CROP AND SOIL RESPONSES TO SEWAGE SLUDGE APPLIED TO RECLAIMED PRIME FARMLAND[1]

BY

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Abstract. Improvements in reclamation of surface mined prime farmland may be abtained by adding sewage sludge to topsoil and subsoil. This prime farmland reclamation study was done in western Kentucky. The experiment was conducted to investigate effects of the sludge amendment to topsoil and subsoil on soil and crop responses. The experiment showed, in most cases at highest application rates, that the sludge addition significantly increased the soil organic matter, total N content, and available P levels. However, water holding capacity, CEC, and exchangeable cations were not significantly affected. Higher microbial populations and activites were also obtained. The wheat biomass, tiller number, tissue N, grain N, grain yield, and N removal in grain were well correlated with application rates of sewage sludge. Corn also responded positively to additions of sewage sludge. The corn ear-leaf N concentration, grain yield, and grain N removal increased with application rates of sewage sludge. Experiments indicated that topsoil and subsoil sewage sludge addition was beneficial practices in terms of increasing crop yield and improving some soil properties.

Additional Key Words: organic matter, reclamation, sewage sludge, soil properties, wheat and corn yields.

Introduction

The original soil ecosystem, structure, horizons, microbial community, and fertility may be drastically affected by surface mining (Barnhisel et al., 1987). Return of the productivity of mined prime farmland to conditions equal to or greater than those of the original soil prior to mining is a requirement of Public Law 95-87, the Surface Mining Control and Reclamation Act of 1977 (SMCRA).

In the past 10 years, several projects have been reported on the use of inorganic fertilizer to meet the requirements of recovery of soil properties and crop yield for reclaimed prime farmlands, but few have included organic amendments. Organic materials, such as sewage sludge, peat, and wood residue have been extremely successful only for spoil reclamation compared to inorganic fertilizers (Fresquez and Lindemann, 1982). The high organic matter of waste amendments largely ameliorates the physical conditions of mine spoil. Soil properties that benefit from sludge incorporation includes water holding capacity, bulk density, water-stable aggregates and hydraulic conductivity. (Sopper, 1992).

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Chemical properties of mine spoils affected by organic amendments include raising acidic spoil pH, and increasing CEC, N and P nutrients, but effect on K, Ca, and Mg levels varies depending on the characteristics of amendments (Sopper, 1992). Microbial population and activities are often stimulated by organic amendments (Sopper, 1992). However, few studies if any have quantitatively measured the effect of organic waste application on physical, chemical, and biological properties as well as on crop yield of disturbed prime farmland.

The objectives of this study were to determine the effects of sewage sludge applied to either topsoil and/or subsoil on soil physical, chemical, and biological properties, as well as wheat and corn responses seeded to a reclaimed prime farmland soil following surface mining. The hypotheses were that adding sewage sludge in topsoil or subsoil may significantly improve soil physical, chemical, and biological properties and increase crop yields.

Materials and Methods

Field procedures

The mine is located in Henderson County, western Kentucky. The replacement of spoil and subsoil was completed in 1989 and seeded to cover crops including wheat and tall fescue. The reconstruction of topsoil was done in the summer of 1992 following sewage sludge additions. The original soil disturbed by surface mining activities was the Grenada (fine-silty, mixed, thermic Glossic Fragiudalfs) silt loam soils. The topsoil and subsoil were separately stockpiled and were mixed during the soil removing and replacing processes.

Two sewage sludge experiments were initiated, one in which sewage sludge was applied only to the subsoil (Zhai, 1995), and the other in which sewage sludge was applied to both subsoil and topsoil. Only the results from the latter experiment will be reported here. The sewage sludge was from the Henderson Water and Sewage Utilities. Characteristics of the sludge are shown in Table 1. The experiment design was completely randomized block with three replications.

Table 1. Physical and chemcal properties of sewage sludge.

Water content	(%)	42.9
Total N	(g kg^{-1})	26.3
NH_4-N	(mg kg^{-1})	536
NO_3-N	(mg kg^{-1})	330
Cd	(mg kg^{-1})	0.16
Cr	(mg kg^{-1})	0.64
Cu	(mg kg^{-1})	2.23
Pb	(mg kg^{-1})	0.16
Ni	(mg kg^{-1})	0.80
Zn	(mg kg^{-1})	0.16

Sewage sludge at rate 22.4 Mg ha^{-1} was uniformly applied to the subsoil prior to the topsoil replacement. Then 0, 11.2, and 22.4 Mg ha^{-1} sewage sludge were applied to the topsoil. All sewage sludge was applied as described above and incorporated to a 15 cm depth in both the topsoil and subsoil with a chisel plow.

The topsoil (0-15 cm) was sampled after sludge application on September 6, 1992. Every soil sample from each plot was taken by a hand sampler and was made up of by ten cores taken throughout the study period.

On October 16, 1992, the entire area received a broadcast application of N fertilizer (NH_4NO_3) at a rate of 70 kg N ha^{-1} and planted to wheat (<u>Triticum aestivum</u>, L.) at seeding rates of 136 kg ha^{-1}. On May 11, 1993, this experiment site was divided into two parts. One part was retained for wheat yield measurements. For the other part, the wheat was killed with a mixture of atrazine (4WDL) and "Roundup" at a rate of 3.0 and 1.8 L ha^{-1}, respectively.

Corn (Zea mays L.) was planted at a seeding rate of 59,000 kernels ha^{-1} using a Kinze no-till planter.

Topsoil (0-15 cm) was sampled again on September 1993 for biological analyses. The soil sampling procedure was the same as described above.

Wheat tiller numbers were counted from 20 randomly selected plants from each plot and their above-ground plant tissue was sampled on May 5 for biomass determination and chemical analyses. Wheat grain was harvested on July 3, 1993 with a plot combine. Yields were measured based on the standard 12.5% moisture. A wheat grain sample (200 g) was collected from each plot at harvest for chemical analyses.

Corn ear-leaves were taken during late silking growth stage on July 29, 1993, from six randomly selected corn plants in each plot. Corn grain was harvested on October 2, 1993 with the same plot combine. Yields were measured and based on the standard 15.5% moisture content. A corn grain sample (200 g) was collected at harvest from each plot for chemical analyses.

Soil analyses

Soil bulk density was determined by Blake and Hartge, except that the core size was 4.5 cm (1986). Water-holding capacity was determined using the method developed by Klute (1986). The soil samples for chemical analyses were air-dried, and ground to pass a 2-mm sieve. Soil pH was determined with a pH meter on a 1:1 deionized water to soil mixture (McLean, 1982). Exchangeable Ca, Mg, K, and Na and CEC were determined with the neutral M NH_4OAc method (Thomas, 1982). Available P was determined using the Bray-I (Bray and Kurtz, 1945). Organic matter (Nelson and Sommers, 1982) and total nitrogen (Bremner and Mulvaney, 1982) were performed by the University of Kentucky Soil Testing Laboratory, Division of Regulatory Services.

Soil microbiological analyses were performed using moist soils. Total heterotrophic and facultative anaerobic organisms were enumerated by the Most Probable Number method (Alexander, 1982). The numbers of organisms were calculated based on oven-dry soil. Microbial biomass (C) was determined using a chloroform fumigation procedure (Parkinson and Paul, 1982). Soil respiration rate (CO_2 evolution rate) in the laboratory was measured by gas chromatography on a Varian 3700 gas chromatograph equipped with Porapak Q column operated at 80°C (Rice and Smith, 1982).

Plant analyses

Wheat tissue and corn ear-leaf samples were dried and ground to pass a 0.425 mm sieve. The samples were then analyzed for N, P, K, Ca, and Mg which were all determined based on Jones and Case (1990).

Statistical analyses

Statistical analyses were performed using the Statistical Analysis System (SAS Institute, 1985). General linear Models (GLM) procedure was used to obtain the analyses of variance based on the experiment design.

Results and Discussion

Soil responses

The effects of sewage sludge application on soil physical, chemical, and biological properties are shown in Tables 2. The significant increase in soil organic matter, total N, and Bray I-P, is attributed to the sludge application. Soil water holding capacity, pH, CEC, and exchangeable Ca, Mg, K, and Na were not significantly altered. Sewage sludge application to subsoil had similar effects on soil physical and chemical properties as observed in the sludge applied to

Table 2. Physical and chemical properties of topsoil (0-15 cm) after sewage sludge application on August 25, 1992.

Sludge (Mg/ha)	WHC† (%)	PH	OM (%)	TN (-- mg/kg -)	Bray I-P	CEC (-------- cmol(+)/kg	Ca	Mg	K	Na ----------)
0	25.2	5.0	0.82	1110	5.5	9.4	3.26	1.34	0.17	0.07
11.2	25.8	5.0	1.15	1470	6.8	9.8	4.04	1.35	0.19	0.07
22.4	25.2	4.9	1.11	1490	9.2	10.1	4.03	1.35	0.17	0.07
$LSD_{(0.1)}$	NS‡	NS	0.23	267	1.7	NS	NS	NS	NS	NS

† WHC, water holding capacity; OM, organic matter content; TN total nitrogen content.
‡ Not significantly different.

Table 3. Total heterotrophic and facultative anaerobic organisms, microbial biomass, and respiration rates after sewage sludge application to topsoil (0-15 cm) on 7 Sept., 1993.

Sludge Rate (Mg/ha)	Total Heterotrophs (10^7/g)	Facultative Anaerobs (10^7/g)	Microbial Biomass C (mg/kg)	Respiration Rate (mg CO_2/kg h)
0	0.31	0.12	224	30.0
11.2	4.49	0.56	267	39.7
22.4	10.9	1.19	331	55.3
$LSD_{0.1}$	4.25	0.31	58	9.6

topsoil. Significantly higher levels of organic matter, total N, and Bray I-P and pH were observed compared to the control, but other measured properties were not significantly affected.

These results were consistent with those that have been reported for spoil reclamation with sewage sludge. Sewage sludge has increased organic matter content, total N, and Bray I-P in reclaimed spoils according to Sopper (1992).

Total heterotrophic and facultative anaerobic organisms, microbial biomass C, and respiration rates of topsoil affected by sewage sludge application are shown in Table 3. Total heterotrophic and facultative anaerobic organisms increased. The significant increases were observed at the highest sludge application rate. Microbial respiration and biomass C also increased in response to increased sludge addition.

Sewage sludge addition stimulated microbial populations. This agrees with previous research that sewage sludge increases the microbial population of disturbed soils (Sopper, 1992). The enhancement of microbial activity in amended soil is primarily due to two factors. Sewage sludge has high microbial activity with the high bacterial numbers and large amounts of fungal hyphae as well as a nutrient-rich composition (Sopper, 1992).

Microbial activity usually increases as sludge application rate increased as observed in this study. However, this is not always consistent, particularly for sewage sludge. Inhibition of microbial activity was observed by others when heavy loading rates were used (Sopper, 1992). The inhibition is usually caused by a high content of heavy metals and/or salt. Such an inhibition was not observed here, probably due to the lower contents of heavy metals and salt (Table 1), as well as the lower application rates used here as compared to the sludge studies conducted by other researchers.

Wheat response

Wheat response to sewage sludge were in Table 4. A significant increase in grain yield was observed as a result of sewage sludge addition. A significant difference was not observed between application rates of 11.2 and 22.4 Mg ha^{-1}. The application rates had significant linear and quadratic effects on yields. Grain N removal followed the same basic trend that was observed for grain yield. The amount of N removed significantly increased as the sludge application rate increased.

Plant biomass and tiller numbers are usually good indicators of wheat growth after improvement of soil nutrient status and other physical and chemical properties by organic amendment (D.A. Van Sanford, personal communication). Application of sewage sludge significantly increased wheat above-ground biomass and tiller numbers, but there was no significant difference between the 11.2 and 22.4 Mg ha^{-1} application rates. Significant linear and quadratic responses to application rates were obtained for both biomass and tillers.

Wheat tissue (flag leaf) or grain N concentrations can be used as indicators of N nutrition (Grove et al., 1984). In this study, greater wheat tissue and grain N concentrations were observed in sewage sludge treatments than in the control. Significant linear and quadratic responses of tissue and grain N concentrations to application rates were observed. Tissue and grain N concentrations were significantly correlated with each other (r=0.87***). Tissue and grain N concentration have been frequently used to evaluate crop N nutrition.

Forage crops, as well as others such as silage corn, have significantly responded to sewage sludge in undisturbed prime farmlands (Smith and Peterson, 1982). Winter wheat response to sewage sludge may not be the same as the forage crops because wheat growth is often more sensitive to available soil N. Wheat grain yield is often low due to either low levels of available soil N or too much N. Grove et al. (1984) reported that the lush growth and lodging of winter wheat was due to excessive available soil N. The results of tissue and grain N concentration, grain yield, N removal in the grain have been related to available soil N in studies of wheat response to N fertilizer (Grove et al., 1984). The response of tissue and grain N concentration, grain yield, grain N removal, and tiller numbers in this study indicates that the increase in each of those parameters is well correlated with the addition of sewage sludge.

The sludge addition did not significantly affect wheat tissue P, K, Ca, and Mg. The sewage sludge contribution to crop growth is probably due to supplying available N from the sludge mineralization. This is consistent with results reported by Smith and Peterson (1982) who demonstrated that crop response to sewage sludge is mainly due to available N supplied by the sludge, although sewage sludge may also provide other nutrients.

Corn response

Grain yields and grain N removal in 1993 are shown in Table 5. Grain yields were significantly increased as the results of sewage sludge addition. There was a linear and quadratic rsponse of yield to application rates.

Table 4. Wheat about-ground biomass, tillers, tissue composition, grain yield, and N removal as affected by sewage sludge applied to topsoil and subsoil.

Sludge†	Biomass	Tiller	Tissue Composition					Grain	Grain	N
			N	P	K	Ca	Mg	N	Yield	Removal
(Mg/ha)	(g/tiller)	(#/plant)	(-----------------		g/kg		-----------------)	(g/kg)	(Mg/ha)	(kg/ha)
0	2.37	4.30	8.43	1.26	15.5	2.11	0.93	15.1	3.31	49.7
11.2	2.84	5.90	10.2	1.18	17.5	2.01	1.05	17.4	4.24	73.0
22.4	3.38	6.40	11.1	1.25	15.7	1.97	1.09	19.6	4.65	89.9
$LSD_{(0.1)}$	0.64	0.82	0.55	NS‡	NS	NS	NS	16.8	0.52	13.3
C.V.	12.8	8.54	4.49	4.6	22.6	17.6	11.0	5.55	8.16	10.8
Linear	**	***	***					***	***	***
Quad.	**	**	***					***	**	***

† Rates of sewage sludge applied to topsoil were 0, 11.2, and 22.4 Mg ha^{-1}, respectively, and 22.4 Mg ha^{-1} was applied to the subsoil for the entire Experiment II. Linear, linear effect; Quad., quadratic effect.

‡ NS, not significantly different; *, significant at $p<0.1$; ** significant at $p<0.05$; ***significant at $p<0.01$.

Table 5. Ear-leaf composition, grain yield, and N removal in 1993 as affected by organic wast application to topsoil and subsoil.

Trt	Ear-leaf					Grain	N
	N	P	K	Ca	Mg	Yield	Removal
	(--------------		g/kg		--------------)	(Mg/ha)	(kg/ha)
0	24.7	2.27	19.2	4.02	2.02	4.03	49.5
11.2	25.7	2.33	23.9	4.36	1.87	5.25	73.1
22.4	26.8	2.47	22.4	4.37	2.24	6.22	85.6
$LSD_{0.1}$	0.7	NS†	NS	NS	NS	0.42	6.1
C.V.	2.0	9.7	9.3	6.7	15.7	2.3	4.3
Linear	*		*	*		***	***
Quad.						***	***

† linear effect; Quad., quadratic effect. NS, not significantly different; *, significant at $p<0.1$; ***significant at $p<0.01$.

Corn yields were measure again in 1994. Significantly higher yields were abserved in sludge rates of 5 Mg ha^{-1} (72.9 Mg ha^{-1}) and 10 Mg ha^{-1} (92.9 Mg ha^{-1}) than control plots (52.2 Mg ha^{-1})

Grain N removal followed the trend observed for grain yields. The sewage sludge addition significantly increased grain N removal.

The application of sewage sludge increased ear-leaf N concentrations. Significant sludge effects occurred between application rates. A significant linear relationship was found between ear-leaf N and application rates. The level of ear-leaf N seemed normal. It was between the critical values of 28.2 g kg^{-1} reported by Steele et al. (1982) and the 23 g kg^{-1} reported by Dirks and Bolton (1980).

Ear-leaf P concentration was not significantly affected by the application of sewage sludge, although there was a slight increase as application rates increased. This was probably due to the fact that sewage sludge also supplied available P. Ear-leaf K was significantly increased in both trials, but Ca and Mg was not significantly affected by sewage sludge amendments in either study.

The addition of sewage sludge to soil had apparently increased of ear-leaf N concentration, grain yield, and grain N removal. The N from sludge mineralization likely contributed to these responses. The response of corn to sewage sludge has been reported in similar experiments on unmined lands. A single application of sewage sludge at rate 7.5 to 30 Mg ha^{-1} following sorghum-sudan significantly increased the corn dry-matter yield at all sludge application rates (Bouldin et al., 1984). Data for yield and N uptake indicate that mineralization of sludge N was supplying a significant amount of N for corn uptake. The amount of N recovered by crops reached 6 to 19 percent of the total N applied, and these values were generally lower than those found for conventional N fertilizer (Bouldin et al., 1984).

The experiment indicated that topsoil and subsoil sewage sludge amendments improved some soil physical, chemical, and biological properties, and crop N nutrition and yields.

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