A RECLAMATION APPROACH FOR MINED PRIME FARMLAND BY ADDING ORGANIC WASTES AND LIME TO THE SUBSOIL[1]

by

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Abstract. Surface mined prime farmland may be reclaimed by adding organic wastes and lime to subsoil thus improving conditions in root zone. In this study, sewage sludge, poultry manure, horse bedding, and lime were applied to subsoil (15-30 cm) during reclamation. Soil properties and plant growth were measured over two years. All organic amendments tended to lower the subsoil bulk density and increase organic matter and total nitrogen. Liming raised exchangeable calcium, slightly increased pH, but decreased exchangeable magnesium and potassium. Corn ear-leaf and forage tissue nitrogen, yields, and nitrogen removal increased in treatments amended with sewage sludge and poultry manure, but not horse bedding. Subsoil application of sewage sludge or poultry manure seems like a promising method in the reclamation of surface mined prime farmland based on the improvements observed in the root zone environment.

Additional Key Words: sewage sludge, poultry manure, horse bedding, liming, corn, forage.

Introduction

The use of organic amendments for mine spoil reclamation has been extremely successful (Seaker and Sopper, 1984) because of its immediate improvement of soil chemical, physical, and biological conditions, acceleration of plant establishment and growth, and achievement of long-term productivity. However, the results may be different for prime farmland reclamation because the soil physical, chemical, and biological properties of prime farmland are different from mine spoils. Currently, there are few studies that have quantitatively measured the effect of organic waste application to reclaimed prime farmland on soil properties and crop response.

Amending subsoil with organic wastes, such as sewage sludge, and lime may eliminate major factors limiting plant growth. Low amounts of available essential nutrients and extreme acidity (Dancer and Jansen, 1987), have been implicated in limiting post-mine plant growth. Subsoil acidity may be and important yield limiting factor (Sumner et al., 1986). It restricts roots from penetrating deeply into such soils (Adams and Moore, 1983). Organic amendments to subsoil may also decrease bulk density. Subsoil compaction often occurs during soil replacement by heavy equipment. Studies on the rooting behavior of row crops in mined soils of southern Illinois (Grandt, 1988) showed the plant root system was confined to the topsoil layer as a result of the adverse physical and structural

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properties of the subsoil. This, in turn, resulted in greater weather sensitivity for corn, resulting in significant yield reductions. Numerous studies have been reported which indicated that subsoil compaction during soil reconstruction by heavy equipment was an important factor limiting the postmine productivity for certain crops, especially row crops (Barnhisel, 1988).

The objectives of organic wastes and lime applications to subsoil for prime farmland reclamation are: (1) to enhance soil organic matter content and nutrient cycling in disturbed subsoil; and (2) to eliminate major factors limiting plant growth by improving subsoil properties.

Materials and Methods

Field procedures

This prime farmland was mined by TDC Coal Co. in Webster County, western Kentucky. The topsoil and subsoil were stored as separate stockpiles for two years. The soil series was the Loring (fine-silty, mixed, thermic Typic Fragiudalfs). The original topsoil and subsoil were replaced separately in the summer of 1990.

Prior to the application of the organic wastes to subsoil, the area was divided into two equal blocks (121.6 x 36.6 m) and agricultural grade limestone was applied at rate of 22.4 Mg ha^{-1} to one block. This lime rate was needed to raise the pH of 30 cm of subsoil to 6.5. Sewage sludge (33.6 Mg ha^{-1}), poultry manure (22.4, Mg ha^{-1}), and horse bedding (112 Mg ha^{-1}) were applied as separate treatments to the subsoil (plot size 30.4 x 36.6 m) prior to topsoil replacement. An control plot with the same size was also included for comparison. The rate of 33.6 Mg ha^{-1} for sewage sludge was the upper limit based on current regulations of N applied for "land farming" under the specifications associated with "permit by rule". The rate of poultry manure was based on recommendations of N need for corn when added to the soil surface (Steele, et al., 1982). The application rate for horse bedding was calculated to provide the same amount of total N as the poultry manure. All organic wastes and lime were incorporated into 0-15 cm of the subsoil with a chisel plow. Then topsoil (15 cm) was placed on the prepared subsoil. The entire area was broadcast with a mixture of alfalfa (*Medicago sativa* L.), red clover (*Trifolium hybridum* L.), and tall fescue (*Festuca arundinacea* Schreb.) on 17 August 1990 at seeding rates of 10.2, 10.2, and 18.2 kg ha^{-1}, respectively.

In May 1991, the limed and unlimed blocks were each divided into two equal parts. One part was sprayed with a mixture of atrazine (4WDL) and 'Roundup' at rates of 3.0 and 1.8 L ha^{-1} , respectively, then corn (*Zea mays* L.) was planted at seeding rate of 59,000 kernels ha^{-1}, Corn was also planted the following year on 25 May. In 1993, the forage was killed by atrazine and 'Roundup' and entire area was planted to corn. Fertilizer was applied uniformly to corn each year. Nitrogen, P, and K fertilizers were surface broadcast at rates of 165, 120, and 120 kg ha^{-1}. These blocks were further divided into four subblocks (4.75 x 30.4 m) for multiple yield measurements and observations of soil preperties (not true replications). Subsoil (15-30 cm) was sampled using a tractor-mounted Giddings coring machine for determination of physical and chemical properties on 15 June of 1991, 8 July 1992, and 20 November 1993 for biological properties.

Soil analyses

Soil bulk density was determined by Blake and Hartge, except that the core size was 4.25 cm (1986). Water-holding capacity was determined using the method developed by Klute (1986).

Four separate samples were collected from the subblocks (4.75 x 36.6 m) within each waste treatment. 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) which has been commonly used in Kentucky for disturbed land. 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). 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

Forage tissue (five samples collected for each treatment) and corn ear-leaf (four samples collected for each treatment) were sampled and dried under vacuum at 65°C. These samples were ground with a Thomas-Wiley mill, pass a 0.425 mm sieve and stored in plastic bags. The samples were then analyzed for N, P, K, Ca, and Mg. Nitrogen and P in plant tissue were determined based on the micro-Kjeldahl method as presented by Jones and Case (1990). Potassium, Ca, and Mg were determined using the nitric-perchloric wet-ashing procedure (Jones and Case, 1990). Element concentrations were determined using an Instrumentation Laboratory S 11 Atomic Absorption Spectrometer.

Statistical analyses

Statistical analyses were performed using the Statistical Analysis System (SAS Institute, 1985). The General linear Model (GLM) procedure was used to obtain the analyses of variance.

Results and Discussion

Soil response

Selected physical and chemical properties of subsoil (15-30 cm) are shown in Table 1 for 1991 and Table 2 for 1992. Subsoil bulk densities were reduced by all organic treatments compared to check plots in 1991. The horse bedding treatment had a lower bulk density than the control in 1992 (two years after waste application) compared to other organic treatments. All three organic amendments increased the recent organic matter, total N, and Bray-P in 1991 and 1992. However, organic amendments generally did not affect water holding capacity, CEC, and exchangeable bases (Ca, Mg, K, and Na). Liming significantly increased exchangeable Ca, but pH and CEC were not significantly increased. Subsoil liming also tended to decrease exchangeable Mg and K, but there were no significant differences between limed and unlimed treatments.

Total soil heterotrophic and facultative anaerobic organisms, microbial biomass C, and respiration rates are given in Table 3. Total heterotrophic and facultative anaerobic organism population, biomass C, and respiration rate were still higher than the check after three years following waste application. The horse bedding treatment had significantly high values among these microbiological parameters. This was probably due to the high amount of carbon added to the subsoil

Table 1. Physical and chemical properties affected by organic wastes and lime application to subsoil (15-30 cm) on 15 June 1991.

Trt	BD† (g/cm^3)	WHC (%)	pH	OM (%)	TN (---mg/kg--)	Bray-P	CEC (--------	Ca	Mg coml(+)/kg	K ---	Na ------)
SS	1.35^{b}	22.0^{a}	4.83^{a}	1.10^{b}	740^{b}	16.0^{a}	11.6^{a}	6.01^{a}	1.18^{a}	0.16^{a}	0.09^{a}
PM	1.30^{b}	20.7^{a}	4.99^{a}	1.41^{b}	766^{b}	21.6^{a}	12.1^{a}	6.19^{a}	1.38^{a}	0.20^{a}	0.11^{a}
HB	1.19^{c}	23.4^{a}	6.07^{a}	2.31^{a}	933^{b}	15.6^{a}	11.2^{a}	6.59^{a}	1.52^{a}	0.35^{a}	0.14^{a}
CK	1.55^{a}	24.5^{a}	4.51^{a}	0.84^{b}	466^{b}	3.4^{b}	11.8^{a}	5.08^{a}	1.03^{a}	0.17^{a}	0.09^{a}
UL	1.34^{a}	23.8^{a}	4.67^{a}	1.52^{a}	747^{b}	13.3^{a}	11.5^{a}	5.22^{a}	1.48^{a}	0.23^{a}	0.12^{a}
L	1.35^{a}	21.5^{a}	5.53^{a}	1.29^{a}	705^{b}	15.0^{b}	11.8^{a}	6.71^{a}	1.07^{a}	0.21^{a}	0.09^{a}

† BD, bulk density; WHC, water holding capacity; OM, organic matter content; TN, total nitrogen content; SS, sewage sludge; PM, poultry manure; HB, horse bedding; CK, check plot; UL, unlimed; and L, limed treatment. Comparison within the same column at p<0.1.

Table 2. Physical and chemical properties affected by organic wastes and lime application to subsoil (15-30 cm) on 8 June 1992.

Trt	BD† (g/cm^3)	WHC (%)	pH	OM (%)	TN (---mg/kg--)	Bray-P	CEC (--------	Ca	Mg coml(+)/kg	K ---	Na ------)
SS	1.48^{a}	24.6^{a}	6.02^{a}	1.21^{b}	852^{b}	7.8^{a}	11.5^{a}	5.73^{a}	1.40^{a}	0.18^{a}	0.10^{a}
PM	1.51^{a}	23.4^{a}	6.84^{a}	1.37^{b}	930^{b}	14.2^{a}	12.0^{a}	6.74^{a}	1.51^{a}	0.22^{a}	0.14^{a}
HB	1.37^{b}	21.6^{a}	6.40^{a}	2.32^{a}	1052^{b}	13.2^{a}	11.2^{a}	6.38^{a}	1.73^{a}	0.22^{a}	0.12^{a}
CK	1.51^{a}	23.4^{a}	6.28^{a}	0.90^{b}	685^{b}	3.7^{b}	11.0^{a}	6.10^{a}	1.50^{a}	0.19^{a}	0.08^{a}
UL	1.43^{a}	22.5^{a}	6.21^{a}	1.64^{a}	997^{a}	13.1^{a}	11.2^{a}	5.73^{b}	1.71^{a}	0.28^{a}	0.07^{a}
L	1.51^{a}	23.9^{a}	6.56^{a}	1.26^{a}	762^{a}	13.4^{b}	11.7^{a}	6.74^{a}	1.36^{a}	0.22^{a}	0.14^{a}

† BD, bulk density; WHC, water holding capacity; OM, organic matter content; TN, total nitrogen content; SS, sewage sludge; PM, poultry manure; HB, horse bedding; CK, check plot; UL, unlimed; and L, limed treatment. Comparison within the same column at p<0.1.

Table 3. Total heterotrophic and facultative anaerobic organisms, microbial biomass, and respiration rates after organic wastes and lime application to subsoil.

Trt	Total Heterotrophs (10^5/g)	Facultative Anaerobes (10^5/g)	Microbial Biomass (C) (mg/kg)	Respiration Rate (mg CO_2/kg h)
Sewage sludge	2.4 b†	0.59 ab	117 b	15.7 b
Poultry manure	3.0 b	0.41 b	103 b	14.1 bc
Horse bedding	11.6 a	0.92 a	187 a	20.1 a
Check	0.1 b	0.06 b	75 b	12.4 c
Unlimed	3.2 a	0.46 a	105 a	15.5 a
Limedb	5.3 a	0.53 a	136 a	15.6 a

† Comparison within the same column at p<0.1.

that could have enhanced microbial activity and development. Second attributing factor may be the higher application rate (112 Mg ha^{-1}) compared to the rates used for sewage sludge (33.4 Mg ha^{-1}) and poultry manure (22.4 Mg ha^{-1}). Another possibility is that lower microbial activity in sewage sludge and poultry manure treatments is due to effect of time, these observations were made three years after the wastes were applied. The results would be different if the microbiological activities were observed soon after application of organic wastes. Decomposition and mineralization rates are usually faster, particularly for poultry manure than horse bedding, as most of the sewage sludge and poultry manure materials were mineralized after three years (Zhai et al., 1993). Subsoil liming did not significantly affect microbial activity. This is probably due to that microbial activity and development is usually confined below pH 4.5 (Tate, 1985).

Corn response

Results for corn grain yield, N removal, ear-leaf element concentrations are presented in Tables 4, 5, and 6 for 1991, 1992, and 1993, respectively. The grain yield and N removal were significantly affected by the different subsoil amendments. Yields were generally higher for sewage sludge and poultry manure treatments than for the check. The horse bedding treatment had the lowest yield over all three years. This is likely due to the high C:N ratio of horse bedding reduced N availability (Zhai et al., 1993). Corn plants in the horse bedding plot were more chlorotic, especially during the grain filling period. Reduced N availability in horse bedding treatment was also shown in an N mineralization-immobilization study in which net immobilization was observed (Zhai et al., 1993).

Average corn yields for all treatments were higher in 1992 than 1991 or 1993. The yields of all treatments in 1991 (Table 4) were far below 6.70 Mg ha^{-1} which is the critical value for Phase III bond release of a reconstructed prime farmland. This was due to heavy rain in planting time which reduced seed germination. The late planted corn in 1991 (two weeks later than normal) suffered moisture stress in the growing season, particularly at the grain filling stage during late July and August.

Table 4. Ear-leaf composition, grain yield, and N removal in 1991 as affected by organic waste application and liming of subsoil.

Trt	Ear-leaf N	P	K	Ca	Mg	Grain Yield	N Removal
	(-------------	g/kg	-------------		)	(Mg/ha)	(kg/ha)
SS†	27.6a‡	2.69a	21.6a	5.89a	2.98a	3.91a	99.2a
PM	25.0a	2.39a	20.1a	5.96a	3.22a	3.35ab	77.1b
HB	20.4b	1.83a	20.3a	5.88a	2.56a	2.31c	58.7b
CK	22.7b	2.03a	19.1a	5.81a	2.97a	3.02bc	58.8b
L	24.4a	2.35a	21.1a	6.05a	3.14a	2.58a	63.1b
UL	23.5a	2.11a	19.5a	5.71b	2.72a	3.72a	83.8a

† SS, sewage sludge; PM, poultry manure; HB, horse bedding; CK, check; L, limed; UL, unlimed.

‡ Comparison within the same column at $p<0.1$.

The ear-leaf N concentration has been repeatedly used as an indicator of the N nutrition of the corn crop (Dirks and Bolton, 1980). Ear-leaf N concentrations found in this study were different, depending on organic amendment. Higher ear-leaf N concentrations were observed for sewage sludge and poultry manure treatments than for the unamended check and horse bedding treatments (Tables 4 and 5). The ear-leaf N concentrations in all organic amendment treatments were generally not much different from that of the check in 1993 (Table 6). Subsoil liming consistently improved ear-leaf N, though not significantly.

Table 5. Ear-leaf composition, grain yield, and N emoval in 1992 as affected by organic waste application and liming of subsoil.

Trt	Ear-leaf N	P	K	Ca	Mg	Grain Yield	N Removal
	(---	---	g/kg	---	---)	(Mg/ha)	(kg/ha)
SS†	25.7a‡	3.02a	20.2a	3.51a	2.13a	9.57a	ND
PM	23.6b	2.81a	23.7a	3.31a	1.63a	8.92ab	ND
HB	15.9c	2.20a	19.3a	3.03a	1.68a	7.19b	ND
CK	22.8b	2.55a	20.1a	3.14a	1.85a	8.11ab	ND
L	22.8a	2.84a	21.7a	3.40a	1.84a	8.30a	ND
UL	21.2a	2.46a	20.1a	3.09b	1.80a	8.68a	ND

† SS, sewage sludge; PM, poultry manure; HB, horse bedding; CK, check; L, limed; UL, unlimed; ND, not determined.

‡ Comparison within the same column at $p<0.1$.

Table 6. Ear-leaf composition, grain yield, and N removal in 1993 as affected by organic waste application and liming of subsoil.

Trt	Ear-leaf N	P	K	Ca	Mg	Grain Yield	N Removal
	(---	---	g/kg	---	---)	(Mg/ha)	(kg/ha)
SS†	21.8a‡	2.71a	20.2a	4.23a	2.10a	4.81a	74.0a
PM	21.7a	2.60a	19.5a	3.60a	1.19a	3.40b	57.1b
HB	19.7a	2.50a	19.0a	3.93a	1.95a	2.67b	45.3c
CK	22.0a	2.79a	19.5a	4.23a	1.68a	1.89c	25.8c
L	23.6a	2.87a	19.7a	4.55a	1.97a	3.18a	50.6a
UL	19.0a	2.44a	19.4a	3.45a	1.85a	3.21a	50.4a

† SS, sewage sludge; PM, poultry manure; HB, horse bedding; CK, check; L, limed; UL, unlimed.

‡ Comparison within the same column at $p<0.1$.

Average values for ear-leaf N were similar. Steele et al. (1982) reported critical values of 28.2 g kg^{-1} for ear-leaf N concentration. Dirks and Bolton (1980) found the level of leaf N was a good predictor of corn grain yields, and that the ear-leaf N concentration of adequately N fertilized corn had values in excess of 23 g kg^{-1}. Asghari and Hanson (1984) found higher critical values of ear-leaf N (29.3 g kg^{-1}). In this study, ear-leaf N for horse bedding ranged from 15.9 to 20.4 over three years. This suggests that a N shortage was probably a major yield limiting factor in this treatment.

Potassium, Ca, and Mg were not consistently affected by organic amendments. Subsoil liming increased P and Ca nutrition throughout the three-year period, though not significant. Potassium and Mg were essentially unaffected by liming.

Forage response

Results for forage yield, N removal, tissue element concentrations for first cutting in 1991 and 1992 are presented in Tables 7 and 8, respectively. Because the results of chemical composition were similar to those of second and third cuttings, only first cutting data was presented each year. Yields were generally higher for the sewage sludge and poultry manure treatments than that for the check, but the horse bedding treatment was usually not significantly different from the check across harvests in both 1991 and 1992. Subsoil liming did not significantly affect forage yield and N removal although limed treatments had slightly higher yield and N removal.

In 1991, higher tissue N concentrations were observed for sewage sludge and poultry manure treatments than check plots (Table 7). There was not much difference between the horse bedding treatment and the check plot. Similar results were also observed for the harvest in 1992 (Table 8). Phosphorus concentrations increased in poultry manure and sewage sludge treatments as compared to the check in the first year, but were not as significant as for N. There was not much difference in P, K, Ca, and Mg concentrations between the horse bedding and the check treatments. Potassium, Ca, and Mg were not consistently affected by organic amendments throughout the study period.

Table 7. Forage tissue, yield, and N removal of first harvest in 1991 as affected by organic waste application and liming of subsoil.

Trt	Forage Tissue					Forage	N
	N	P	K	Ca	Mg	Yield	Removal
	(--------------	g/kg	--------------		)	(Mg/ha)	(kg/ha)
SS†	29.7a‡	2.77a	22.7a	2.70a	2.81a	6.36a	189.7a
PM	27.3b	2.34a	19.4a	2.72a	2.73a	5.99a	160.7b
HB	24.9c	2.23b	21.1a	2.70a	2.66a	4.77b	120.1c
CK	25.2c	2.17b	20.2a	2.68a	2.65a	5.22b	130.1c
L	26.8a	2.87a	21.1a	2.83a	2.59a	5.72a	153.8a
UL	26.7a	2.44a	20.5a	2.55a	2.84a	5.45a	146.5a

† SS, sewage sludge; PM, poultry manure; HB, horse bedding; CK, check; L, limed; UL, unlimed.

‡ Comparison within the same column at $p<0.1$.

Table 8. Forage tissue, yield, and N removal of first harvest in 1992 as affected by organic waste application and liming of subsoil.

Trt	Forage Tissue					Forage	N
	N	P	K	Ca	Mg	Yield	Removal
	(--------------	g/kg	--------------		)	(Mg/ha)	(kg/ha)
SS†	18.1a‡	3.02a	24.5a	3.19a	2.25a	6.41a	118.3a
PM	20.2ab	3.07a	25.1a	3.80a	2.11a	6.66a	135.1a
HB	13.3b	2.97a	25.9a	3.35a	2.00a	5.66b	75.2 b
CK	13.8b	2.85a	23.8a	3.70a	2.20a	5.97b	82.8 c
L	17.2a	3.11a	24.4a	3.73a	2.10a	6.32a	110.3a
UL	15.5b	2.84a	25.3a	3.34a	2.18a	6.03a	95.2 a

† SS, sewage sludge; PM, poultry manure; HB, horse bedding; CK, check; L, limed; UL, unlimed.

‡ Comparison within the same column at $p<0.1$.

Subsoil liming slightly increased forage tissue N concentrations in 1991 (Table 7). However, liming effects were not significant. Subsoil liming always increased Ca, but did not consistently affect P, K, and Mg.

Overall, the sewage sludge, poultry manure, and horse bedding applications to subsoil tended to lower the subsoil bulk density and increase the soil organic matter and total nitrogen, as well as promoted microbial activities. Surprisingly,- subsoil liming produced small increases in subsoil pH and exchangeable Ca, decreased exchangeable Mg and K, and these effects usually were not significant as reported by Sumner et al. (1988). Sewage sludge and poultry manure treatments showed higher N nutrition and yield for corn and forage. Results from this study suggest that subsoil amendments of sewage sludge and poultry manure to reclaim prime farmlands are a beneficial practice in terms of improving some soil properties, particularly N and P status, as well as plant N nutrition and yields.

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