphorus, and potassium contents were 0.6%, 0.8% and 0.5%, respectively. Therefore, the 20-ton/acre sludge supplied N, P, K at 240, 320 and 200 lb/acre respectively, and the 40-ton/acre sludge supplied 480, 640 and 400 lb/acre of N, P, K respectively. The sludge had a pH of 7.5 and a moisture content of 55%.

The two fertilizers we chose for this study allowed the separation of nutrients between a high nitrogen fertilizer (22-6-8) and a high phosphorus and potassium fertilizer (0-25-25). When combined, these fertilizers provided all three of these essential nutrients for plant growth. Application rates were 450 lb/acre of 22-6-8 and 400 lb/acre of 0-25-25. Thus, 22-6-8 supplied 99, 27 and 36 lb of N, P and K per acre and 0-25-25 supplied 100 lb each of P and K.

Site preparation and treatment installation

Since we had used the demonstration site for previous revegetation studies, the plots and collection tanks were ready for use. The surface had to be prepared, however, to make it ready for planting. Plots 1-14 received a new cover of loam that was dumped at the top of the slope and spread with a bulldozer (Fig. 2). Plots 15-27 were tilled and then compacted slightly with the bulldozer after the turned-up vegetation had been raked off. As a final preparation, we lightly raked the soil surface of all the plots.

After staking out the plot boundaries, we applied the treatments. Sludge was applied first by dumping the appropriate amount on each plot and spreading it with a rake (Fig. 3). Next, we applied the fertilizer and seed by hand broadcasting. Finally we raked the plots lightly on 6 May 1977 to complete the installation.

Data acquisition

Weather, vegetation, and soil loss data were collected to determine the effectiveness of the applied treatments.

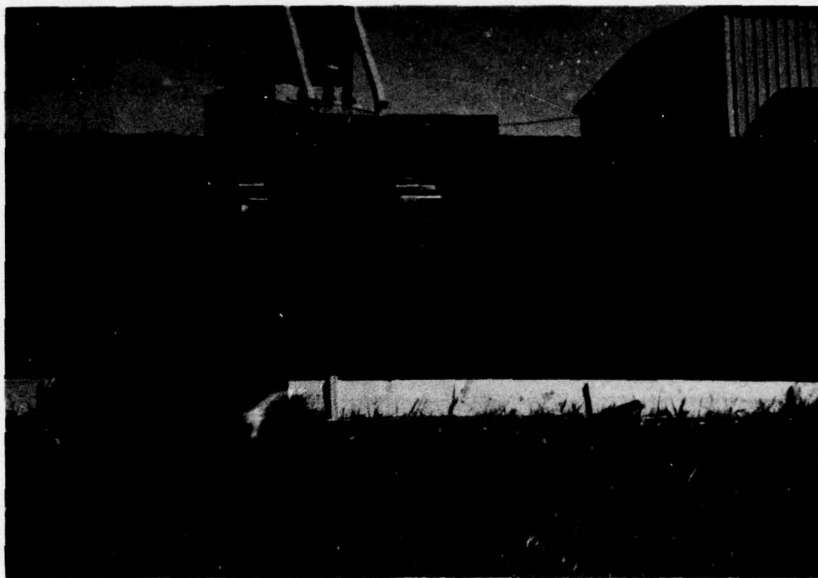


Figure 2. Spreading loam on plot.

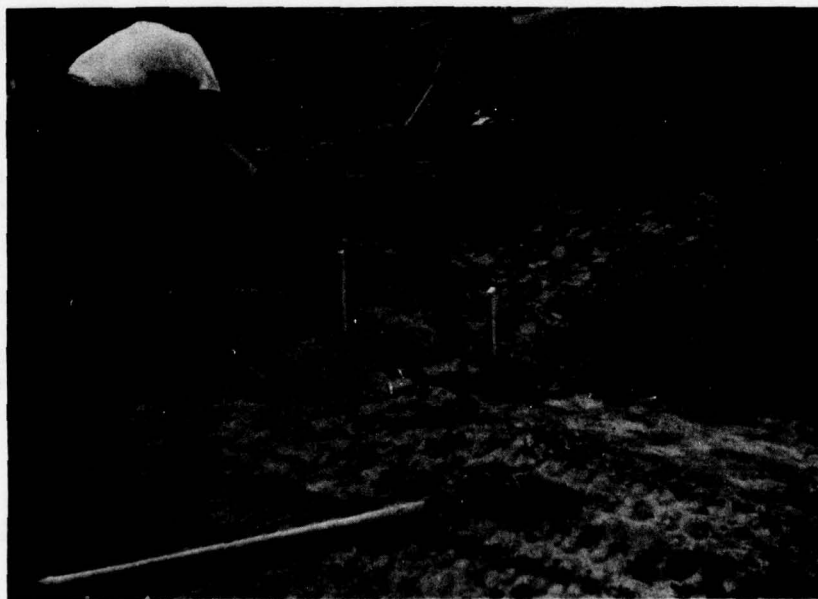


Figure 3. Sludge application.

The Hanover Meteorological Detachment, U.S. Army Atmospheric Sciences Laboratory, recorded precipitation and air temperature hourly to help us note any variations from the climatic normal.

We assessed the vegetation by determining plant yields and estimating percent coverage. Plant yields were taken the first year on 18-19 July 1977 and the second year on both 5-7 July and 14-15 August 1978. The plants were cut at a 3-in. height with a sickle-bar mower and weighed to give total fresh weight yields per plot. A hand-size grab sample of the vegetation from each plot was dried at 110°F for 48 hours to determine its water content (wet weight minus dry weight). We then used the water content data to convert the total fresh weight readings for each plot to the equivalent dry weight. Vegetation cover was determined on 9 August 1978 by visually estimating the percent coverage of vegetation over the soil surface of the entire plot.

Soil loss measurements were taken once each year - during 9-19 August 1977 and on 14 July 1978. We removed the material that had collected in the tank at the base of each plot and weighed it. The moisture content was determined in the same manner as the plant yields and the total wet weights were converted to equivalent dry weights.

RESULTS

Climate

Figure 4 and Table A1 summarize the air temperature and precipitation data recorded at the CRREL meteorological site from May 1977 to August 1978 (U.S. Army Atmospheric Sciences Laboratory 1977-78). They also list the 30-year (1941-1970) long-term normals for Hanover (U.S. Dept. of Commerce 1973).

Figure 4 shows that during the first growing season of the study (1977) air temperatures averaged 1.5°F below normal for the period and precipitation was quite variable. May, July, and August were dry (1.8, 3.2 and 1.2 in. below normal, respectively) whereas June, September and October were wetter than usual (2.2, 0.8 and 2.8 in. above normal, respectively).

The second growing season was similar to the first with average air temperatures only 0.4°F below normal. Precipitation was again variable. May and July were dry (1.6 and 1.9 in. below normal), while June and August were wet (both had 0.8 in. more rain than normal).

Vegetation

Plant yield results from individual plots are listed in Table A2 and the average yield for each treatment is shown in Table 4 and Figure 5.

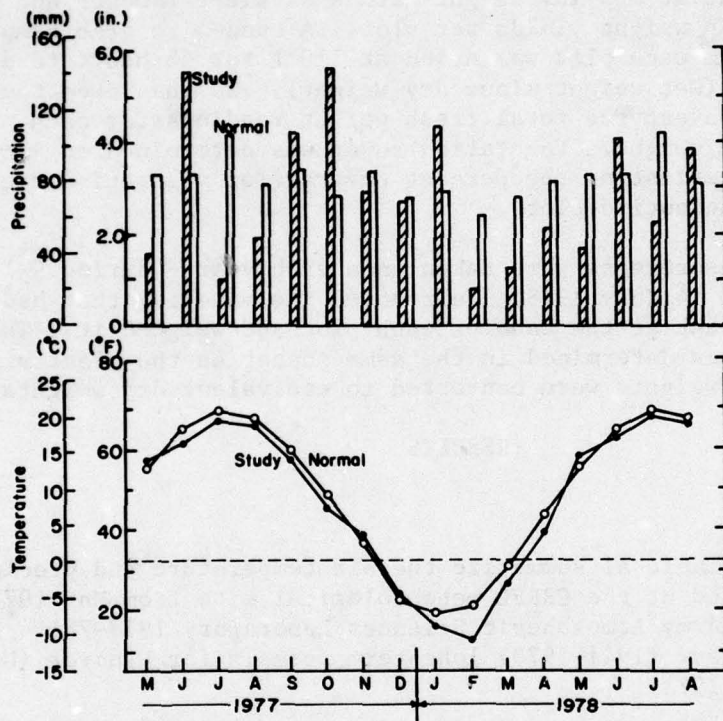


Figure 4. Study temperature and precipitation vs 30-year normal (1941 - 1970).

Table 4. The effects of sewage sludge and commercial fertilizer applications on average plant yields (dry wt.).

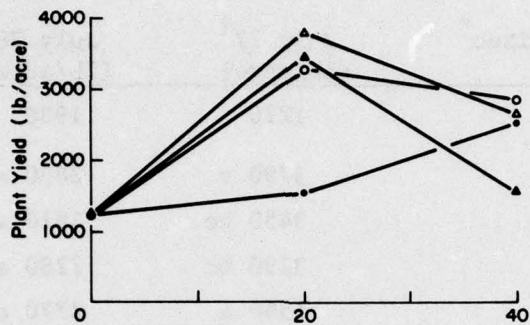
Treatment		July 77 [†] (lb/acre)	July 78 (lb/acre)	Aug. 78 (lb/acre)
Sludge (tons/acre)	Fertilizer*			
0	0	1210	1930	1470
20	F1F2	3790 c	2830 a	1230 a
20	F2	3450 bc	1910 a	1360 a
20	F1	3290 bc	2280 a	1370 a
20	-	1550 a	2770 a	1390 a
40	F1F2	2640 b	5520 a	916 a
40	F2	1560 a	4100 a	1150 a
40	F1	2830 b	4030 a	1230 a
40	-	2510 b	4710 a	1330 a

* F1F2 (N+P+K) = 99, 127, and 136 lb/acre N, P₂O₅ and K₂O, respectively,

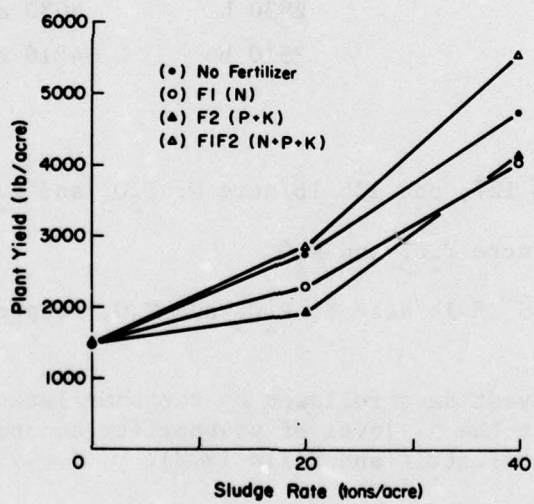
F2 (P+K) = 100 lb/acre P₂O₅ and K₂O

F1(N) = 99, 27, and 36 lb/acre N, P₂O₅ and K₂O, respectively.

[†] Yields at each harvest date followed by the same letter were not significantly different at the 5% level of probability according to Duncan's Multiple Range Test (Little and Hills 1972).



a. July 1977 harvest



b. July 1978 harvest

Figure 5. Plant yields (lb/acre dry weight).

Some general patterns can be found in the results of the first year harvest (Table 4). Treated plots produced more vegetation than the seeded control. Plant yield for the treatment with sludge alone was higher at the 40-ton/acre rate than at the 20-ton/acre rate.

At the 20-ton/acre sludge rate, the fertilizer-supplemented treatments were more productive than treatment with sludge alone, indicating a stimulating effect of the fertilizer additions at low sludge rates. These fertilizer-supplemented treatments at 20 tons/acre were also significantly more productive (average yield 3510 lb/acre) than the corresponding fertilizer-supplemented treatments at 40 tons/acre (average yield 2340 lb/acre).

One possible cause for the depressed yields at the high sludge rate when supplemented with fertilizer may be combined salt and ammonia toxicity originating from the sludge and fertilizer. Inhibition in seed germination and seedling establishment associated with Hanover sewage sludge was previously observed in a greenhouse study at CRREL (Palazzo and Graham 1977). It should be noted here that we seeded the present study immediately after spreading the sludge. Therefore, no time was allowed for NH_3 volatilization or leaching of salts from the sludge.

Yields from the July harvest of the second year (1978) were quite different. The 20-ton/acre sludge treatments had yields lower than the previous year, while the 40-ton/acre sludge treatment yields increased considerably so that they were the better producers (Table 4 and Fig. 5). It appears that the effects of the fertilizer diminished during the second year at the low sludge rate. At the same time, the nutrients in the sludge at the high rate became more available. At both sludge rates, the unfertilized and fertilized treatments had similar yields. This indicates that sludge was probably the dominant influence for plant nutrients at that time.

The delayed influence of sewage sludge on plant growth when applied to the cool spring soils as shown in this study helps confirm the results reported for the 1975-76 slope study at CRREL (Gaskin et al. 1979). In that study, plots treated with sludge that were installed on warmer fall soils responded more rapidly to the sludge than those installed on cooler spring soils. It was postulated that the coolness of the spring soils inhibited the process of sludge breakdown. This seems to be the case also in the present study.

A second harvest was taken in August 1978 (Table 4). Plant yields were fairly uniform for all treatments.

In August 1978, the vegetation present was also rated for percent coverage over the soil surface (Table 5). A large percentage of the species present consisted of weeds not sown in the treatments. These

Table 5. Average vegetation ratings (percent coverage, 9 August 1978).

Treatment	Sown			Weeds			Clover
	BFT*	Tall fescue	Red fescue	Crab-grass	Quack-grass	Orchard grass	
S20	45	18	8	10	8	5	X [†]
S20 F1(N)	18	8	12	33	17	7	X
S20 F2(P+K)	32	8	10	30	8	7	X
S20 F1F2(N+P+K)	<u>20</u>	<u>5</u>	<u>7</u>	<u>32</u>	<u>23</u>	<u>8</u>	X
	29	10	9	26	14	7	
S40	27	15	12	5	10	17	
S40 F1(N)	18	17	5	13	27	15	X
S40 F2(P+K)	43	22	13	7	3	10	X
S40 F1F2(N+P+K)	<u>25</u>	<u>12</u>	<u>2</u>	<u>20</u>	<u>27</u>	<u>10</u>	
	28	17	8	11	19	13	
Control	15	7	12	38	17	X	7
Average of both sludge rates:							
No F	36	17	10	8	14	11	
F1(N)	18	13	9	13	22	11	
F2(P+K)	38	15	12	19	6	9	
F1F2(N+P+K)	23	8	5	26	25	9	

* BFT = Birdsfoot trefoil

† X = trace amounts

were probably introduced by the topsoil brought in from neighboring areas. Of the species sown, tall fescue and red fescue were the grasses that performed well in all treatments studied. Birdsfoot trefoil (the legume) had the highest variability and was present in the greatest amounts. The highest amounts of this legume grew on treatments which did not receive nitrogen fertilizer (Table 5). The birdsfoot trefoil was not only a dominant species but it also was aesthetically pleasing with its yellow flowers appearing during the late spring-early summer. Annual ryegrass and the bentgrass, which had been included in the seed mixture, were not present on the plots at this time.

Soil Loss

The soil loss data (Tables 6 and A3) show that the treatments were quite effective in controlling erosion. During the first season, soil loss from the individual treated plots ranged from 35 lb/acre to 2,340 lb/acre as compared to an average loss from the control plots of 12,470 lb/acre. Soil loss on only two of the individual plots (8, 12) fell outside the acceptable limit of 1 ton/acre per year set by the U.S. General Accounting Office (1977). In the second year, soil loss from all plots including the controls decreased dramatically to a range between 7 and 740 lb/acre.

Soil loss measurements for the three replicates of each treatment were sometimes quite variable (Table 6). This variability may have resulted from differences in the type of soil on each plot or from problems with the soil/lip interface of the tank. However, an average of the soil loss results taken over a two-year period from the three replicates should give a figure that is generally representative of each treatment's ability to retard erosion.

Table 6 and Figure 6 show the treatments arranged by increasing average soil loss and include individual plot results for both years. The soil loss averages were all lower than the General Accounting Office limit (1977). They do not show conclusively that either sludge rate is significantly more effective in controlling erosion. The two lowest soil loss averages were from treatments at the 40-ton/acre sludge rate, but the highest loss average was also from a treatment of this sludge rate. The two highest soil loss averages were from the treatments at both sludge rates supplemented with high N fertilizer (Table 6, Fig. 6).

There is no clear relationship between soil loss and vegetation. At both sludge rates, the plots with the lowest percent coverage of birdsfoot trefoil also had the highest soil loss, but those plots with the highest birdsfoot trefoil coverage did not have the lowest soil loss.

Table 6. Average soil loss per treatment (dry wt.).

Rank	Treatment		Treatment	Total soil loss (lb/acre)			Avg	
	Sludge (tons/acre)	Fertilizer		I*	II*	III*		
1	40	F1F2 (N+P+K)	5	1977	109	127	144	150
				1978	47	11	7	
				Total	156	136	151	
2	40	-	8		283	191	35	190
					43	7	7	
					326	198	42	
3	20	F2 (P+K)	2		318	863	183	495
					65	51	11	
					383	914	194	
4	20	-	4		181	312	259	515
					32	742	19	
					213	1,054	278	
5	20	F1F2 (N+P+K)	1		224	1,160	244	585
					73	48	9	
					297	1,210	253	
6	40	F2 (P+K)	6		941	795	249	700
					43	10	65	
					984	805	314	
7	20	F1 (N)	3		114	2,340	167	905
					39	37	10	
					153	2,380	177	
8	40	F1 (N)	7		2,030	740	148	1,100
					73	282	9	
					2,100	1,020	157	
9	Control		9		7,770	2,040		4,900
					19	6		
					7,790	2,050		
10	Control w/grass		10		27,600			27,700
					83			
					27,700			

*I, II, III = replicate plots of same treatment as listed in Table 1.

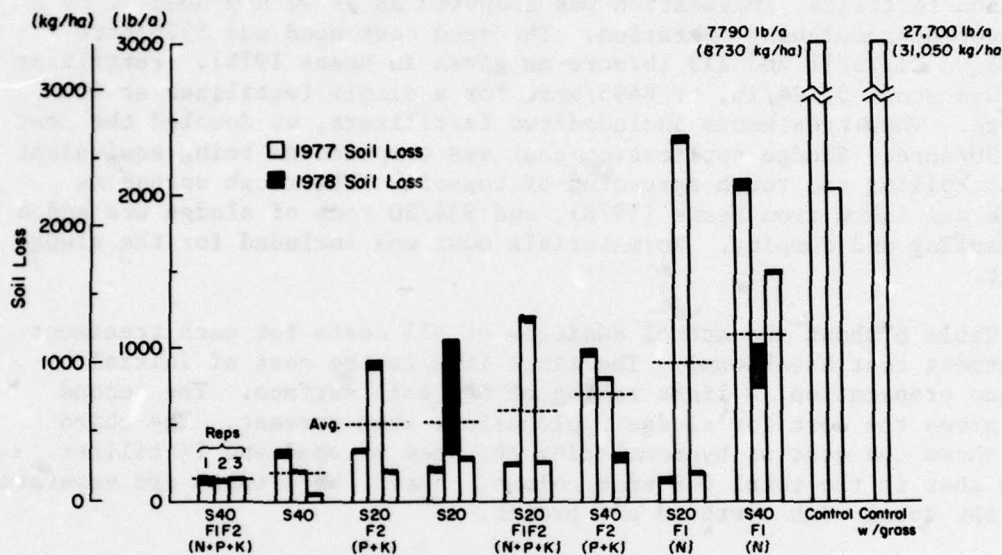


Figure 6. Soil loss results and averages.

In summary, all revegetation treatments in this study involving sewage sludge application and supplemental fertilizer had average soil losses within acceptable limits that were significantly lower than those of the untreated controls. The addition of N+P+K or P+K fertilizer at the rates studied appears to be slightly more beneficial than N alone.

COST ANALYSIS

In order to determine the relationship between treatment cost and effectiveness, we calculated the installation cost for each treatment by adding together all the material and labor costs involved in its installation. We chose these costs from the national averages given in Building Construction Cost Data (Robert Snow Means Co. 1978), a reference to aid contractors in calculating their construction expenses.

Table 7 lists all the costs we used in the calculations, along with a reference to the line in Means (1978) from which they were taken. Bare costs are separated from the total cost, which includes a materials profit equal to 10% of the bare materials cost and an overhead equal to 40% of the bare labor cost.

A few modifications were made to simplify the cost calculations. Seed and fertilizer application was computed as if we had done it by a one-step hydromulching operation. The seed cost used was \$376/acre (based on \$1.75/lb and 215 lb/acre as given in Means 1978). Fertilizer cost was about \$1.24/lb, or \$495/acre for a single fertilizer at 400 lb/acre. When treatments included two fertilizers, we doubled the cost to \$990/acre. Sludge application cost was computed as being equivalent to stockpiling and rough spreading of topsoil. The rough spreading charge was taken from Means (1978), and \$34/20 tons of sludge was added for hauling and dumping. No materials cost was included for the sludge itself.

Table 8 shows the actual addition of all costs for each treatment (treatment cost breakdown). The first line is the cost of initial surface preparation, a light raking of the soil surface. The second line gives the cost for sludge application, when present. The third line shows the cost of hydromulching the seed or seed and fertilizer. Below that is the total for each column. Again, bare costs are separated from the total with overhead and profit.

As seen in Table 8, there is a wide range in installation costs among the treatments. Total cost with overhead and profit ranges between \$2,850/acre for 20-ton/acre sludge and grass to \$4,735/acre for 40-ton/acre sludge with grass and both fertilizers. For an area of 50 acres, this translates to a difference of about \$94,000. Obviously, higher rates of sludge and fertilizer increase the cost.

Table 9 compares total cost with the effectiveness of each treatment, arranged in order of increasing total soil loss (1977 + 1978). The only apparent correlation is that the most expensive treatment had the least soil loss. Since all treatments have acceptable soil loss, the most cost-effective is the least expensive or 20-ton/acre sludge with grass.

Table 7. Materials and installation costs per acre.*

<u>Materials</u>	<u>Abbr.</u>	<u>Bare Cost</u>		<u>Total w/o & p[†]</u>	<u>Means (1978) line reference</u>
		<u>Mat.</u>	<u>Labor</u>		
<u>Fertilizer</u>					
Single (F1 or F2)	F	495		545	2.8 45 100
Double (F1F2)	2F	990		1090	" " "
Grass seed	G	376		415	" " "
Sludge	S	No charge			
<u>Installation Labor & Equipment</u>					
Hydromulching	-		581	815	2.8 45 100
Sludge (20 tons/acre)	S20				
Hauling and stockpiling			34	50	Estimated
Spreading			532	745	2.8 25 10
			566	795	
Sludge (40 tons/acre)	S40				
Hauling and stockpiling			68	100	Estimated
Spreading			1064	1490	2.8 25 10
			1132	1590	
Surface preparation - light racking	SP		592	830	2.8 25 60

* Costs taken from Building Construction Cost Data (Robert Snow Means Co, 1978, p. 44).

† w/o & p = with overhead and profit.

Table 8. Treatment cost breakdown.

<u>Treatment Number</u>	<u>Treatment</u> *	<u>Bare Cost (\$/acre)</u>			<u>Total w/o & p</u>
		<u>Mat.</u>	<u>Labor</u>	<u>Total</u>	
10	SP	-	592	592	830
	G	<u>376</u>	<u>581</u>	<u>957</u>	<u>1225</u>
		376	1173	1549	2055
4	SP	-	592	592	830
	S20	-	566	566	795
	G	<u>376</u>	<u>581</u>	<u>957</u>	<u>1225</u>
		376	1739	2115	2850
2, 3	SP	-	592	592	830
	S20	-	566	566	795
	G F	<u>871</u>	<u>581</u>	<u>1452</u>	<u>1770</u>
		871	1739	2610	3395
8	SP	-	592	592	830
	S40	-	1132	1132	1590
	G	<u>376</u>	<u>581</u>	<u>957</u>	<u>1225</u>
		376	2305	2681	3645
1	SP	-	592	592	830
	S20	-	566	566	795
	G 2F	<u>1366</u>	<u>581</u>	<u>1947</u>	<u>2315</u>
		1366	1739	3105	3910
6, 7	SP	-	592	592	830
	S40	-	1132	1132	1590
	G F	<u>871</u>	<u>581</u>	<u>1452</u>	<u>1770</u>
		871	2305	3176	4190
5	SP	-	592	592	830
	S40	-	1132	1132	1590
	G 2F	<u>1366</u>	<u>581</u>	<u>1947</u>	<u>2315</u>
		1366	2305	3671	4735

* Abbreviations - see Table 7.

Table 9. Cost vs effectiveness.

<u>Rank</u>	<u>Treatment number</u>	<u>Treatment</u>	<u>Avg total soil loss (lb/acre)</u>	<u>1977 Plant yield (lb/acre)</u>	<u>Cost (\$/acre)</u>
1	5	S40 F1F2	150	2,640	4,735
2	8	S40 -	190	2,510	3,645
3	2	S20 F2	495	3,290	3,395
4	4	S20 -	515	1,550	2,850
5	1	S20 F1F2	585	3,790	3,910
6	6	S40 F2	700	1,560	4,190
7	3	S20 F1	905	3,290	3,395
8	7	S40 F1	1,100	2,830	4,190
9	9	Control	4,900	1,700	-
10	10	Control w/G	27,700	1,210	2,055

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Appendix A. Supplementary data.

Table A1. Summary of weather data, CRREL meteorological site, May 1977-August 1978*.

Month	Temperature, °C (°F)				Precipitation, mm (in.)	
	1977			Normal Mean	1977 Total	Normal Total
	Max	Min	Mean			
May	35.6 (96.0)	-4.4 (24.0)	13.9 (57.0)	12.9 (55.3)	39.4 (1.55)	83.8 (3.30)
Jun	31.1 (88.0)	2.8 (37.0)	16.3 (61.4)	18.1 (64.6)	140 (5.50)	83.8 (3.30)
Jul	35.0 (95.0)	5.5 (41.9)	19.4 (66.9)	20.7 (69.2)	24.7 (0.97)	106 (4.18)
Aug	33.0 (91.4)	6.0 (42.8)	18.7 (65.7)	19.6 (67.2)	47.4 (1.87)	78.0 (3.07)
Sep	29.0 (84.2)	3.0 (37.4)	14.0 (57.2)	15.2 (59.4)	106 (4.20)	85.9 (3.38)
Oct	22.5 (72.5)	-5.5 (22.1)	7.3 (45.1)	9.1 (48.3)	141 (5.57)	71.6 (2.82)
Nov	19.0 (66.2)	-9.5 (14.9)	3.6 (38.5)	2.5 (36.5)	73.2 (2.88)	85.3 (3.36)
Dec	10.5 (50.9)	-28.5 (-19.3)	-4.5 (23.9)	-5.1 (22.9)	68.1 (2.68)	69.1 (2.72)
	1978				1978	
Jan	12.0 (53.6)	-23.0 (-9.4)	-9.0 (15.8)	-7.1 (19.2)	109 (4.31)	72.9 (2.87)
Feb	5.0 (41.0)	-29.0 (-20.2)	-11.0 (12.2)	-6.2 (20.9)	19.6 (0.77)	61.0 (2.40)
Mar	11.5 (52.7)	-24.0 (-11.2)	-3.0 (26.6)	-0.8 (30.5)	30.3 (1.19)	70.4 (2.77)
Apr	19.0 (66.2)	-8.0 (17.6)	3.9 (39.0)	6.3 (43.4)	53.0 (2.09)	79.5 (3.13)
May	31.0 (87.8)	-2.0 (28.4)	14.5 (58.1)	12.9 (55.3)	42.8 (1.69)	83.8 (3.30)
Jun	32.0 (89.6)	2.5 (36.5)	17.0 (62.6)	18.1 (64.6)	104 (4.09)	83.8 (3.30)
Jul	34.5 (94.1)	4.0 (39.2)	20.0 (68.0)	20.7 (69.2)	56.9 (2.24)	106 (4.18)
Aug	31.0 (87.8)	7.5 (45.5)	19.0 (66.2)	19.6 (67.2)	97.4 (3.83)	78.0 (3.07)

*U.S. Army Atmospheric Sciences Laboratory, Hanover Detachment (1977-78).

Table A2. Plant yields (lb/acre dry weight).

Plot Number	Plant yields		
	18-19 Jul 1977	5-7 Jul 1978	14-15 Aug 1978
1	4300	2460	1110
2	2870	1400	980
3	3950	1910	796
4	1920	1570	1440
5	3020	3020	861
6	1210	1490	1050
7	1660	2320	1300
8	3480	1830	981
9	1950	2310	1130
10	3270	1850	1030
11	4020	1320	1300
12	2620	1530	1660
13	1930	501	534
14	1370	2070	1260
15	2330	9250	857
16	1590	6040	1210
17	1470	4180	272
18	2080	3810	1470
19	925*	4620	1610
20	286*	4180	1540
21	3580*	3020	1810
22	2220*	3410	1650
23	1360	4680	1460
24	2580	4300	1030
25	1430	3930	952
26	2940	6460	1240
27	3060	7190	1240

*Questionable data due to confusion during harvesting.

Table A3. Soil loss results (dry weight).

Plot	Soil loss				Rank
	9-19 Aug 1977 (lb/A)	14 July 1978 (lb/A)	Total (lb/A)	Total (kg/ha)	
1	224	73	297	327	13
2	318	65	383	421	16
3	114	39	153	168	4
4	181	32	213	234	10
5	109	47	156	172	5
6	27,600	83	27,700	30,500	27
7	941	43	984	1,080	19
8	2,030	73	2,100	2,310	24
9	283	43	326	359	15
10	1,160	48	1,210	1,330	22
11	863	51	914	1,010	18
12	2,340	37	2,380	2,610	25
13	7,770	19	7,790	8,570	26
14	312	742	1,054	1,160	21
15	127	11	138	152	2
16	795	10	805	886	17
17	2,040	6	2,050	2,260	23
18	740	282	1,020	1,120	20
19	191	7	198	218	9
20	244	9	253	278	11
21	183	11	194	213	8
22	167	10	177	195	7
23	259	19	278	306	12
24	144	7	151	166	3
25	249	65	314	345	14
26	148	9	157	173	6
27	35	7	42	46	1