THE USE OF ORGANIC AMENDMENTS IN THE RESTORATION OF PRIME FARMLAND[1]

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Abstract - - Organic matter status of reconstructed soils will usually decrease during removal, storage, and redistribution operations. This will, in turn, decrease the initial productivity. We initiated a study to evaluate the effectiveness of adding organic matter amendments to the surface horizon of reconstructed prime farmland on crop yields and changes in soil properties. Dried sewage sludge and Real Earth® (a commercially-available, dried sewage sludge/garbage compost) were applied to reconstructed soil at rates of 10 and 20 dry tons per acre for each material and compared to a non-amended control. Soil ripping was introduced as a split treatment. Yield of grain sorghum was highest for sludge-amended plots, followed by control, followed by Real Earth®, applications. Yield of corn was highest for sludge-amended plots, followed by Real Earth® and by the control. Soil ripping increased yields of both grain sorghum and corn regardless of organic matter amendment. Target level yields were exceeded for grain sorghum on sludge-amended and ripped plots the first year after soil reconstruction. This was attributed to the ability of organic matter additions to decrease soil acidity, increase soil organic matter content, increase soil N, P, and Ca, and the ripping treatment's ability to effectively reduce soil bulk density.

Additional Key Words: Reclamation; Sewage Sludge; Real Earth®; Soil Ripping; Grain Sorghum; Corn; Soil Chemical Properties; Soil Physical Properties; Grain Analysis

Introduction

A significant amount of progress has been made within the past five years pertaining to restoration of prime farmland disturbed by surface mining. Factors such as soil depth replacement, method of soil reconstruction, soil-stabilizing crops, fertility adjustments, and plant varietal selection can influence crop yield. From observations of these yet-to-be published experiments, we have determined that topsoil quality is not always optimum for prime farmland reconstruction in Kentucky for several reasons. First, the A horizon thickness for most prime soils ranges from 15-25 cm thick, and a layer of this thickness is relatively difficult to remove exclusively from the underlying B horizon with scraper pans. Second, the natural decrease in organic matter content with increasing soil depth, and the relative difficulty of completely segregating the A horizon from the underlying subsoil, results in a significant reduction in organic matter of the topsoil. This effect is more pronounced for upland soil series. An organic matter content of 2 percent would be typical for the upper 25 cm of soil, decreasing to around 0.25 percent for the 25 to 50 cm increment. Third, topsoil is typically stored in soil stockpiles for relatively long periods of time, in some instances 3 years or more, before it is redistributed. Of course other chemical and physical properties are altered by the mixing of the A horizon with underlying subsoil materials.

Applications of organic materials such as sewage sludge, manure, and other organic wastes should enhance the reclamation of surface-mined areas. An increase of organic matter content of a soil that was otherwise low should promote soil structure formation, increase water-holding capacity, increase infiltration rate, decrease bulk density, and decrease erosion potentials. All of these attributes are important to the restoration of the yield potential of reconstructed prime farmland.

Studies by Speaker and Sopper (1984) and Topper and Sabe (1986) have shown that applications of organic matter (sewage sludge) to mined-land will lead to lasting positive effects in relation to plant growth. Berry (1985) reported that trees (loblolly pine) grew taller and produced greater stem diameters on mine soil that had been amended by organic matter applications. Since studies pertaining to organic amendments and their effect on the restoration of "row crop" productivity on

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reconstructed prime farmland are few, we initiated a study to test the use of organic amendments for restoration of reconstructed prime farmland row crop productivity potential.

Methods

During the fall of 1983 a block of prime farmland was reconstructed by standard state-of-the-art scraper operations at River Queen Mine, Muhlenberg County, Kentucky. The final soil profile consisted of mixed acid spoil (fragmented sandstone, shale, siltstone, and mudstone) which had been covered by a lift of subsoil (mixed fine-silty) with a mainly silt loam texture to a depth of approximately 30 inches. The lift of subsoil was capped with 8 inches of predominately A horizon material which had a silt loam texture with an organic matter content which averaged 1.5 percent. After reconstruction of the soil horizons, the area was limed with agricultural limestone at a rate of 1.5 tons per acre, incorporated to a depth of 7 inches with a disk harrow, and allowed to overwinter.

During April of 1984 a plot area with dimensions of 130 by 530 feet was located on the reconstructed block. The entire area received 350 and 200 pounds per acre of triple super phosphate and muriate of potash, respectively. The fertilizers were then incorporated into the soil by a single pass of a disk harrow. Within this area the main plots and split plots were established in late May. Main plots were 30 by 60 feet and split treatments were 30 by 30 feet.

The main treatments included (1) a control (no organic amendment), (2) 10 tons per acre (dry wt. basis) of sewage sludge, (3) 20 tons per acre of sewage sludge, (4) 10 tons per acre of Real Earth® (a commercially-available, garbage/sewage sludge compost[3]), and (5) 20 tons per acre of Real Earth®. Before the organic amendments had been applied, the main treatment blocks were split (30 by 30 feet) with one-half of each treatment being ripped with a Rome® ripper. The ripper had 4 shanks spaced approximately 30 inches apart and the ripping depth was approximately 24 inches. The organic amendments were then applied to the soil surface of their appropriate area and incorporated by a single pass with a disk harrow. Both the sludge and the Real Earth® materials were applied with a spreader truck. The control plot received an application of 240 pounds per acre of N. This value represents the estimated N that would be released from the highest sewage sludge treatment.

On, June 6, 1984, Northup King® 1580 grain sorghum (*Sorghum bicolor* (L.) Moench) was planted with a John Deere® conservation planter into 30-inch rows at a rate of 8 pounds per acre. Atrazine® was broadcast applied at a rate of 1.5 pounds active ingredient per acre for weed control. Sorghum was harvested in the fall and yield determined. After harvest of the grain sorghum had been completed, the sorghum residue was shredded by a rotary mower and left as an overwinter mulch.

In April of 1985, corn (*Zea mays* L.) was planted into 30-inch rows at a population of 21,000 kernels per acre. A John Deere® conservation planter was used and the variety tested was Pioneer® 3184. Nitrogen was applied to all plots at the time of planting by row placement of 80 pounds per acre of actual N as ammonium nitrate. The corn was harvested in the fall and yield determined.

Elemental analyses were performed for harvested grain sorghum and corn, and soil samples were taken and analyzed to monitor changes in both soil chemical and physical properties.

Soils were extensively sampled approximately one year after organic matter additions and soil ripping operations. A hydraulic probe was used to obtain undisturbed cores from each replication of each main and split treatment. Cores were taken to an approximate depth of 30 inches and partitioned into six-inch increments for appropriate chemical and physical analyses.

Results and Discussion

A yield response for grain sorghum was obtained in 1984 for both ripping and organic matter amendments and these data are given in Table 1. Bond release target yield for grain sorghum is approximately 75 bushels per acre for Sadler soil. The mean yield averaged for all main treatments was 47.1 bushels per acre for non-ripped treatments as compared to 67.4 bushels per acre for ripped treatments. For both ripped and non-ripped sub treatments the 10-ton per acre rate of sewage sludge was significantly higher in yield than either of the Real Earth® treatments. Both ripped and non-ripped control treatments had numerically higher yields (though not statistically significant) than either of the Real Earth® treatments. The manufacturer of this material claims continuous nitrogen release as one of the advantages of this material. Apparently this was not the case for crop year 1984. The 10-ton per acre rate of sewage sludge outyielded (though not significantly) the 20-ton per acre rate of sewage sludge. Had this been a "bond release" year, the target level yield of 75 bushels per acre would have been attained only for the ripped subtreatments at of both rates of sludge. The sorghum produced was the first crop of any type produced on this reconstructed soil, i.e., no soil-stabilizing perennial crop had been produced prior to grain sorghum production.

Table 1. Yield of grain sorghum as a function of organic matter amendment and soil ripping.

Treatment	Rate	Ripping Treatment	
	(tons/a)	(non-ripped)	(ripped)
Sewage Sludge	10	58.9 a*A	88.3 a B
Sewage Sludge	20	57.0 a A	81.7 abB
Real Earth®	10	37.3 b A	57.4 bcA
Real Earth®	20	34.3 b A	52.0 c A
Control	0	47.9 abA	57.6 bcA
Treatment Mean		47.1 A	67.4 B

*Means followed by same letter are significantly different at alpha = 0.10. Small case letters are for comparisons of main treatment within ripping or non-ripping. Large case letters are for comparisons between columns, ripped versus non-ripped for any given treatment.

Corn yields obtained in 1985 were without further applications to determine if there were

3 The use of trade names or products in this report does not indicate a preference or endorsement of these products or the exclusion of similar products.

residual effects from ripping and organic matter amendments, and these data are given in Table 2. For all cases except the non-ripped subtreatments of the 10-ton per acre rate of Real Earth®, organic amendments increased yields above the control. For non-ripped subtreatments, the two rates of sewage sludge produced a higher corn yield than did the two rates of Real Earth®. As would be expected, the 20-ton per acre of sewage sludge produced the highest overall yield within non-ripped subtreatments. In general, yields for ripped plots were higher than those obtained from non-ripped plots, but the relative increase (10%) attributed to soil ripping was less than the relative increase obtained for grain sorghum during the preceding year. Two factors may account for this. First, there were no prolonged dry periods during the 1985 growing season, and secondly, nitrogen fertilizer was applied to all corn plots in 1985 at the same rate. Both of these attributes probably lessened the "positive effects" of both organic matter amendments and soil ripping.

Table 2. Yield (bushels per acre) of corn as a function of organic matter amendment and soil ripping.

Treatment	Rate	Ripping Treatment		Ave. Treat.
	(tons/a)	(non-ripped	(ripped)	
Sewage Sludge	10	69.8ab*A	77.0a A	73.4
Sewage Sludge	20	75.9a A	71.0a A	73.5
Real Earth®	10	53.9c A	78.6a B	66.3
Real Earth®	20	63.5abcA	67.6a A	65.6
Control	0	59.5bc A	63.5a A	61.5
Split Treat Mean		64.5 A	71.5 A	

*Means followed by same letter are significantly different at alpha = 0.10. Small case letters are for comparisons of main treatment within for ripping or non-ripping. Large case letters are for comparisons between columns, ripped versus non-ripped for any given treatment.

The target level yield of corn would have been 90 bushels per acre had this been a "bond release" year. Obviously, none of the treatments equalled or exceeded the target yield. Technically, the 1985 growing season had a very high yield potential for corn. A good stand was attained, ears were large and well filled. However, the insecticide did not adequately control corn root worm, and, in addition, corn borer damage was very severe. Severe lodging prior to combine harvest reduced corn yields substantially. The lodging losses seemed to be most severe in the sludge-amended and ripped plots, but lodging estimations were not made. In any event, corn yields of this magnitude (greater than 70 bushel per acre average for ripped subtreatments) are very good considering that these yields were attained on recently reconstructed land.

Chemical analyses were performed on harvested grain of both grain sorghum and corn. A number of elements were monitored to assess accumulations of heavy metals that may occur from the sludge or Real Earth® applications. No unacceptable accumulations of heavy metals occurred, so these values will not be reported.

Table 3 presents results of grain analyses for N, P, and K. Grain concentrations of N were generally highest in control plots, P concentrations were generally higher in plots amended with Real Earth® (except for corn in the ripped subtreatment), and K concentrations were generally similar. Since the yield trend for both corn and grain sorghum followed sludge, greater than Real Earth®, equal to control, it is fairly obvious that grain concentrations of N, P, and K do not exhibit this same trend. This can be explained by the "dilution" effect. Plants from higher yielding plots will generally show lower levels of these elements because much more dry matter is produced, which will tend to "dilute" tissue concentrations of plant nutrients. Since significant yield responses were attained for both crops for both main treatment and ripping subtreatments, it is obvious that these responses were occurring as an indirect result of soil properties being affected by organic matter additions and soil ripping. Ripping may have allowed greater aeration of O.M. amended plots which released more N during grain filling as shown by the increased N concentrations.

Total N analyses of grain sorghum indicated that highest nitrogen concentrations came from grain harvested from the control plots. This was expected, as control plots received a very heavy application of N fertilizer. In general, the nitrogen content of the grain reflected the magnitude of the organic matter amendment treatment. For the non-ripped subtreatments, N levels of the grain from plots receiving 20 tons of sludge were greater than those receiving 10 tons of sludge. Likewise, N levels from plots receiving 20 tons Real Earth®, were greater than those receiving 10 tons of Real Earth®, however, these differences were not statistically significant. This trend was somewhat reversed for the ripped subtreatments. Grain from plots receiving sludge were significantly higher in N than grain from Real Earth® plots. The corn grain analyzed did not exhibit significant differences in nitrogen between either main treatment or split treatment. Remember that N fertilizer was applied equally to all corn plots at the time of planting, and this would diminish any residual effects of nitrogen release from the organic matter treatments.

Phosphorus levels of harvested grain exhibited some significant differences between treatments. For grain sorghum grown on the non-ripped subtreatment, both rates of Real Earth® and the highest rate of sludge showed significantly higher P levels in the grain than those of the control plot. The same trend was evidenced in the ripped subtreatments, but the differences were not statistically significant. In general, Real Earth® treatments showed higher P levels in grain of sorghum than did sewage sludge treatments. This same trend was found for corn for the non-ripped subtreatments, but the reverse was true for the ripped subtreatments. In this case the corn grain from the 10-ton rate of sewage sludge showed significantly higher P content than did grain from plots receiving the 20 ton rate of Real Earth®.

Potassium concentrations of harvested grain also showed significant differences. For grain sorghum, K concentration of all Real Earth® treatments was significantly higher than for all sewage sludge treatments and the control treatment for both the ripped and non-ripped subtreatments. For corn produced in the following year from these same plots, these differences had diminished and no significant differences of K content in grain were exhibited in the non-ripped subtreatments. However, for the ripped subtreatments, both rates

Table 3. Nitrogen, phosphorus and potassium percentages of grain from grain sorghum and corn plots as a function of organic amendments and soil ripping treatment.

Crop/Main Treatment	Nitrogen		Phosphorus		Potassium	
	NR*	R*	NR*	R*	NR*	R*
1984	- - - - - - - - - -	- - - - - - -	%	- - - - - - -	- - - - - - -	- - - - - -
Sorghum - 10 ton sludge	1.95bA**	2.18abA	0.29cA	0.29aA	0.25bA	0.26bA
Sorghum - 20 ton sludge	1.97abA	2.16abA	0.32bcA	0.27aA	0.24bA	0.24bA
Sorghum - 10 ton Real Earth®	1.93bA	1.81bcA	0.37abA	0.32aA	0.27abA	0.27abA
Sorghum - 20 ton Real Earth®	1.94bA	1.57cA	0.41aA	0.30aA	0.30aA	0.30aA
Sorghum - Control	2.20aA	2.54aA	0.25cA	0.29aA	0.24bA	0.25bA
1985	- - - - - - - - - -	- - - - - - -	%	- - - - - - -	- - - - - - -	- - - - - -
Corn - 10 ton sludge	1.36aA	1.59aA	0.29aA	0.35aA	0.28aA	0.31aA
Corn - 20 ton sludge	1.46aA	1.33aA	0.29aA	0.30abA	0.30aA	0.31aA
Corn - 10 ton Real Earth®	1.49aA	1.34aA	0.31aA	0.28abA	0.30aA	0.27abA
Corn - 20 ton Real Earth®	1.49aA	1.30aA	0.31aA	0.27bA	0.31aA	0.29abA
Corn - Control	1.67aA	1.58aA	0.29aA	0.28abA	0.30aA	0.24bB

*NR denotes non-ripped splits; R denotes ripped splits.
**Means followed by same letter are significantly different at alpha = 0.10. Small case letters are for comparisons of main treatment within for ripping or non-ripping. Large case letters are for comparisons between columns, ripped versus non-ripped for any given treatment.

of sludge and Real Earth® showed significantly greater K content in grain than the control treatment.

Space does not allow us to report all chemical analyses of soils from all incremental depths. However, we have reported the data of analyses from the surface soil samples (0-6 inch depth) because these, in part, explain many of the differences in grain yield. Table 4 and 5 report selected chemical properties and selected physical properties, respectively.

The most obvious properties affected by additions of organic matter are those related to soil acidity. Additions of sewage sludge and Real Earth® increased the pH of the soil and decreased total exchangeable acidity. Water pH and buffer pH (i.e., SMP lime requirement test results) for both ripped and non-ripped subtreatment were highest for the 20 tons of sludge rate and descended in order followed by 10 tons sludge, greater than 20 tons Real Earth®, greater than 10 tons Real Earth® greater than controls. This same trend was also true for total exchangeable acidity, except in the non-ripped subtreatment. In this case the 20-ton rate of Real Earth® had higher total exchangeable acidity than did the 10-ton Real Earth® rate. For the non-ripped subtreatment, the two rates of Real Earth® were not significantly lower in total exchangeable acidity than the control treatment.

Extractable Ca levels were related somewhat to the soil acidity data. For both ripped and non-ripped subtreatments, soil extractable Ca was significantly higher where sewage sludge was applied as opposed to Real Earth® and control treatments. The 20-ton rate of sludge was always significantly higher than the 10-ton sludge rate for both the ripped and non-ripped subtreatments. There was not a significant difference for extractable Ca levels between the two rates of Real Earth® for both the ripped and non-ripped subtreatments.

Differences observed for changes in pH, exchangeable acidity, and extractable Ca are probably related to the fact that in the sewage treatment process, calcium hydroxide is used to maintain the pH of the digestion at a desired level and/or to remove solids. Hence, both sewage sludge and Real Earth® have some liming benefits.

Extractable Mg levels were significantly different for some comparisons within the ripped subtreatment. Both Real Earth® treatments exhibited higher Mg levels than those from sewage sludge treatments or the control treatment. The 10-ton per acre rate of Real Earth® provided for a significantly higher level of soil extractable Mg than both sludge treatments, but the soil Mg level for the 20-ton rate of Real Earth® was not significantly higher than for the two rates of sludge. These differences in soil properties had no significant effect on Mg concentrations of the grain for either grain sorghum or corn, (data not shown). Since we did not collect vegetative samples of either corn or grain sorghum, we do not know if the differences in Mg levels of the soil caused difference in Mg levels of the plant tissues.

Total N and Bray-1P followed the same trends as that for Mg. Soil N and P content usually followed a descending order of 20 ton sludge > 10 tons sludge, > 20 tons Real Earth®, > 10 tons Real Earth®. Both rates of Real Earth® did not produce statistically different levels of N or P than those from control plots.

From inspection of data presented in Table 5, it is obvious that organic matter amendments had effects on critical soil physical properties. As would be expected, soil organic matter levels were raised by applications of organic amendments. The high rate of sludge (20 tons/acre) produced a significant increase in soil organic matter. It was also noted that ripped plots had slightly higher, although not significantly greater, organic matter contents than did non-ripped treatments, even though the ripping was performed prior to application of either sludge or Real Earth® treatments. It was assumed that the organic amendments were incorporated to a greater depth because of the much better "workability" of the ripped splits.

Water-holding capacity was not significantly affected by organic matter additions with ripped treatments. However, for the non-ripped treatments. The highest rate of sludge and the highest rate of Real Earth® both provided for a significantly higher water-holding capacity than the control.

Table 4. Selected chemical properties of soil as affected by organic amendments one year after application.

Main Treatment (Non-Ripped	Water pH	SMP Buffer pH	Total N	Total Acidity	Bray 1P	Extractable Cations K	Ca	Mg
			(lbs/a)	(meq./100g)	-----	---lbs/a---	-----	-----
				Non-Ripped				
10 Ton Sludge	5.16b*	6.53b	1897b	0.255bc	47.8b	167ab	1878b	376a
20 Ton Sludge	5.66a	6.66a	2165a	0.060c	119.0a	162b	2248a	345a
10 Ton Real Earth®	5.00bc	6.43bc	1672c	0.485ab	18.3c	181ab	1625c	404a
20 Ton Real Earth®	5.12b	6.46bc	1631c	0.553ab	21.3bc	188a	1543c	394a
Control	4.85c	6.35c	1798bc	0.680a	25.0bc	187a	1543c	364a
				Ripped				
10 Ton Sludge	5.44ab	6.63a	1884b	0.145b	67.8b	165a	1940b	350b
20 Ton Sludge	5.69a	6.66a	2162a	0.128b	139.3a	192a	2188a	325b
10 Ton Real Earth®	5.20b	6.54a	1617d	0.280b	22.0c	190a	1738c	437a
20 Ton Real Earth®	5.40ab	6.59a	1764c	0.110b	22.0c	197a	1755c	387ab
Control	4.80c	6.32b	1717cd	0.855a	15.8c	187a	1308a	370ab

*Means followed by same letter are significantly different at alpha = 0.10. The only comparisons that are valid are those within columns for ripped or non-ripped splits separately.

Table 5. Selected physical properties of surface 6 inches of soil as affected by organic amendment one year after application.

Main Treatment	Organic Matter		Water Holding Capacity		Bulk Density	
	--- % ---		--- % ---		-- (g/cc) --	
	NR*	R*	NR	R	NR	R
10 Ton Sludge	1.76abA**	1.73bA	26.6abA	25.7aA	1.54aA	1.49aA
20 Ton Sludge	1.93cA	2.03aA	27.3aA	26.6aA	1.51aA	1.44aA
10 Ton Real Earth®	1.54bA	1.65bA	26.8abA	26.8aA	1.56aA	1.47aA
20 Ton Real Earth®	1.64bA	1.77abA	27.4aA	25.6aA	1.54aA	1.49aA
Control	1.71abA	1.54bA	25.6bA	25.8aA	1.53aA	1.46aA
Main Treatment Mean	1.72(A)***	1.74(A)	26.7(A)	26.1(A)	1.54(A)	1.47(B)

* NR indicates non-ripped splits; R indicates ripped splits.
** Means followed by same letter are not significantly different at alpha = 0.10. Small case letters are for comparisons within columns. Large case letters are for comparisons between ripped and non-ripped splits of separate main treatments.
***The large case letters enclosed by parentheses are for comparing statistical significance of split treatments averaged for all other treatments. Means followed by same letter are not significantly different at alpha = 0.10.

Soil bulk density was not significantly affected by organic matter amendment. However, the overall effect of soil ripping, when averaged across all combinations of main treatments, did show a significant difference. In this case, the ripped treatments had significantly lower bulk densities than did the non-ripped treatments. This would allow for a more permeable soil and, coupled with the fact that sludge-amended plots increased soil organic matter, undoubtedly provided for a higher amount of water infiltration.

We contend that combinations of these various properties explain why yields were highest on sludge-amended soils. First, the sludge-amended soils exhibited more favorable physical properties in relation to soil organic matter content which increased infiltration. Chemically, the sludge-amended soils had higher pH, reduced total exchangeable acidity, and higher soil extractable N, P, and Ca levels. In addition, ripping treatments reduced soil bulk density so that plant roots could exploit the soil mass for moisture and nutrients. This was supported by the fact that grain analyses revealed generally lower values of grain N, P, and Ca for sludge-amended plots, but yet produced greatest yields. This indicated that the plants were producing dry matter with greater efficiency on sludge amended plots. Therefore, we contend that yield increases attained from organic amendments (and in particular sludge-amended plots) was from both direct (slow N release and high P content of added organic matter) and indirect (improvement of both chemical and physical properties of the soil) effects. It appears that soil ripping further increased the magnitude of these effects.

Conclusions

1 Additions of sewage sludge provided for increased yields of corn and grain sorghum.
2 Additions of Real Earth® provided for increased yields of corn and grain sorghum, but to a lesser extent than did sewage sludge.
3 Soil ripping increased yields for corn and grain sorghum (reduced bulk density).
4 Organic matter-amended soils were less acidic than non-amended soils.
5 Organic matter-amended soils had increased organic matter content, higher soil N, and higher extractable P levels.
6 Sludge-amended soils that had been ripped provided for attainment of target level yield one year after reconstruction of prime farmland.

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