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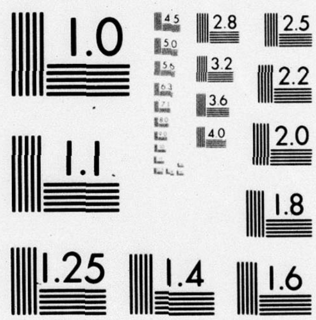

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RECLAMATION OF ACIDIC DREDGE SOILS WITH SEWAGE SLUDGE AND LIME AT THE CHESAPEAKE AND DELAWARE CANAL

Antonio J. Palazzo

June 1977

CORPS OF ENGINEERS, U.S. ARMY
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A field study was conducted to assess the effects of sewage sludge and lime on the revegetation and reclamation of acidic (pH 3.0) and infertile dredge soils. Sewage sludge at 100 metric tons/ha (45 tons/acre) and lime at 25 metric tons/ha (10 tons/acre) were applied during the summer of 1974 on a seven hectare ~~(17 acre)~~ site and plowed into the soil to a depth of 20 cm (8 in.). Soils were sampled 20 months later after sludge incorporation at three depths, 0-20, 20-40, and 40-60 cm (0-8, 8-16 and 16-24 in.) within the sludged and control areas.

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20. Abstract (cont'd)

A total of 29 grass treatments, containing grasses seeded alone or in combinations, were also evaluated and seven grass types analyzed for mineral composition. At the 0-20-cm (0-8-in.) soil depth, sewage sludge plus lime increased pH, cation exchange capacity, exchangeable calcium and magnesium, organic carbon, and total, organic and plant available phosphorus. Exchangeable potassium and sodium were unchanged. Below the 20-cm, (8-in.) depth, concentrations of plant-available phosphorus and soil pH were similar to the control soils, indicating a possible restriction to deep rooting of plants. Applications of sewage sludge appreciably increased the levels of total and extractable metals in the 0-20 cm (0-8 in.) soil layer and Ca and Mg in the two lower soil depths as well. Smaller increases in other constituents were detected in the two lower soil depths. A large percentage of the zinc, chromium, lead and mercury applied to the soil was in a form not available to plants, while approximately 50% of the nickel and cadmium applied was available. Good seed germination and seedling vigor were evident for all grasses, indicating that the amended soil could support plant growth. Differences among species and varieties were noted after one complete growing season. The Kentucky bluegrasses, red fescues and K-31 tall fescue produced good growth after one season. The ryegrasses provided the densest soil coverage during the initial growing season, but competed excessively with the other, truly perennial grasses, resulting in inferior vegetative coverage eventually. No differences in mineral composition were noted among the seven grasses analyzed. Among the elements analyzed, only nickel was high, with two species near the toxic range (> 20 ppm). The extractable soil level of this element was 30.2 ppm, with only 48% being in the unavailable form.

Zn, Cr, Pb and Hg

Ni and Cd

PREFACE

This report was prepared by Antonio J. Palazzo, Research Agronomist, of the Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding was provided under the auspices of the Wastewater Management Program.

Technical reviewers of this report were Dr. Robert W. Duell of Rutgers University, Larry Johnson of CRREL, and Dr. John Burnes and John Lakatosh of the Philadelphia District, U.S. Army Corps of Engineers.

The author would like to express his appreciation for the contributions made by the following individuals: Dr. H.L. McKim, Dr. I.K. Iskandar, and J.M. Graham.

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CONTENTS

LIST OF FIGURES

INTRODUCTION

The Chesapeake and Delaware Canal, located between the upper reaches of the Chesapeake Bay and the Delaware River, crosses the Delmarva Pennisula (Fig. 1). More than 22,000 vessels of all types use the canal annually, making it one of the busiest waterways in the world (U.S. Army Corps of Engineers 1974). To accommodate the increased use of the canal and more modern and larger vessels, Congress authorized a program to widen the canal in 1954. This widening program was completed in 1966. Due to the widening operations, along with maintenance dredging, areas of dredge deposits now exist along the canal.

Problems have developed in vegetating the dredged soils in the disposal areas located about 10 to 12 miles west of the Delaware River (Fig. 1). The subsoils placed in this area are pyritic and low in pH, organic matter, and fertility. Pyritic soils, when brought into contact with the atmosphere, turn highly acidic.

Prior revegetation operations are sketchy and exact rates of previous applications of lime and fertilizer and kinds of seed sown are not available. Past operations usually included spreading a 7.5- to 15- cm (6- to 12- in.) layer of topsoil and hydromulching of seed, fertilizer, and lime. Seeds would germinate normally on the topsoil and begin to establish themselves, but then die. This loss appeared to be related to the drying out of the topsoil where plant growth was taking place and also to the inability of plant roots to penetrate the acidic material below.

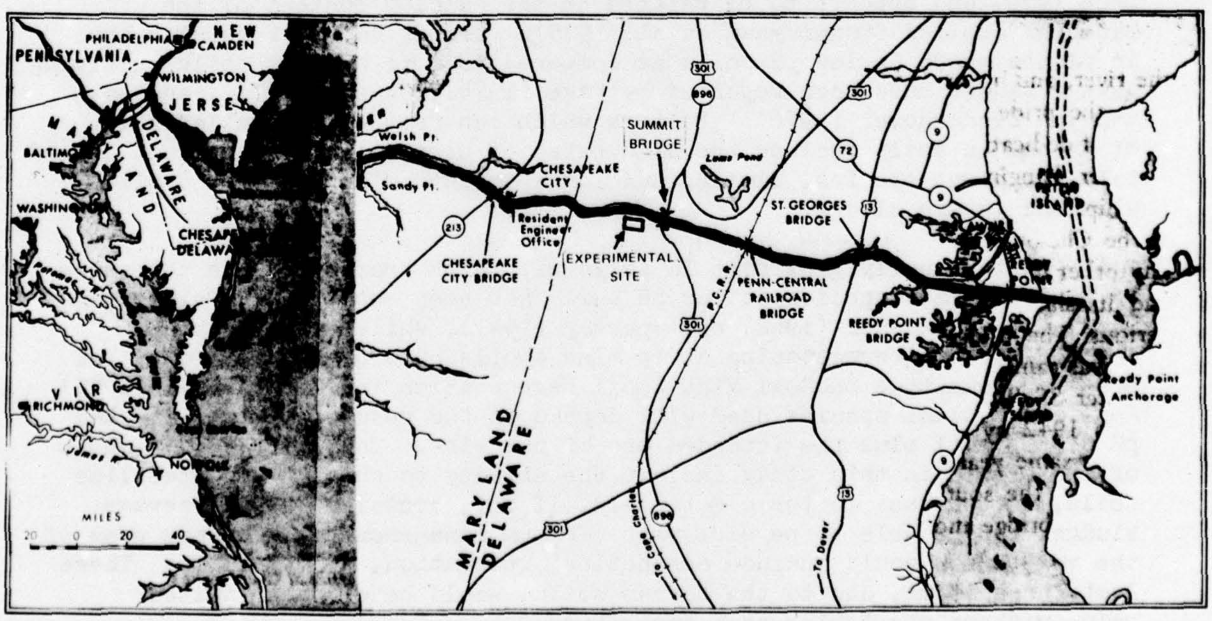

Figure 1. General geographic location of the Chesapeake and Delaware Canal and the experimental revegetation test site.

The terrain of the disposal areas consists of terraced land on 2:1 slopes with high plateaus. The barren soils are subjected to surface erosion down the embankments, as shown in Figure 2, and wind erosion off the high plateaus and onto roads and bridges which cross the canal. Plant establishment would appear to be the key to stabilization of the soils in this area.

Past revegetation operations indicate that plant establishment is benefited if the pH of the soil is raised, organic matter added for increased moisture holding capacity, and soil amendments mixed into the existing soil to make conditions more conducive to plant growth and allow for deep root penetration. Heavy applications of dolomitic limestone and sewage sludge appear to be the answer to these requirements. Dolomitic limestone can increase soil pH and soil levels of calcium and magnesium, while applications of sewage sludge could be important in raising levels of soil organic matter for improved soil moisture and nutrient retention to enhance plant growth.

A major problem to consider when applying sewage sludge to low pH soils is the possibility of toxic metals. Webber (1972) noted that copper, zinc, and nickel appeared to be the metals most likely to become toxic to plants when applying sewage sludge to land. It is generally known that in acidic soils, metals are more available to plants and are more susceptible to leaching. Chaney (1974) has recommended that soils which receive sewage sludge be adjusted and maintained at pH 6.5 or greater. Monitoring of sites is important since decreases in soil pH with continuous application of sewage sludge have been reported (Hinesly et al. 1972, Lunt 1959) and appears to be related to the calcium content of the material applied (Cunningham et al. 1975). Higher rates of metal uptake in plants grown in low pH soils as compared to more neutral soils receiving sewage sludge have been reported by Page (1974), Chaney (1973), and John and Van Landerhoven (1976). Factors which can reduce the availability of metals in soils include the high rates of organic matter applied, use of tolerant plant species, liming, and large amounts of phosphorus applied with the sewage sludge.

Plants usually grow best in soils with a pH near 6.5. The tolerance of various grass species to low pH soils has been reported by Palazzo and Duell (1974), Musser (1962) and Spurway (1941), while lists of plant species used in revegetating strip mine spoils have been compiled by the Research Committee on Coal Mine Spoil Revegetation in Pennsylvania (1971). Applicable plant species used will depend on the resulting fertility and pH of the soil plus the intended use of the site. The major requirements of the plants in this study include the ability to survive and stabilize soils, be tolerant to toxic materials, if any, contained in the sewage sludge, and be able to persist with minimum management. Secondary uses of the vegetation would include aesthetics, recreation, and wildlife. These last three items, due to the barren soils, would be of only limited value without vegetating this area (Fig. 3).

Figure 2. Slope erosion of barren soils at the Chesapeake and Delaware Canal.

Figure 3. Unaesthetic views of the canal caused by the barren soils.

The objective of this study was to determine if applications of sewage sludge and dolomitic limestone could be useful as soil amendments to help stabilize the highly acidic dredged soils and to study the kinds of plants which are most suited to this environment. Visual ratings of grasses and soil and plant analyses were performed to help determine the successfulness in revegetating and reclaiming these soils.

MATERIALS AND METHODS

This study was performed by the U.S. Army Corps of Engineers at a location along the Chesapeake and Delaware Canal in Delaware. The experimental site is located on the south side of the canal near the Summit Bridge as shown in Figure 1. The soils consist of acidic dredged disposal material (which is predominantly a silt loam in texture), and the terrain is a series of plateaus with 2:1 slopes.

During July and August 1974 sewage sludge, on a dry weight basis, and dolomitic limestone were applied on a 6.6- ha (17-acre) site at rates of 100 and 23 metric tons/ ha (45 and 10 tons/acre), respectively. Anaerobically digested primary sludge was obtained from Wilmington, Delaware, and was applied as approximately 15% solids. The sewage sludge was trucked to the site, sumped and spread at the desired rate. The average chemical composition of sludge, determined from samples taken in July 1974, is shown in Table I. Dolomitic limestone was then applied by broadcasting the material over the soil surface. The site was then plowed to a 20-cm (8-in.) depth. The area was seeded with a Brillion seeder in September with a K-31 tall fescue (*Festuca arundinacea* Scheb.) and annual ryegrass (*Lolium multiflorum* L.) seed mixture (50% of each by weight). Hay was applied at 2200 kg/ha (2000 lb/acre) as a mulch.

Table I. Average and range in concentration (ppm) of metals contained in the Wilmington sludge as compared to the ranges found in other sludges in the United States.

Metal	Wilmington		Page* (1974)	Peterson* et al. (1973)
	Average	range	range	range
Cr	9,844	5,560 - 12,890	tr - 19,600	190 - 3900
Cu	2,772	1,290 - 4,654	100 - 11,700	324 - 1200
Zn	3,470	2,186 - 4,230	373 - 28,400	690 - 3500
Pb	1,327	724 - 2,520	15 - 1,900	390 - 1800
Ni	227	140 - 311	11 - 3500	>10 - 340
Co	15.7	9.2 - 20.3	---	---
Cd	27.3	9.2 - 49.4	1 - 830	.9 - 360

*Modified from reviews by Page (1974) and Peterson et al. (1973).

Within the sludge applied area, a 576-m^2 (6400-ft^2) site was prepared but not seeded, and used as a grass species evaluation test site. This test site was set up as a complete randomized block design and contained 87 individual plots with an area of 5.76 m^2 (64 ft^2) each. Included in these plots were 16 grass species and varieties, sown alone or in combination (Table II). The respective seeding rates and composition of each mixture is shown in Table III. Each grass seeding treatment was replicated three times.

Table II. Common and botanical names of grasses included in the species evaluation test plots.

Variety	Common Name	Botanical Name
common, Baron Victa, Vantage, and Ba 62-55M	Kentucky bluegrass	*Poa pratensis* L.
Jamestown, Highlight Fortress, Pennlawn, and P_p15E	red fescue	*Festuca rubra* L.
K-31	tall fescue	*Festuca arundinacea* Scheb.
common	annual ryegrass	*Lolium multiflorum* L.
common, Eton	perennial ryegrass	*Lolium perenne* L.
Exeter	colonial bentgrass	*Agrostis tenuis* Sibth
Emerald	creeping bentgrass	*Agrostis palustris* Huds.

In May 1975, approximately nine months after sludge and lime applications, general vigor ratings of the grasses were taken. In May 1976, soil samples from the treated and an adjacent control area were taken at the 0 to 20, 20 to 40 and 40 to 60 cm (0 to 8, 8 to 16, and 16 to 24 in.) depths. Plant samples from the species evaluation plots of seven grass types, plus visual quality ratings were also taken. Soil samples were air dried (25°C), thoroughly mixed and sieved, and a < 2-mm fraction was taken for chemical analysis. Soil pH (1:1 wt/vol), soluble salts (measured as specific conductance), cation exchange capacity, exchangeable Ca, Mg, Na, K, organic carbon, organic nitrogen, free iron oxides, organic-P, total-P (acid digestion), exchangeable-P, and soluble-P (1:2 soil to water) were determined according to Black (1965). Two forms of heavy metals were determined, total and acid-extractable (plant available). For total heavy metals (except Hg) soil and vegetative samples were digested with concentrated HNO_3 and $HClO_4$ according to Iskandar and Kenney (1974) and subsequent determination of heavy metals was made by atomic absorption spectrophotometry. A Perkins-Elmer model 403 equipped with an HGA 2100 graphite furnace was employed. Acid-extractable (plant available heavy metals, except Hg) were determined by shaking 10 g

Table III. Rates and composition of seed mixtures sown in the species evaluation plots.

GRASS	Seeding rate (kg/ha)	Composition of mixture by weight (%)
Baron Kentucky bluegrass	132	100
Victa Kentucky bluegrass	132	100
Vantage Kentucky bluegrass	132	100
Ba 62-55M Kentucky bluegrass	132	100
Jamestown red fescue	176	100
Highlight red fescue	176	100
Fortress red fescue	176	100
Pennlawn red fescue	176	100
P_P 15E red fescue	176	100
K-31 tall fescue	176	100
Common annual ryegrass	220	100
Common perennial ryegrass	220	100
Eton perennial ryegrass	220	100
Exeter colonial bentgrass	44	100
Emerald creeping bentgrass	44	100
Sports Turf*	176	100
Transition Blend**	176	100
Exeter, AR***	132	17,83
Exeter, Highlight	132	17,83
Exeter, Highlight, AR	132	17,66,17
Exeter, K-31	132	17,83
Highlight, K-31	176	50,50
Highlight, Baron	176	63,37
Highlight, AR	176	75,25
Highlight, K-31,AR	176	38,38,25
Highlight, Baron, AR	176	50,25,25
Baron, K-31, AR	176	25,50,25
K-31, AR	176	75,25

*The composition by weight of Sports Turf is: 50% Victa Kentucky bluegrass and 50% Manhattan perennial ryegrass.

**The composition by weight of Transition Blend is: 45% Vantage, 30% Victa, 15% common, and 10% Windsor Kentucky bluegrasses.

***The names of grasses listed for seed mistures relate to varieties shown above, except for common annual ryegrass which is listed as AR.

of soil with 50 ml of 0.1 N HCl for one hour and determining heavy metals in the supernatant by atomic absorption spectrophotometry. Samples for total Hg were predigested with concentrated HNO_3 and aqua regia according to Hamm and Stewart (1973). Extractable Hg was determined by shaking 5 g of soil with 50 ml of 0.1 N HCl. The suspension was filtered and the soil was leached with an additional amount of 0.1 N HCl until a total filtrate volume of 100 ml was collected. Mercury analyses of the extracts and water samples were done on a Perkins-Elmer Mercury Analyzer.

For plant analysis, plant tissue was washed in distilled water, dried and ground through a 20 mesh sieve. Sample preparation for all elemental analyses, except mercury, was performed by dry ashing for four hours at 260°C. For mercury, plant samples were dry ashed at 150°C for four hours. Standard analytical procedures (Jackson 1958) utilized were as follows: nitrogen - Kjeldhal, phosphorus - colorimetric, potassium and metals - atomic absorption.

RESULTS AND DISCUSSIONS

Sludge Composition

The composition of the sewage sludge applied to the acidic dredge soils is shown in Table I. The range in metal content of the material used in this study can be compared to the concentrations noted for other sludges in the United States. The highest value for lead at Wilmington (2,520 ppm) was above that noted by Page (1974), while this element plus chromium, copper, and zinc were higher than those reported by Peterson et al. (1973). The high concentration of metals in the sludge indicates that industrial input containing these metals is appreciable.

Various recommendations have been developed to suggest what kinds of sewage sludges are environmentally safe for land application. Most pertain to repeated applications on agricultural lands which produce food crops. The revegetation techniques in this study include only a single application of sludge and the growth of nonfood crops. Concern here arises as to plant toxicities, effects on foraging wildlife, and movement of metals from the site by soil erosion and leaching through the soil profile and into the canal.

The concentrations of metals in the sludge used exceeds the maximum recommended levels reported by Melsted (1973), Chaney (1973), and Chumbley (1971) for the growth of food crops. Chaney (1973) suggested that on lands not to be used for food crop production, sludges with a Cd content of greater than 1% of the Zn content should not be used. The Cd/Zn content in the sludge used for this study is below this level at 0.7%.

To reclaim the acidic dredge soils, sewage sludge and dolomitic limestone were incorporated into the soil to a 20-cm (8-in.) depth. Twenty months after soil incorporation and seeding, plant and soil samples were taken from treated and control areas and analyzed for various chemical parameters. Analyses were performed to determine changes in soil characteristics which may affect 1) plant growth, 2) deficiencies of plant nutrients, and 3) toxicities of metals in the soil to plants.

Soils

As noted in Table IV, the dredged soils were initially acidic (pH 3.0) and infertile. Soil levels of plant-available phosphorus or orthophosphate and the exchangeable cations (calcium, magnesium and potassium) along with soil pH were generally below levels for optimum plant growth.

Applications of sewage sludge and dolomitic limestone increased soil pH, cation exchange capacity, exchangeable calcium and magnesium, organic nitrogen, organic carbon, total phosphorus, organic phosphorus, and orthophosphate in the top 20 cm of soil (Table IV). Total soluble salts, exchangeable potassium and sodium in the soil, remained essentially unchanged and at a low level.

Although increased by one unit, soil pH at 4.0 was still low for optimium plant growth for most plants. Greater plant use of nutrients and a higher rate of immobilization of metals would occur with a higher soil pH. Due to the high amounts of sewage sludge applied and the low pH of the soil, soil pH should be monitored at this site. To achieve a greater increase in soil pH in the soils of this study, supplemental applications of a more rapidly neutralizing type of lime such as calcium oxide or calcium hydroxide should be considered. These types of liming materials should be immediately and thoroughly incorporated into the soil.

Table IV. Changes in soil chemical properties due to applications of sewage sludge and lime.

Soil parameter	Soil: Control	Soil: Treated
pH	3.0	4.0
soluble salt (mmhos/cm)	2.0	2.2
CEC (meq/100 g)	18.4	23.1
Exchangeable cations:		
Ca (meq/100g)	1.55	12.45
Mg (meq/100g)	1.28	4.43
K (meq/100g)	0.15	0.17
Na (meq/100g)	0.04	0.06
organic nitrogen (%)	0.016	0.179
organic carbon (%)	0.183	2.112
total phosphorus (ppm)	102.0	836.0
organic phosphorus (ppm)	22.0	324.0
orthophosphate (ppm)	28.0	102.2

Soil exchangeable calcium and magnesium increased greatly due to the large applications of dolomitic limestone plus additions from the sewage sludge. Therefore, increased use of dolomitic limestone to increase soil calcium and magnesium is not justified. Soil exchangeable potassium and sodium did not change.

The concentration of potassium in the sewage sludge, a major element in plant growth, was 0.25%. At the sludge application rate of 100 metric tons/ha (45 tons/acre) approximately 250 kg/ha (225 lb/acre) of potassium was applied. Soils which initially have low concentrations of this element may require supplemental applications of potassium fertilizer.

Organic nitrogen and organic carbon, many forms of which ultimately benefit plant growth, increased in the lime and sludge-treated soil. Phosphorus, total and extractable, and as orthophosphate also increased to high levels. This is important in plant nutrition and in the immobilization of several heavy metals in soils. The level of orthophosphate or plant-available phosphorus was above the range needed for optimum plant growth.

Changes in soil chemical constituents in the soil profile are important in noting movement of elements and in determining if root growth of plants could occur below the treated soil layer. Figure 4 shows changes of some soil constituents in the treated soil occurring to a 60-cm (24-in.) soil depth. Increases in exchangeable calcium and magnesium, organic nitrogen, organic carbon, total phosphorus, and organic phosphorus were noted to a depth of 60 cm (24-in.). An increase in exchangeable potassium was noted at the 20- to 40-cm depth (8 to 16 in.) while exchangeable sodium values in the control and treated soil profiles were erratic and cannot be explained. Soil pH was slightly lower than the control soils at the 20- to 60- cm (8- to 24-in.) depth, while orthophosphate increased slightly from an average of 10 to 22 ppm. Due to the low pH and low levels of the orthophosphate, it appears that plant rooting below a 20-cm (8-in.) depth could be restricted.

Applications of sewage sludge increased the concentration of metals in the soil. Although the concentration of zinc, chromium, lead, nickel, and cadmium increased (Table V) the concentrations were still within the range typically found in soils (Allaway 1968). This fact is probably related to the very low levels of metals orginally present in the soil. The highest copper concentration noted was 201 ppm which exceeds the 2 - 100 ppm range noted by Allaway (1968). Although the total copper in this soil was high, the amount of extractable or plant available copper noted here is below the concentration toxic to plants as reported in a review by Page (1974).

Total and extractable concentrations for zinc, copper, chromium, cadmium, nickel, total lead and mercury were greatest at the 0 to 20-cm

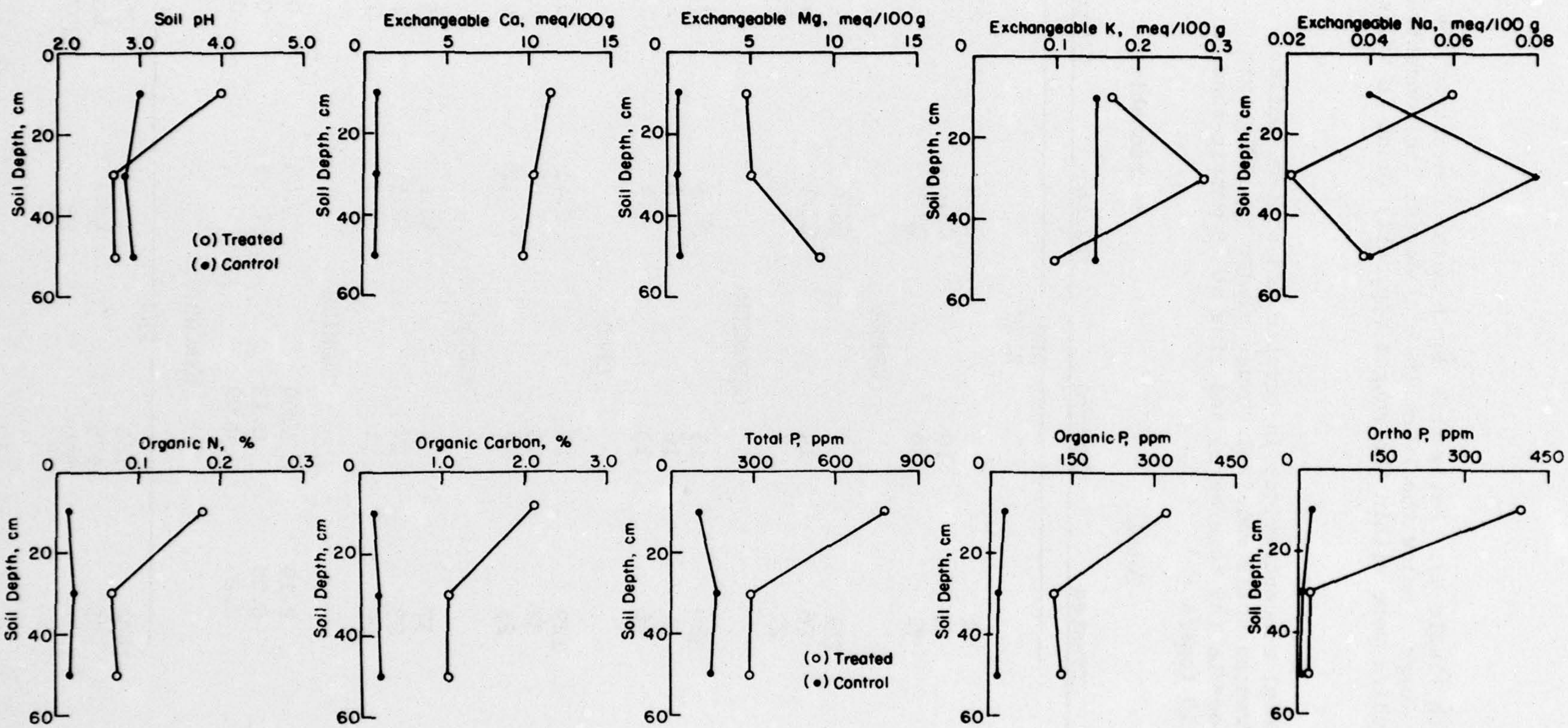

Figure 4. Distribution with depth in soil of various soil chemical properties, in sludge and lime treated vs control plots.

(0 to 8-in.) depth (Table V). Below this depth metal concentrations were appreciably lower. Below the 20-cm (8-in.) depths the concentrations of all metals studied were within the ranges typically found in soils (Allaway 1968).

Table V. Metal concentrations in treated and control soils. Treated soils received sewage sludge at 100 metric tons/ha (45 tons/acre) and lime at 25 metric tons/ha (10 tons/acre).

Soil Depth	Total Treated	Total Control	Extractable Treated	Extractable Control
cm	ppm			
	ZINC			
0 - 20	306	7	57.0	2.4
20 - 40	57	10	28.6	4.3
40 - 60	71	6	22.5	2.6
	COPPER			
0 - 20	201	6	66.0	1.5
20 - 40	26	14	12.1	4.5
40 - 60	21	7	5.9	2.9
	CHROMIUM			
0 - 20	380	15	28.5	0.4
20 - 40	51	16	5.6	1.5
40 - 60	46	13	3.4	1.1
	LEAD			
0 - 20	129	25	0.41	0.04
20 - 40	32	15	1.63	0.07
40 - 60	25	32	0.12	0.12
	NICKEL			
0 - 20	57	4	30.2	5.1
20 - 40	23	17	12.5	7.4
40 - 60	26	14	15.1	7.5
	CADMIUM			
0 - 20	2.19	0.09	1.06	0.05
20 - 40	0.28	0.13	0.25	0.05
40 - 60	0.25	0.09	0.11	0.08
	MERCURY			
	ppb			
0 - 20	1400	750	17	36
20 - 40	925	575	53	40
40 - 60	1275	650	23	297

Zinc, copper, and chromium were the three metals applied in the greatest amounts (Table VI). As noted in Table VI, the soils absorbed 81% to 99% of the zinc, chromium, lead and mercury to a form not available to plants. The percentage of nonextractable nickel and cadmium was the lowest for the metals studied and was approximately 50%. A lower percentage of copper than zinc or chromium was in the nonextractable form, which means that a greater amount of this element is available to plants.

Table VI. Soil absorption of metals at the 0-20-cm (0-8-in.) depth.

Metal	Amount Applied in sludge	Soil Concentration: Total	Soil Concentration: Extractable	% not Extractable
	kg/ha	ppm	ppm	
Zn	34,700	306	57	81
Cu	27,720	201	66	67
Cr	95,840	380	28.5	92
Pb	13,270	129	0.41	99
Ni	2,270	57	30.2	48
Cd	273	2.19	1.06	52
Hg	---	1.40	0.017	99

It appears from the data in Table V that 20 months after sludge applications most of these toxic metals have remained in the 0-20-cm layer of the soil. Movement of these elements probably is not yet a serious factor. To further ensure against metal movement, greater, deeper and more thoroughly incorporated applications of lime should be considered to increase soil pH at a greater depth in the soil profile. Care should be taken in future applications of sewage sludge so that metal additions are not toxic to plant establishment or survival.

Grasses

Sixteen species and varieties of grasses, seeded alone or in combination, were studied within the species evaluation plots (Table III). The objective here was to identify a grass or mixture of grasses that would cover the soil surface to halt soil erosion, have low maintenance requirements, be aesthetically acceptable, and persist on the sludge and low pH soil amended by lime. Persistence or survival over more than one growing season involves perennial plants and adequate plant growing conditions. Plant analyses were performed to note deficiencies or toxicities, if any, occurring at the site. Grass quality ratings were performed on all grass plots. The ratings were based on percentage soil cover, grass vigor and color. A rating of 10 is best and 0 is poorest.

In May 1975, nine months after seeding, a preliminary analysis was taken. Good seed germination and seedling vigor were evident within the species evaluation plots for all grasses tested (Fig. 5), indicating that the amended soil could support plant growth. The importance of the sewage sludge in promoting grass growth is shown in Figure 6. The stunted plants in the center of picture are in an area which was skipped during sludge applications.

Table VII shows the percentage cover and height measurements of the grasses in May 1975. The Kentucky bluegrasses provided fair to good soil cover. All varieties, except common, were dark green in color. Common Kentucky bluegrass is a lighter green then the more recently developed varieties. The bluegrasses were 5 to 18 cm (2 to 7 in.) high at this time. The red fescues were considered acceptable with both good cover and color. K-31 tall fescue, a grass usually employed in low maintenance areas, provided good cover and was taller than the red fescues and bluegrasses. The annual and perennial ryegrasses were growing vigorously and were taller than all other species. A newer variety of perennial ryegrass, Eton, was similar in growth to the red fescues. Eton developed a dense uniform vegetative cover and was not as tall as the other ryegrasses. The two bentgrass species had fair to good soil cover and were light green in color.

Figure 5. Grass establishment during initial growing season in the species evaluation test plots.

Of the seed mixtures tested (data not shown), those which contained annual ryegrass along with Sports Turf developed a good vegetative cover ($\geq$ 95%). Sports Turf contains a variety of perennial ryegrass. The mixture of Exeter colonial bentgrass and Highlight red fescue received

Figure 6. Importance of sewage sludge in promoting grass growth. Stunted grass in center of picture is an area where soil was not treated with sewage sludge.

Table VII. Preliminary percentage soil cover ratings and height measurements taken in May 1975.

GRASS	Cover	Height*
	%	cm
Kentucky bluegrasses	60-85	5-18
Red fescues	80-90	12-20
K-31 tall fescue	90	25
Common annual ryegrass	85	60-75
Common perennial ryegrass	90	30-45
Eton perennial ryegrass	90	20
Exeter colonial bentgrass	60	12
Emerald creeping bentgrass	80	5

*2.54 cm = 1 in.

the lowest rating with a fair soil cover (65%). It was evident at this time that the ryegrasses were tall, aggressive, and overly competitive with the perennial type grasses. The other mixtures studied gave fair to good soil cover.

Table VIII. Grass quality ratings of species evaluation plots taken in May 1976.

GRASS	Quality Rating*
common Kentucky bluegrass	6.3
Baron Kentucky bluegrass	8.3
Victa Kentucky bluegrass	9.0
Vantage Kentucky bluegrass	7.7
Ba 62-55M Kentucky bluegrass	9.3
Bluegrass average	8.1
Jamestown red fescue	6.3
Highlight red fescue	8.0
Fortress red fescue	9.0
Pennlawn red fescue	8.5
Pp15E red fescue	6.0
Red fescue average	7.6
K-31 tall fescue	6.3
Common annual ryegrass	3.5
Common perennial ryegrass	5.0
Eton perennial ryegrass	5.0
Exeter colonial bentgrass	7.0
Emerald creeping bentgrass	7.0
Sports Turf**	6.3
Transition Blend**	8.0
Exeter, AR**	2.7
Exeter, Highlight	8.0
Exeter, Highlight, AR	6.0
Exeter, K-31	7.0
Highlight, K-31	8.3
Highlight, Baron	9.3
Highlight, AR	5.0
Highlight, K-31, AR	5.0
Highlight, Baron, AR	6.5
Baron, K-31, AR	6.0
K-31, AR	4.0

*10 = best, 0 = poorest

**see footnotes in Table 3.

In May 1976, 21 months after seeding and after the plants completed one full growing season, the species evaluation plots were again rated. The ratings for each of the 29 seed variables, which were unmowed are shown in Table VIII.

When the various grass types were seeded alone, the Kentucky bluegrasses and red fescues were similar in the ratings. Both species gave good soil cover but differences among varieties were noted. The ratings of the three types of ryegrasses studied were relatively low due mostly to lodging. (Lodging is defined here as when the grasses do not stand erect and fall over, matting the soil surface and smothering or retarding the growth of other grasses.) Eton perennial ryegrass, which performed well earlier in the study, appeared to die out slightly and became spotty. K-31 tall fescue ratings were also somewhat lower due to lodging. The bentgrasses maintained a fair to good soil cover.

Seed mixtures containing ryegrasses, which earlier did well, received the lowest rating. The ryegrasses, were overly competitive with the other species during establishment and by the following spring had lodged and were smothering the perennial grasses. The perennial grasses sown in the mixtures with annual ryegrass were not as vigorous as when they were seeded alone. The other mixtures studied were at this time providing good soil cover.

From the species evaluation plots it is apparent that the ryegrasses germinated quickly and stabilized the soils during the initial growing season. It was also noted that excessive amounts of ryegrass used in the seed mixture may jeopardize the establishment of the more perennial grass species. After 21 months, treatments containing only perennial grass species were more effective in stabilizing soils than those which also included the ryegrasses. Since soil erosion is not a major problem on level soils it is questionable if ryegrasses, or any other annual grass species, should be included in seed mixtures, especially where a mulch is also included.

On sloping soils, ryegrasses should be included to minimize soil erosion during plant establishment. When ryegrasses are used on either sloping or level soils, they should not exceed 10% by weight of the seed mixture or 11 kg/ha. It should also be noted that the effects of lodging on perennial type grass establishment may be reduced by mowing at a height of 10 cm (4 in.) in the late summer. This technique would reduce the competitiveness of the taller ryegrasses.

K-31 tall fescue and the varieties of Kentucky bluegrass and red fescue appeared compatible in the seed mixtures. Therefore, when considering the above data, mixtures including two of the three species along with annual ryegrass, if so desired, could be acceptable.

Seven plant types included in the species evaluation plots were sampled for nutrient and heavy metal analysis (Table IX). No significant differences were found between plant types, and therefore only the average concentration of each element is discussed.

Table IX. Elemental analyses of grass samples in May 1976.

GRASS	N	P	K	Zn	Cu	Cr	Pb	Ni	Cd	Hg
	%			ppm						ppb
K-31 TF	1.82	0.32	2.10	107	8.8	2.04	0.09	18.6	0.97	177
Eton PR	1.78	0.25	1.74	110	12.7	0.94	0.16	20.0	0.54	176
Pennl. RF	1.64	0.26	1.67	64	9.6	0.87	0.23	10.7	0.36	193
Emerald BG	2.12	0.28	1.81	76	8.8	1.05	0.18	10.7	0.98	64
Common KB	2.05	0.24	1.77	89	6.9	0.88	0.17	14.3	0.44	69
BA62-55M KB	2.18	0.21	1.64	69	10.2	0.94	0.24	11.9	0.58	109
Baron RB	2.22	0.24	1.78	75	7.6	0.80	0.30	15.4	0.48	131
average	1.97	0.76	1.79	84	9.2	1.07	0.20	14.5	0.62	131

Optimum or adequate concentrations of nitrogen, phosphorus and potassium in plant tissues vary as to the intended use of the crop and reflect the composition of the growing medium. Plant phosphorus concentrations in this study appeared adequate, but nitrogen and potassium could be considered low (Martin and Matocha 1972). Furthermore, since good seedling establishment and growth were obtained, the concentrations of the three elements listed here do not appear to be overly deficient.

Heavy metal concentrations of plant tissue might be of concern when considering the high concentration of metals applied and the low pH of the soil. Metal uptake can retard or prevent plant growth and in turn cause serious problems in stabilizing soils. It is generally known that metals are more available to plants in low pH, than more neutral, soils.

The metal concentrations of the plants grown in this study are shown in Table IX. Nickel appears to be one element that may be of concern. Although the average nickel concentration for all grasses was low, one replication each of K-31 tall fescue and Eton perennial ryegrass (data not shown) contained 21.1 and 32.1 ppm nickel, respectively. Toxic levels of nickel have been reported as being >20 ppm (Patterson 1971) and >50 ppm (Allaway 1968). If the 20 ppm value is considered, two plant samples of the 21 analyzed (7 grasses x 3 replications) were within the toxic range. Applications of nickel which will further increase the plant content of this element should be avoided. Although the total and extractable soil concentrations were within typical values

(Allaway 1968) only 48% of the nickel in the soil was in the nonextractable form. This resulted in a soil concentration of 30.2 ppm of plant available nickel with 52% of the total soil nickel concentration in the plant available form.

Plant concentrations of the other metals studied did not appear to be within the toxic range. Toxic plant concentrations of zinc and copper have been noted as being >200 ppm and >20 ppm, respectively (Allaway 1968, Jones 1972). Chromium concentrations, an element not readily available to plants (Lisk 1972), was considered low in this study. Mortvedt and Giordano (1975) noted that chromium concentrations in corn were not affected when receiving sewage sludge containing up to 1.36% chromium. The sewage sludge in this study contained less than 1.0% chromium (Table I). Warren and Delavault (1962) have reported that normal lead concentrations in plants vary from 0.3 to 3.0 ppm. Lead concentrations similar to those found in this study were also noted without toxicity by John and Van Laerhoven (1976). Cadmium concentrations of plants in this study were lower than the amounts needed to cause 25% reductions in the growth of crops (Bingham et al. 1975). Plant mercury concentrations of 1.68 ppm in velvet bentgrass (Agrostis canina L.) were noted without any symptoms of toxicity by Estes et al. (1973).

Problems with nickel, and other metals in general, may be avoided by increasing the pH, phosphorus and organic matter content of the soil and by using metal tolerant plant species. In this study more metal tolerant plant species (grasses) are presently being used and the amended soils contain high amounts of phosphorus and organic matter. Therefore, the most logical and cost-effective method is increased lime application to increase soil pH.

SUMMARY AND CONCLUSIONS

This field study was conducted to assess the effects of sewage sludge and lime on the revegetation and reclamation of acidic (pH 3.0) and infertile dredged soils. Sewage sludge at 100 metric tons/ha (45 tons/ acre) and lime at 25 metric tons/ha (10 tons/acre) were applied during the summer of 1974 on a 7-ha (17-acre) site and incorporated into the soil to a depth of 20 cm (8 in.). Soils were sampled 20 months after sludge incorporation at three depths (2-20, 20-40, and 40-60 cm, 0-8, 8-16 and 16-24 in.) within the sludged and control areas. A total of 29 grass treatments, containing grasses seeded alone or in combinations, were also evaluated and seven grass types analyzed for mineral composition.

The soils were initially low in soil pH, fertility, and metal concentrations. Applications of sewage sludge and dolomitic limestone produced a better overall plant growth environment in the soil. They increased soil pH, cation exchange capacity, exchangeable calcium and magnesium, organic nitrogen, organic carbon, total phosphorus, organic phosphorus, and plant-available phosphorus in the surface soil (0 to 20 cm, 0 to 8 in.). Total soluble salts remained at a low level.

Applications of 25 metric tons/ha of dolomitic limestone increased soil-exchangeable calcium and magnesium to high levels. Therefore, increased application rates of dolomitic limestone to increase the soil levels of these two elements is not justified. Soil potassium levels did not increase due to the applications of sewage sludge and lime. This is due to the low concentration (0.25%) of this element in the sludge. Exchangeable sodium values in the treated soil were similar to those in the control soil.

In the 20- to 60-cm (8- to 24-inch) depth, the treated soil was low in pH and similar to the control soil (pH 3.0). Plant-available phosphorus increased slightly at this depth but was still considered low. Due to these low values, deep root penetration by the grasses would appear to be restricted. Increases in soil concentrations over the control soils of most of the other soil parameters were noted below the soil depth in which sewage sludge and lime were incorporated (20 to 60 cm, 8 to 24 in.).

The greatest soil concentrations for metals were found in the upper 20 cm (8 in.) of soil. Below this depth metal concentrations were appreciably lower. Only the concentrations of total copper in the upper 20 cm (8 in.) of soil were outside the range of metals typically found in soils.

During the first growing season the ryegrasses became established and stabilized the soils more quickly than the other grasses studied. This was due to their rapid germination and development rates.

After one full growing season the Kentucky bluegrasses, red fescues, and K-31 tall fescue, when seeded alone or in combinations excluding ryegrasses, were the more desirable species as related to soil cover and growth. At this time the ryegrasses had lodged and partially smothered other grass types. No species differences in chemical composition were noted between the seven grasses analyzed.

Plant concentrations of nickel were high with two species near the toxic range (> 20 ppm). The extractable soil level of this element was 30.2 ppm, while 52% of the total soil concentration was in a form available to plants, Plant concentrations of the other metals studied were not great enough to be toxic.

RECOMMENDATIONS

1. To achieve a greater increase in soil pH and to lower the availability of metals to plants, supplemental applications of more

rapidly neutralizing types of lime such as calcium oxide or calcium hydroxide, should be applied and immediately incorporated into the soil.

2. Deeper incorporation of soil amendments is needed to increase soil pH and plant available phosphorus at soil depths greater than 20 cm. This would allow for deeper root penetration and a greater degree of protection against the movement of metals through the soil profile.

3. Supplemental applications of potassium fertilizer should be considered for soils low in this element.

4. Applications of toxic metals, especially nickel, should be considered to avoid plant toxicities by these elements. Applications which would increase the extractable soil levels of nickel above 30 ppm should be avoided.

5. From the kinds of plants studied it appears that grass mixtures including two of the following perennial type species (Kentucky bluegrass, red fescue, K-31 tall fescue) plus annual ryegrass, if desired, at no more than 10% of the seed mixture, should be best able to stabilize the soils at this site.

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