Restoration of Eroded Prairie with Digested Sludge

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Experiments on restoration of eroded areas have been conducted on a 220-acre farm near Criner, Oklahoma. During the spring of 1976, gullies were graded to a smooth contour, fertilized, and sprigged with Bermuda grass. Various grasses, legumes and forbs became established gradually, but in 1981 stands remained thin over approximately half the reclaimed areas, and some eroding bare areas persisted. During spring of 1981, anaerobically digested, dried sludge was mixed into the surface layer of eight test plots totaling four acres, at the rate of 100 tons per acre. Subsequently, on the test plots the biomass increased greatly, and erosion became negligible and remained so into 1985. On control plots, eroding bare areas present in the late 1970s persisted with continued erosion.

Analyses of portions of plants growing on the sludge-amended plots show that metals present in the sludge appear in the plants but are within normal ranges. Analyses of tissues of calves that grazed both the sludge-amended plots and the much larger untreated pasture showed clinically insignificant levels of lead and cadmium present in the sludge. We conclude that no hazard from mineral uptakes accompanied the soil conservation practice described. We regard our findings for central Oklahoma as confirmatory of other experimental results widely reported.

INTRODUCTION

In central Oklahoma, a principal cause of soil erosion is heavy rains that fall on sloping soils with thin vegetative cover. Soil erosion is a major national problem involving questions of land use, agricultural practices, and related government policies (1). Municipal sewage sludge can be an important restorative for abused land (2), and we show here that it can be substantially more effective than treatment of eroded areas that involves only grading and one-time fertilizing at planting. Sludge can improve soil condition, restore fertility, and maintain gentle contour while simultaneously solving the problem of disposal. In our experiment, no harmful concentrations of metals in plants or animals were found from its use.

The experimental farm of 220 acres is 25 mi (45 km) south of Oklahoma City, in Section 21, Twp 6N, Range 3W; topography is shown in Fig. 1. The farm was purchased by the first author in 1973, and has been his home since 1974. It had been intensively cultivated (60

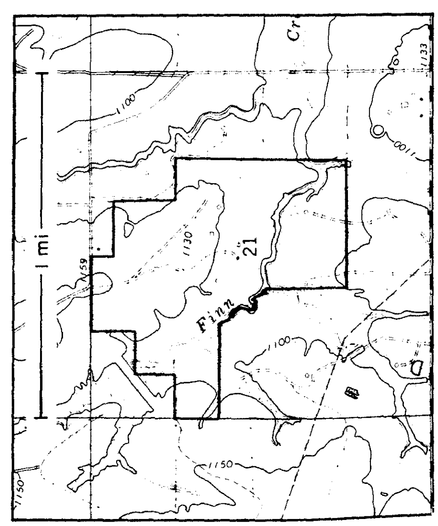

Figure 1. Portion of the Criner Quadrangle, McClain Co., Okla., 7.5-minute series. The contour interval is 10 feet. The outlined area in Section 21 of Twp 6N, R3W, represents the experimental farm, 34° 59′ N × 97° 31′ W.

acres mainly in small grains) and grazed (160 acres), with intensive practices continuing until 1976. In 1977, the number of cattle was sharply reduced, and about 30 acres of land previously tilled was committed to permanent grass. By 1980, fence had been erected to prevent access by cattle to about 30 acres of woodland bordering the channel of Finn Creek, which transects the farm.

During April 1976, the U.S.D.A. Soil Conservation Service 80 - 20 program paid 80% of the cost of reclaiming 5.6 gullied and nearly barren acres on the experimental farm, including 3.7 acres very seriously eroded (Fig. 2). The total cost of this project was about $1,000, including grading and fertilizing the soil and planting bermuda grass. The project was only partially successful, however, since bare areas remained and erosion continued, albeit at a lower rate, as shown in the bottom photograph of Fig. 2 and in Fig. 3.

During spring 1981, on eight test sites (Fig. 4), sewage sludge was mixed into the upper 6 in of soil. This portion of the project was supported by the National Science Foundation (3). The three A - plots and the B - plot shown in Fig. 4 are areas that had been treated in 1976. The application of sludge was highly beneficial on these plots and also on a small area about 100 ft north of the oil well shown in Fig. 4.

MATERIALS AND METHODS

Sewage sludge from the Southside Sewage Treatment Plant in Oklahoma City was used in our experiment. Before that plant was closed in April 1984, sludge there was digested under anaerobic conditions and then settled in

Figure 2. Top: Gullies on the experimental farm before treatment for soil conservation. Center: During April 1976, the gullies were filled with adjacent soil, then fertilized and planted with grasses to prevent further losses. During spring 1977, scarified crownvetch seed was planted with a grain drill on the A-sites. Bottom: On March 23, 1981, seasonal rapid growth of crownvetch had begun, and there was a thin cover of grasses, but substantial bare areas persisted. All of these photographs were made on the A-plots shown in Fig. 4.

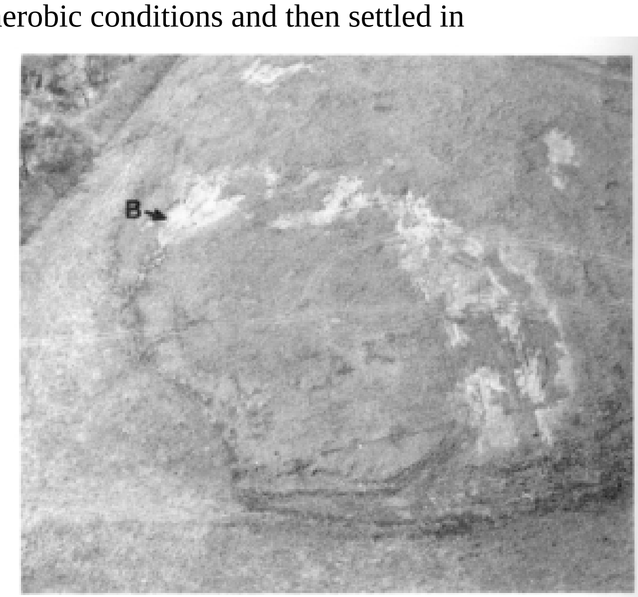

Figure 3. B test plot, marked by arrow, and adjacent control areas extending to the right (north) in this photograph from an aircraft made on 24 March 1981, before sludge was deposited. Although major eroded areas were objects of the SCS 80 - 20 program in 1976, it is evident that vegetation had not become well reestablished by the time of this photograph.

lagoons. When a lagoon was substantially filled with sludge, the surface water was drained away and the sludge was allowed to become drier over two to three years. Then the sludge was removed and stockpiled above the level of surrounding ground. Air-dried sludge, from heaps that had remained for about three years, was hauled to the experimental farm. The total 400 cubic yards comprised six loads delivered on 24 March 1981 and nine loads delivered on 3 April 1981. The cost of loading the sludge at the Southside Plant and transporting it 40 miles to the farm was $2,600. The specific gravity of the sludge in bulk was measured and found to be near 1.1. The mass of sludge in relation to the size of the test plots represents an application rate of about 100 tons/acre; of this, moisture represented approximately 50 %, according to officials of the Southside plant.

The sludge was dumped directly at the principal test sites, and spread with the aid of a front-end loader (Fig. 5); a disc plow was used

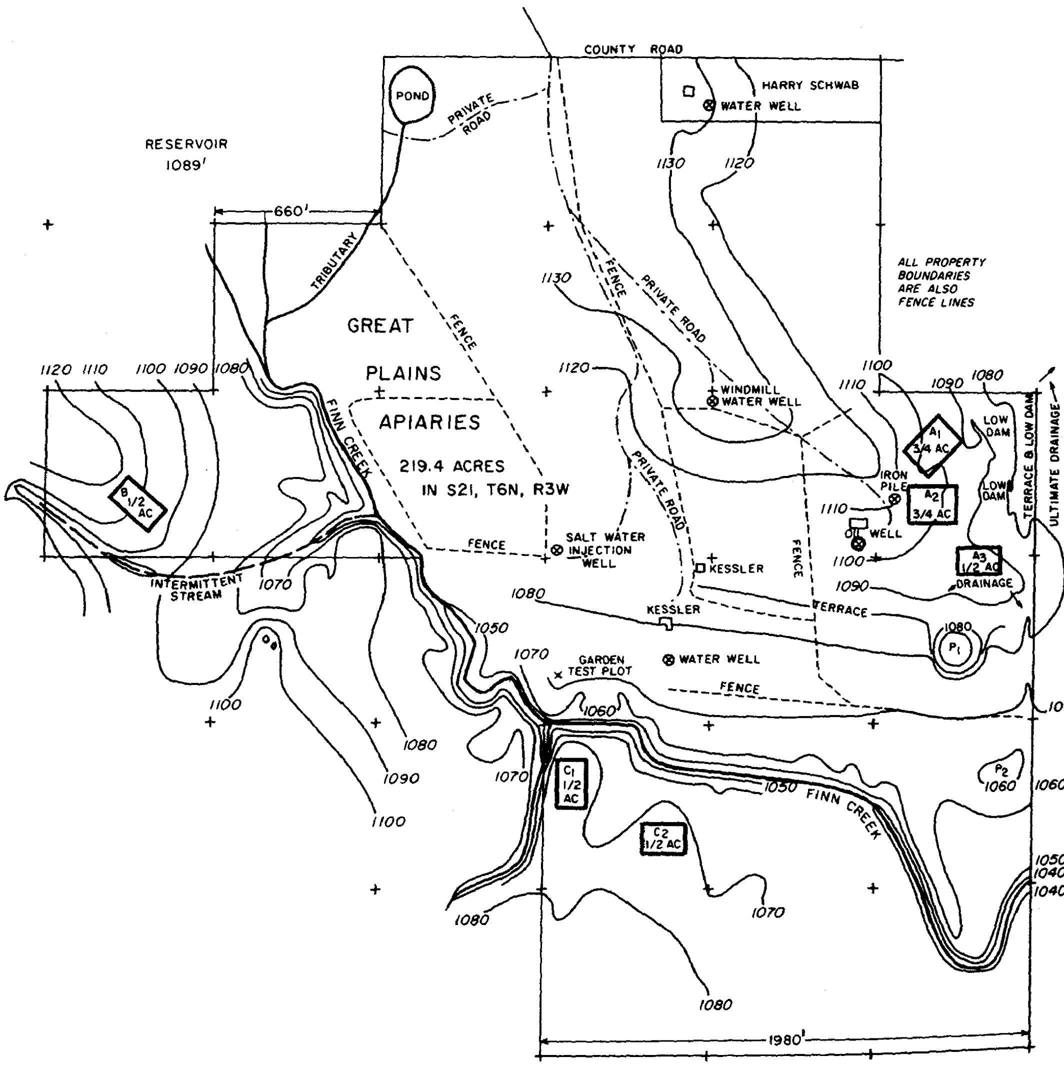

Figure 4. Map of the experimental farm with focus on the test plots. The three A-plots and oil well plot are east of center, B-plot is far to the west, two C-plots are south of Finn Creek, and the garden plot is 400 feet north of C_1. Contours show elevation in feet above MSL.

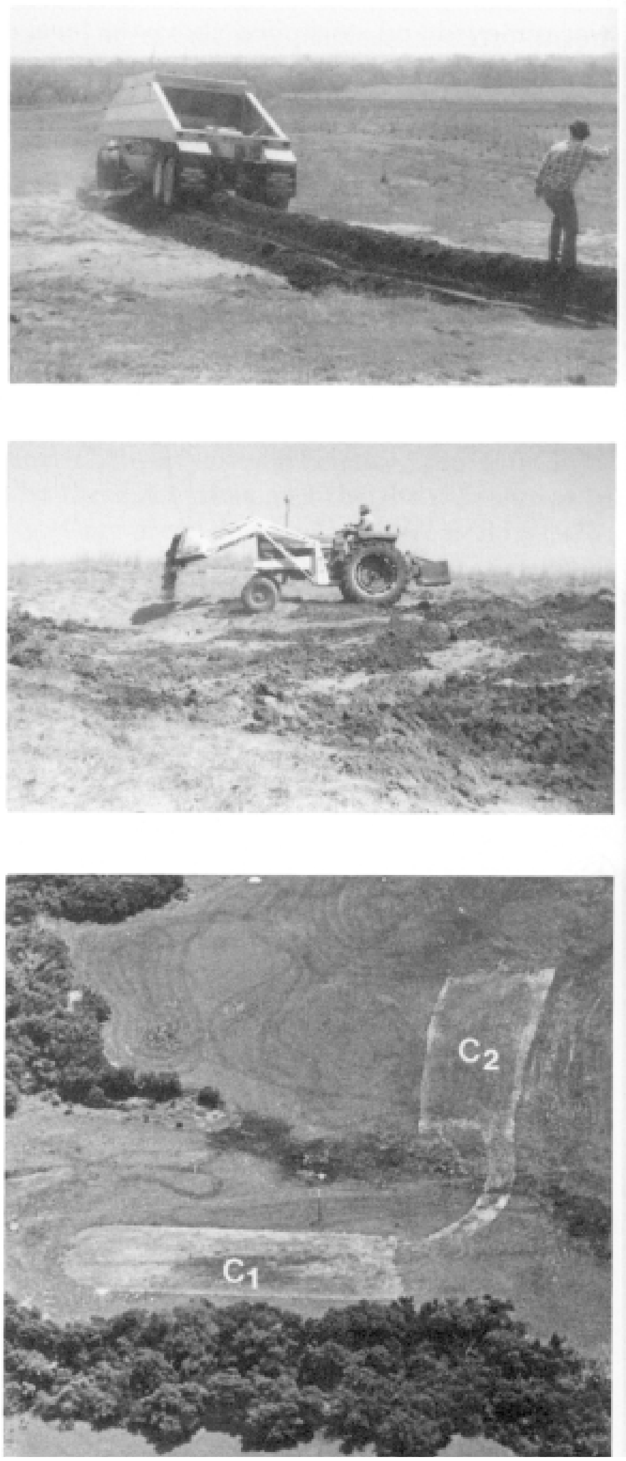

Figure 5. Top: The sludge was deposited in rows at the test sites. This photo shows the A_2 test site. Center: The sludge was spread roughly with a front end loader, then spread more evenly and mixed into the surface layer of soil with a disc plow. This photo shows the B-test site. Bottom: Aerial photo with infrared film showing the C-plots on 27 May 1981, after sludge was spread.

to mix the sludge into the soil. About 500 pounds of sludge was also transferred by a pickup truck from the oil well test plot to a garden test plot of about 1/42 acre (100 ft^2 or 0.001 ha) for study of uptake of metals by vegetables. On all plots except the garden test plot, native climax grasses were planted; seed was deposited by both a tractor-drawn spreader and hand broadcasting. The grass species planted were little and big bluestem, switch grass, and Indian grass in respective amounts of 1.8, 0.8, 1.4 and 1.0 pounds in each 5 pounds of pure live seed (pls). The seeding rate was about 2.5 pounds pls/acre. Out-of-pocket cost of spreading the sludge, mixing it into the soil, and planting grasses was about $300.

Specifics of the sites are detailed in the application for a permit granted to the first author under the Oklahoma Solid Waste Management Act (4). Briefly, sites A and B are on slopes of the Lucien-Nash complex with sandstone of Permian age at shallow depths and occasionally at the surface. Oil recovery activities that began in the 1940s affected the A-sites. Sand and clay are present at both the A and B sites, but the ratio of sand to clay is much higher at the B-site. The C-sites are on nearly level silty-loamy Port soil with a silty clay loam subsoil, in a former wheat field. Soil in the garden test plot is a silty loam. The sludge spread on 1/4 acre near the old oil well was used in an attempt at reclamation of land particularly barren. Soil descriptions are detailed in a report of the Soil Conservation Service (5).

Samples of soil, sludge, and water runoff, and of parts of plants and grazing animals on test plots and control areas, were analyzed for extractable elements by the Oklahoma State Department of Health, Oklahoma City; by Keltner Laboratories, Inc., Manhattan, Kansas (now out of business); by the Plant and Soil Testing Laboratory at Kansas State University, Manhattan, Kansas; and by the Animal Disease Diagnostic Laboratory, Oklahoma State University, Stillwater.

RESULTS

Plant growth on all sites responded dramatically to the presence of sludge, but native grasses were established with difficulty, and generally became prominent only after two years or more. All sites are currently populated abundantly though not uniformly nor exclusively with native grasses. Remarkably, the C-sites, in a field formerly usually planted in wheat and most productive of all the sites, were most resistant to reduction of undesirable weeds such as gumweed and horseweed. Allelopathy strongly influences establishment of native grasses in previously cultivated areas (6).

Since the C-plots were always nearly level, erosion was negligible there from the start, and it became negligible on the A- and B-test plots also after sludge application, but spotty erosion continues on A and B control sites. Erosion reduction after application of sludge appears to result both from heavier plant populations, which reduce the velocity of flow of rainwater across the soil surface while binding the soil with roots, and from change in physical properties of the soil itself, especially increased cohesiveness of elementary particles. Conditions at the test plots and controls in 1984 are ilustrated in Figs. 6 and 7.

When cattle are allowed to do so, they graze the vegetation that grows on the sludgeamended sites more vigorously than that which grows on adjacent control sites. However, this heavy intermittent grazing only slightly offsets the benefits in reduction of soil erosion on the test sites that stem from the increased biomass and improved soil condition.

Results of chemical analyses are shown in Tables 1 - 5. Table 1 shows that before sludge was spread the amount of toxic heavy metals present in the soil was very low. The large variability of some other soil constituents per-

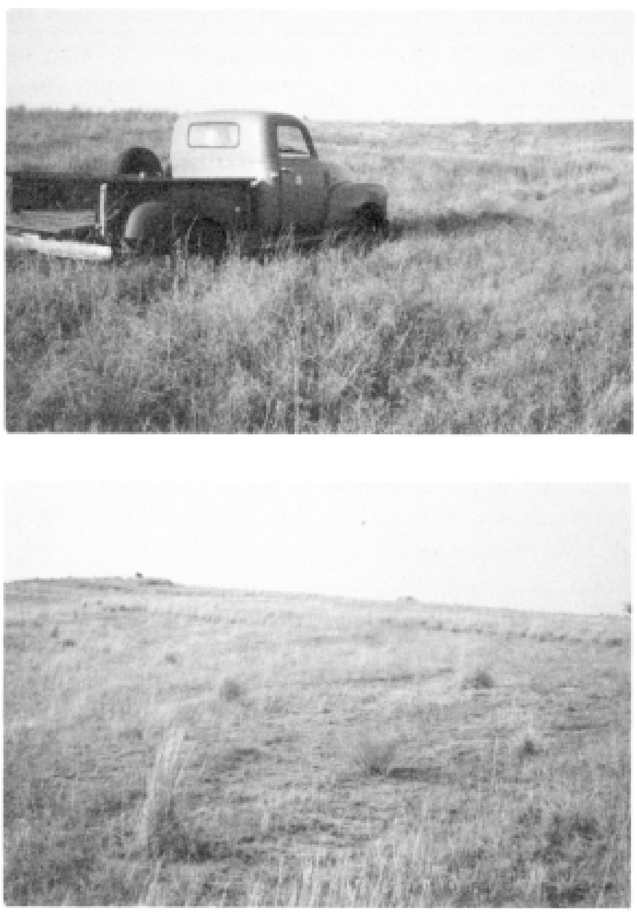

Figure 6 (above). View toward SW on the A_1 test plot, 7 Sept 1984. (below). Control plot for the A test sites as seen during October 1984. This plot lies immediately to the south of A_2, west and south of A_3, and drains directly into Pond P_1 shown in Fig. 4. Vegetative growth is much less than on the sludge-amended plot shown in Fig. 6 (above).

Figure 7 (above). View toward SE showing B-plot control area NE of the B test plot, 23 Sept 1984. Grass has not become well established although the area has not been grazed during growing seasons since 1976. See Fig. 3 also. (below). View toward NW from the SE edge of the B test plot on 23 Sept 1984. The plot had been ungrazed since the previous winter. Erosion is virtually nil everywhere on this plot. See Fig. 3 also.

haps reflects contamination of the A - sites by petroleum-related activities and the partial mixing of different strata by grading in 1976.

Tables 2 and 3 indicate the composition of sludge stockpiled at Oklahoma City. They show that the proportions of potentially toxic materials in the Oklahoma City sludge were below levels characteristic of 'EP Toxicity' as defined by EPA and incorporated into rules and regulations of the Oklahoma Department of Health (14). One would not expect to have harmful uptakes from this sludge at the application rate used, except perhaps in case of its admixture with an acid soil (15). The composition of the sludge-amended soil can be calculated with the method presented by Kirkham (16).

The report to NSF (3) presents extensive tables listing the constituents of vegetables, forbs, and grasses grown in the sludge-amended plots and in control plots on the experimental farm. Several comparisons between plants from test and control sites were highly variable, perhaps reflecting problems in measurement of small concentrations. Among the analyses of vegetables for which 'normal ranges' have been established (19, 20), two for cadmium and one for chromium (among a total of 40 tests for chromium and heavier metals) showed levels above normal. Reanalyses of samples, however, indicated chromium within its normal range; suspicion was cast on the validity of the cadmium analyses of plant tissues because there was no significant correla-

TABLE 1. Concentration of extractable elements, soluble salt, and soil pH for six soil samples from different sites on the experimental farm near Criner, Oklahoma, before sludge was spread. Samples #1-#5 were gathered in October 1980; the garden-plot sample was collected in April 1981.

	Sample #1 Site A	Sample #2 Site A	Sample #3 Site A	Sample #4 Site A	Sample #5 Site C	Garden Plot
	Fair stand of bermuda-grass, crown vetch, and native grasses	Poor stand of native grasses	Barren	Barren; contaminated with oil residues	Only weeds; no native grasses	
Element	Concentration, mg/kg					
N [a]	42.0	5.6	4.3	4.2	8.5	16.5
P [a]	4.5	16	88	26	65	128
K [a]	417	137	203	297	141	315
Ca [a]	1148	2163	2450	2485	574	653
Mg [a]	301	161	504	273	126	180
Cd	0.048	0.024	0.028	0.036	0.068	0.1
Cr	<0.004	<0.004	<0.004	<0.004	<0.004	0.16
Cu [a]	0.4	0.4	0.04	0.9	0.4	0.7
Fe [a]	11.9	4.6	4.2	69.3	70	22.2
Mn [a]	6.8	3.0	1.4	18.0	15.5	16.7
Ni	0.312	0.112	0.076	0.248	0.444	0.54
Pb	1.12	0.828	0.556	1.612	0.872	1.8
Zn [a]	0.9	1.2	0.3	1.5	0.5	-
pH [a]	7.0	7.1	7.1	7.0	6.8	-
	Conductivity, mS/cm					
Soluble Salts [a]	0.60	0.38	0.86	15.9	0.40	-

[a]Soil samples represented in the first five columns were analyzed by the Plant and Soil Testing Laboratory, Kansas State University, Manhattan, Kansas, by the following methods: pH (soil/water ratio, 1:1) (7); extractable P (8); exchangeable K, Ca, and Mg (9); DTPA-extractable Cu, Fe, Mn, and Zn (10); NH_4-N and NO_3-N (11); and soluble salts (electrical conductivity of a saturation extract) (12). Because the laboratory does not determine non-essential elements, half of the soil samples had to be submitted to a commercial laboratory (Keltner Laboratories, Inc., Manhattan, Kansas) for analysis for Cd, Cr, Ni, and Pb (rows not marked by superscript a). Keltner Laboratories also reported all items in the last column. Analyses by Keltner Laboratories for extractable and total elements used atomic absorption spectroscopy (13).

tion between cadmium levels in plant tissue samples first analyzed in 1981 and reanalyzed in 1982, and because the reported cadmium content of control plants was higher than expected. (We consider the analyses for cadmium reported in Table 5 below to be reliable and representative.)

Analyses for nitrogen, phosphorus, and metals in runoff waters showed some elevation of constituents in runoff from the sludge-amended site A_1 (Table 4), but all values with the possible exception of nitrate remained well within standards for drinking water (21).

During 1980 - 1982, comparisons were also made between constituents of liver, kidney, and muscle of two calves that had grazed on sludge-amended plots and constituents of corresponding tissues of one calf that had not grazed upon these plots. Values were generally in normal ranges, i.e., comparable to values in cattle not fed with sludge or feeds grown with sludge (22).

Partly in view of uncertainties in early analyses, especially with respect to the significant element cadmium, and partly from a desire to evaluate long-term effects of the sludge treatment, a few more samples were collected in 1984 and analyzed at the Oklahoma Animal Disease Diagnostic Laboratory (OADDL), Stillwater. Results are given in Table 5. The OADDL report noted with respect to the plant tissues, 'These values are within the normal background levels that we have established for lead and cadmium,' and with respect to the liver sample, 'These levels are not clinically significant.'

DISCUSSION

Some vegetative cover was established and erosion was reduced though not halted through the SCS 80 - 20 program, applied to gullied land. Further effort, involving the topical application of anaerobically digested sludge at the rate of 100 tons/acre to test plots on the Oklahoma experimental farm, halted erosion where it had existed before, increased the biomass substantially, and almost eliminated bare spots. A more highly valued speciation developed over three years on the sludge-amended sites, and grazing improved. A further benefit of the sludge application lay in constructive use of a product requiring disposal.

The areas treated with sludge were characterized by nearly neutral pH and represent about 2% of the area of the whole farm. The concentration of sludge constituents in tissues of plants and animals exposed to sludge were only slightly elevated above their concentration in tissues of biota exposed only to untreated areas.

TABLE 2. Total and extractable elements in anaerobically digested sewage sludge from Oklahoma City, Oklahoma as reported by analysts. Mean and standard deviation are given (N = 6). Range, median, and mean values for total concentration of elements in anaerobically digested sludges in the U.S.A. are also given for comparison (17). All analyses are on a dry-weight basis. Oklahoma City analyses were performed at Keltner Laboratories, Manhattan, Kansas.

	Oklahoma City amounts (mg/kg)		U.S.A. amounts (mg/kg)		
Element	Extractable	Total	Range	Median	Mean
Nitrogen	...[a]	11,270 ± 1,840	5-176 × 10^3	42 × 10^3	50 × 10^3
Phosphorus	...[a]	9,330 ± 1,040	5-143 × 10^3	30 × 10^3	33 × 10^3
Potassium	...[a]	5,800 ± 921	20-264 × 10^2	30 × 10^2	52 × 10^2
Calcium	...[a]	1161 ± 54 × 10^2	19-200 × 10^3	49 × 10^3	58 × 10^3
Magnesium	...[a]	3,270 ± 403	30-192 × 10^2	48 × 10^2	58 × 10^2
Aluminum	3.4 ± 0.5	5,140 ± 700	1-135 × 10^3	5 × 10^3	17 × 10^3
Cadmium	8.3 ± 4.9	51.2 ± 15.0	3-3,410	16	106
Chromium	0.7 ± 0.1	1,170 ± 311	24-28,850	1,350	2,070
Cobalt	0.8 ± 0.1	13.1 ± 1.9	3-18	7.0	8.8
Copper	58.8 ± 18.0	460 ± 119	85-10,100	1,000	1,420
Iron	173 ± 30	10,120 ± 1,530	1-153 × 10^3	12 × 10^3	16 × 10^3
Manganese	36.9 ± 7.3	314 ± 39	58-7,100	280	400
Nickel	91.5 ± 23.5	255 ± 59	2-3,520	85	400
Lead	1.2 ± 0.1	871 ± 169	58-19,730	540	1,640
Zinc	726 ± 135	1,680 ± 373	108-27,800	1,890	3,380

[a]Not analyzed.

The cash investment in reclamation of eroded areas on the experimental farm was approximately $1,000 for repair of 5.6 eroded acres in 1976, and $3,000 for sludge-related activities on 4 acres in 1981. Savings are implicit in use of sludge on land where it provides a restorative value, rather than on land already productive; transportation costs are probably the principal limiting factor for sludge application. Extension of this practice would depend on the value attached to restoration of eroded land, to reduction of sedimentation at dam sites and estuaries that receive the drainage, and on the costs of other suitable methods for disposing of sludge.

Although this study was not replicated, the results are credible because test and control areas were compared and because similar conclusions concerning sludge as a soil conditioner and uptakes of sludge constituents are documented elsewhere.

ACKNOWLEDGMENTS

The Soil Conservation Service in McClain County, Oklahoma, has provided advice and assistance. Through Grant No. NSF/ISP-8014715 the National Science Foundation paid the costs of transporting sludge to the farm, spreading it on the test plots, planting grass, analyzing samples, and documenting results in the final report to NSF (3). Information was provided from the Oklahoma Department of Health and Oklahoma City Southside Treatment Plant. Also participating in the project were Christian Construction Co.; Canadian Hauling, Inc.; Sun Exploration and Production Co.; neighbors Larry McAlister and Harry and Verna Schwab; and aerial photographer Ray Jacoby. Graphics were prepared by Joan Kimpel of NSSL, and Lindsay Murdock and others anonymous were good editors and reviewers.

TABLE 3. Results of analyses performed on samples received 3 January 1981 by the Water Quality Laboratory of the Oklahoma State Department of Health. Sludge samples collected at the Oklahoma City Southside Sewage Treatment Plant.

Component	Amount of component in dry sample		
	Sample #75778	Sample #75779	Sample #75780
total		μg/g	
Silver	64.5	82.5	45
Cadmium	41	45	47
Chromium	425	550	465
Lead	795	995	535
Barium	100	140	120
Arsenic	1.68	1.85	1.76
Selenium	<0.25	<0.25	<0.34
Mercury	0.68	1.26	0.38
extractable[a]		μg/L	
Silver	<3	<3	<3
Cadmium	50	60	<20
Chromium	$<10^2$	$<10^2$	$<10^2$
Lead	$<2 \times 10^2$	$<2 \times 10^2$	$<2 \times 10^2$
Barium	23×10^2	19×10^2	13×10^2
Arsenic	20	29	<10
Selenium	<5	<5	<5
Mercury	<5	<5	<5
		μg/L (by extraction)[a]	
Toxaphene, EP	<15	<15	<15
Endrin, EP	<1	<3.5	<1.5
Lindane, EP	<1.5	<1	<1
2,4-D, EP	$<10^3$	$<10^3$	$<10^3$
Methoxychlor, EP	<3.5	<1.5	<3.5
Silvex, EP	$<10^2$	$<10^2$	$<10^2$

[a]Extractable amounts determined according to the U.S. Environmental Protection Agency's EP (Extraction Procedure) test, described in the Federal Register (18).

TABLE 4. Concentration of elements of runoff water from Site A_1 previously treated with sludge from Oklahoma City, and in pond water receiving little runoff from a site spread with sludge. Samples were taken the last week of May 1982. Analyses were performed by Keltner Laboratories, Manhattan, Kansas.

Element	Concentration (mg/L) Runoff from A_1 site	Pond P_2	Maximum for drinking water[a]
N	32.5	10.8	10 (nitrate)[b]
P	0.318	0.149	—
K	8.56	4.36	—
Ca	95.4	23.3	—
Mg	34.0	7.56	—
Cd	0.004	0.004	0.010[b]
Cr	0.021	<0.001	0.05[b]
Cu	0.016	<0.001	1[c]
Fe	0.026	0.236	0.3[c]
Mn	0.009	0.001	0.05[c]
Ni	0.016	0.004	—
Pb	0.037	0.035	0.05[b]
Zn	0.131	0.052	5[c]

[a]Taken from Oklahoma State Department of Health (21).
[b]Primary standards, related to constituents that may adversely affect health.
[c]Secondary standards related to constituents with cosmetic significance.

TABLE 5. Results of analyses of soil, plant, and animal tissues[a].

	Concentration (μg/g, dry weight) Lead	Cadmium	pH
Surface soil, Test plot C_2	26.77	8.39	6.68
Soil control, near C_2	1.43	0.099	5.73
Switchgrass, Test plot C_2	0.378	0.104	—
Switchgrass control, near C_2	0.294	0.075	—
Liver (net weight)	0.001	0.003	

[a]Soil samples collected 12 Aug. 1984. The liver sample was taken from a bull calf, approximately 600 lb., slaughtered 6 Sept. 1984. Its grazing area for six weeks during spring had included the C-plots, and for three weeks during summer had included the A-plots.
These results of analyses were provided by the Oklahoma Animal Disease Diagnostic Laboratory, Oklahoma State University, Stillwater, Oklahoma.

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