CORN YIELD FROM AND PHYSICAL PROPERITES OF SOIL RECONSTRUCTED BY THE UNIVERSITY OF KENTUCKY *SOIL REGENERATOR*[1]

L.G. Wells[2] and S. Bodapati

Abstract. A 0.4 ha field was completely excavated to a depth of 900 mm at the University of Kentucky north research farm in 2006 and reconstructed during 2007 using the University of Kentucky *Soil Regenerator*. The *Soil Regenerator* is a mechanical system which mounts on a conventional bulldozer and works in coordination with scrapers or trucks to reconstruct soil while completely avoiding traffic compaction. The average measured soil reconstruction rate using the system is approximately 0.33 ha/hr.

Four treatments of soil reconstruction were implemented in triplicate plots: 1) A- and B-horizons mixed, no compost (AB); 2) A- and B-horizons mixed, 50 Mg/ha of compost mixed with soil (AB-C); 3) A-horizon (300 mm) placed over B-horizon (600 mm), with no compost (A/B); and 4) A-horizon (300 mm) mixed with 25 Mg/ha of compost placed over B-horizon (600 mm) mixed with 25 Mg/ha of compost (A/B-C)

Corn (*Zea Mays L.*) was grown on the plots during 2009, 2010 and 2011. In 2009, plot yield ranged from 12.08 to 16.65 Mg/ha, in 2010 from 10.37 to 12.72 Mg/ha and in 2011 from 10.15 to 13.43 Mg/ha. Standard analysis of variance indicated no treatment effect on corn yield at $\alpha = 0.05$, however, when yield data from all three years was pooled, treatment 1 yield was significantly less than the average yield of treatments 2, 3 and 4 ($\alpha = 0.05$). Although identification and harvesting of control plots (undisturbed soil) was not feasible in this study, average corn yield measured in the reconstructed plots was greater than the average yield recorded for the most proximate corn grown on the University of Kentucky north research farm during 2009 and 2010, while being slightly less in 2011.

Soil bulk density was measured using a dual-probe gamma/neutron soil moisture/density gauge. Measurements taken in 2008 indicated bulk density varied between 1.20 and 1.30 g/cm^3 in most plots. By 2009, bulk density had increased, exhibiting a range from 1.45 to 1.55 g/cm^3 and in 2011, the AB plots showed bulk density approaching 1.60 g/cm^3. Similarly, soil cone index (CI) was measured using multiple recording cone penetrometers. Cone index measured in 2008 ranged from 0.4 to 0.7 MPa, while in 2009 CI had increased to 0.8 to 1.2 MPa. All CI measurements were well below the 2.0 MPa magnitude associated with restricted crop root growth.

Additional Key Words: reclamation, prime farmland

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Introduction

Reconstruction of prime farmland has been a challenging component of surface coal mining in the U.S. and throughout the world. Societal concern regarding potential stream pollution and land degradation led to enactment of the 1977 Surface Mining Control and Reclamation Act (SMCRA, 1977). Regulations were promulgated by states under supervision of the U.S. Office of Surface Mining. Reclamation of prime farmland was given special emphasis by SMCRA, specifically requiring reconstruction of cropland to equal conditions existing prior to mining.

Successful reconstruction of cropland has been compromised by compaction of soil by heavy equipment during reconstruction operations. The use of scrapers and rubber tired haulers, which are used extensively for earthmoving operations such as highway construction and building site development, has proven problematic in reconstructing surface soils traversed by these machines due to extremely high axle loads. Dunker et al. (1988) measured penetration resistance in prime farmland soils reconstructed in western Illinois using two methods; a) placement of mixed A- and B- horizon with a bucket wheel excavator, and b) placement of B- horizon with bucket wheel excavator and placement of 450 mm of A-horizon using scrapers. Surfaces for both methods were graded by small bulldozers. Penetration resistance at a depth of 640 mm (25 in.) was 30% greater when scrapers were used to replace A-horizon. Corn (*Zea Mays L.*) yield was slightly greater when A-horizon was added, however, yield from both reconstruction methods was approximately 60% that of un-mined soil from that location.

Hooks et al. (1992) studied methods of soil reconstruction which attempted to minimize adverse compaction. Plots were constructed whereby B-horizon was placed on graded spoil using scrapers and trucks. In one treatment, B-horizon was placed by scrapers in layers 100-200 mm deep with requisite scraper wheel traffic. In the other treatment, trucks dumped B-horizon onto graded spoil and bulldozers leveled the surface. A-horizon [200 mm (8 in)] deep was placed atop the plots by three methods. On the scraper plots, scrapers deposited A-horizon along opposite boundaries of the plots and bulldozers spread the A-horizon across the plots. In one set of truck plots, trucks hauled A-horizon onto the plots, while on the other, trucks dumped A-horizon at opposite boundaries. Penetration resistance was highest in the scraper placed plots and lowest in the truck end-dumped plots where traffic was minimized. Average corn and soybean yield measured over six years was highest in the truck-with-minimum-traffic plots and lowest in the scraper plots. Yields from truck-with-minimum-traffic plots were slightly less than, but not significantly different from yields from an undisturbed nearby soil.

Dunker et al. (1995) studied the effect of deep tillage in alleviating adverse compaction of soil during replacement using scrapers. They applied tillage treatments using chisel implements reaching 200-350 mm and subsoiler treatments reaching depths from 800 to 1200 mm. In four of five years after tillage, corn yields from plots tilled to 1200 mm (47 in) were not significantly different from an undisturbed soil nearby, while yields were significantly lower in all the other tillage treatments.

University of Kentucky *Soil Regenerator*

Fulton et al. (2002) developed a concept for reconstructing soil after surface mining which utilized a powered auger in front of a modified conventional bulldozer blade (Fig. 1). Most of the power available from the bulldozer engine (rated at 150 kW) was required by the running gear so an auxiliary engine mounted on the rear of the bulldozer was used to produce about 75 kW needed to operate the hydraulic motor which powered the auger.

Scrapers were used to place soil atop a graded spoil base in long windrows. As the bulldozer moved forward, soil rose up the blade and the rotating auger displaced soil into a windrow. Soil in the windrow was displaced to the void beneath the auger extending beyond the right end on the blade. When the auger height was set at the same elevation as the top of a previously deposited soil layer, that layer would be extended leftward. For example, if a scraper deposited a windrow 0.3 m deep and 3.7 m wide and the bulldozer moved forward at 1.6 km/hr, the soil reconstruction rate would be 1776 m^3/hr.

Initial testing of the *Soil Regenerator* prototype revealed that the actual soil reconstruction rate was approximately 330 m^3/hr (430 yd^3/hr) Fulton et al. (2002). Later testing on a surface mine suggested that a reconstruction rate of 610 m^3/hr (800 yd^3/hr) could be achieved if critical improvements to the system were implemented Fulton and Wells, 2005. The auger was not capable of displacing soil at the rate of engagement as the bulldozer moved forward. Furthermore, because of variation in the volume of soil deposited in the windrows, maintaining a level surface of reconstructed soil was difficult.

Figure 1. The University of Kentucky *Soil Regenerator*.

Modifications of the *Soil Regenerator* are described by Bodapati and Wells (2012). The modifications included: remounting the blade at 94 degrees relative to the bulldozer azimuth, adding a movable extension on the left side of the blade and the addition of soil sensors at the end of the blade to control the length of the blade extension to modulate the volume of soil being displaced. They found that the modifications improved the levelness of reconstructed soil and increased reconstruction capacity to the target of 611 m^3/hr (800 yd^3/hr).

The objectives of this study, therefore, were:

1. To demonstrate that the modified *Soil Regenerator* can successfully reconstruct soil without traffic compaction.
2. To demonstrate that resulting levels of soil bulk density and soil strength remain at acceptable levels for crop production.
3. To determine effects of soil horizon segregation and compost addition upon corn yield in reconstructed plots.
4. To demonstrate that corn yield in plots reconstructed using the *Soil Regenerator* are greater than or equal to yield in undisturbed nearby cropland.

Experimental Procedure

Site Reconstruction

A 0.4 ha site at the University of Kentucky north research farm was completely excavated to a depth of 900 mm in 2006 in order to evaluate the University of Kentucky *Soil Regenerator* as a means of reconstructing severely disturbed prime farmland. The soil texture was silt loam. The A-horizon, approximately 300 mm deep, was removed from approximately one half of the site and stockpiled using a conventional scraper (Fig. 2). The B-horizon, approximately 60 cm (24 in) deep was also removed and stockpiled separately. On the remaining half of the site, A- and B-horizons were excavated simultaneously using the scraper and stockpiled as a mixture in a third location.

Figure 2. Excavating the experimental soil reconstruction site.

The site was divided into 12 plots for the purpose of determining the effects of mixing soil horizons and/or adding compost during soil reconstruction. Composted wheat straw bedding from a beef cattle research facility was used. Thus, the experimental treatments were:

- A- and B-horizons mixed, no compost (AB)
- A- and B-horizons mixed, 50 Mg/ha of compost mixed with soil (AB-C)

- A-horizon (300 mm) placed over B-horizon (600 mm), with no compost (A/B)
- A-horizon (300 mm) mixed with 25 Mg/ha of compost placed over B-horizon (600 mm) mixed with 25 Mg/ha of compost (A/B-C)

The experimental treatments were replicated three times and were assigned randomly determined locations within the site (Fig. 3). Each plot was 3.7 m wide and approximately 99 m long. Reconstruction was accomplished during May through September 2007.

Plots comprised of mixed A- and B-horizons were reconstructed as follows. The scraper would fill with soil from the mixed A- and B-horizons stockpile and deposit soil in a layer approximately 300 mm deep and 2.7 m wide. This was repeated until soil was deposited over the entire length of the site (99 m). The *Soil Regenerator* would then engage the deposited soil and displace it to create a 900 mm wide strip 900 mm deep. This process was repeated four times to create plots of reconstructed soil 900 mm deep and 3.7 m wide. For AB-C plots, compost was spread onto each layer of soil in appropriate amounts using a manure spreader prior to displacement by the *Soil Regenerator*.

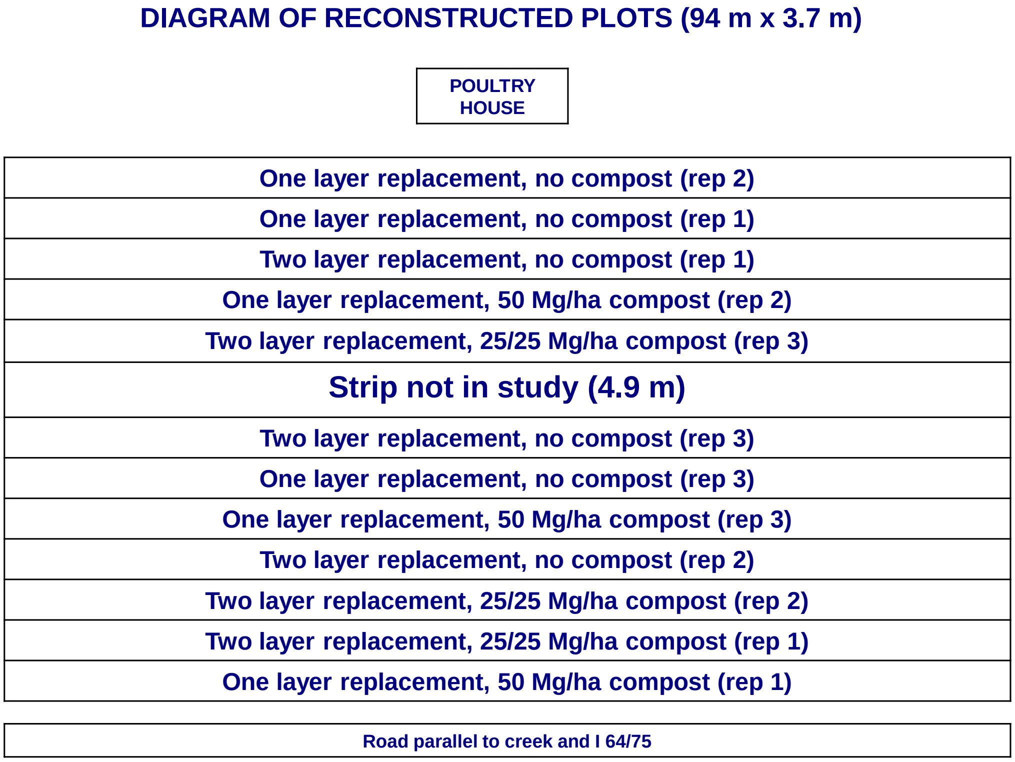

DIAGRAM OF RECONSTRUCTED PLOTS (94 m x 3.7 m)

POULTRY HOUSE

One layer replacement, no compost (rep 2)
One layer replacement, no compost (rep 1)
Two layer replacement, no compost (rep 1)
One layer replacement, 50 Mg/ha compost (rep 2)
Two layer replacement, 25/25 Mg/ha compost (rep 3)
Strip not in study (4.9 m)
Two layer replacement, no compost (rep 3)
One layer replacement, no compost (rep 3)
One layer replacement, 50 Mg/ha compost (rep 3)
Two layer replacement, no compost (rep 2)
Two layer replacement, 25/25 Mg/ha compost (rep 2)
Two layer replacement, 25/25 Mg/ha compost (rep 1)
One layer replacement, 50 Mg/ha compost (rep 1)

Road parallel to creek and I 64/75

Figure 3. Diagram of reconstructed soil plots.

Plots comprised of segregated A- and B-horizons were reconstructed as follows. The scraper deposited B-horizon onto the site base in strips 2.66 m wide and 0.40 m deep. The *Soil Regenerator* then displaced such strips into strips 0.61 m deep and 1.83 m wide. The scraper would then deposit A-horizon in a strip 2.74 m wide and 0.20 m deep adjacent to the B-horizon strip and the *Soil Regenerator* would displace the A-horizon atop the B-horizon to reconstruct soil with 0.30 m of A-horizon over 0.60 m of B-horizon. Again, compost was added when appropriate to deposited strips of A- and B-horizons prior to displacement by the *Soil Regenerator.*

The *Soil Regenerator* reconstructed soil at the approximate rate of 663 m^3/hr when mixing the A- and B-horizons. This would correspond to a rate of approximately 0.054 ha/hr when reconstructing soil to a depth of 1.22 m as mandated by SMCRA. The reconstruction rate is necessarily less when reconstructing A/B soil. While technically achievable without introducing traffic compaction of reconstructed soil, it may not be necessary or beneficial. A detailed evaluation of the operation of the *Soil Regenerator* is presented by Bodapati and Wells (2012).

The plots were hydro-seeded with milo and mulched after reconstruction in September 2007. No traffic was permitted on the plots until May 2008 when soil bulk density and cone index measurements were taken.

Measuring Soil Physical Properties

Soil bulk density was measured in the reconstructed plots using a dual probe nuclear soil moisture/density gauge (Fig. 4). Parallel vertical 25 mm diameter access holes 300 mm apart were created by a tractor-mounted mechanism. Gamma photon (Ce^{137}) and neutron sources (Am^{241}) and a neutron detector are mounted in one probe and a gamma photon detector is mounted in the other probe. The probes are lowered into the holes to the same depth to determine soil water content and soil bulk density. Soil dry bulk density is determined by subtracting bulk water density from wet soil bulk density.

Soil bulk density was measured at five locations in each plot 50 mm at depth intervals between 100 mm and 600 mm. Measurements were recorded in May 2008, April 2009 and June 2011.

Soil strength was also measured using soil cone penetrometer measurements. The measurements were recorded using a special apparatus by which five simultaneous measurements could be recorded at a location (Fig. 5). Fifty measurements of soil cone index were recorded in each plot at 100 mm depth intervals to a depth of 600 mm. Soil cone penetrometer measurements were recorded in May 2008 and May 2009. A final set of measurements will be recorded during 2012. All soil cone index measurements were made with soil moisture conditions near field capacity.

Measuring Corn Yield

Corn was planted in the plots during 2009, 2010 and 2011. Since soil reconstruction was completed in mid-2007, planting of the plots was delayed until 2009 to allow natural consolidation to occur. Standard fertilization, seeding and herbicide protocol was followed as per all fields planted on the University of Kentucky research farms. The corn grown on the reconstructed plots and in adjacent fields on the research farm was produced using no-till procedures.

Figure 4. Dual probe soil moisture density gauge with tractor-mounted apparatus to create vertical access holes.

Figure 5. Five probe mechanical soil cone penetrometer system.

Four 760 mm rows were planted in each plot. Yield was measured by harvesting each plot and then emptying grain into a wagon equipped with a weighing system (Fig. 6). The weight

Figure 6. Combine unloading grain harvested from reconstructed plots into a weigh-wagon.

harvested from each plot was recorded and samples were collected to determine grain moisture content at the time of harvest. Crop yield in Mg/ha was determined by determining the equivalent mass of grain harvested at 15.5% wet basis grain moisture content.

Results and Discussion

Soil Bulk Density-

Figure 7 shows soil bulk density versus depth (z) between 100 and 600 mm measured in the plots in May 2008. The four profiles correspond to the four reconstruction treatments; with each point the average of 15 replicated measurements. These measurements corresponded to soil conditions approximately one year following reconstruction but prior to any cropping operations. In fact, no traffic occurred on the plots prior to these measurements. Bulk density was slightly greater than 1.3 g/cm^3 at depths of 100 and 600 mm and varied between 1.2 and 1.3 g/cm^3 for 100 mm < z < 600 mm. These densities were substantially less than 1.5 to 1.6 g/cm^3 which is typical of this soil in a productive non-compacted state.

Figure 8 shows bulk density measured in the plots in March 2009. These measurements were recorded prior to planting the plots in corn for the first time following reconstruction. Natural consolidation caused bulk density levels to increase in all of the plots to levels of 1.5 to 1.6 g/cm^3. Such levels are typical of this soil in a productive non-compacted state. Bulk densities were approximately 0.1 g/cm^3 greater at the 100 mm depth than for the remaining profile. Bulk density of the mixed AB treatment seemed to be trending to values greater than other treatments for $z \geq 200$ mm.

Figure 9 shows bulk density measured in the plots during June 2011. This is following the production of corn crops on the plots in 2009 and 2010 and the corresponding equipment traffic associated with planting, harvesting, etc. Bulk density continues to increase at z = 100 mm but seems to remain stable at 1.4 to 1.5 g/cm^3 for $z \geq 200$ mm, with the exception of the AB treatment which continued to trend higher.

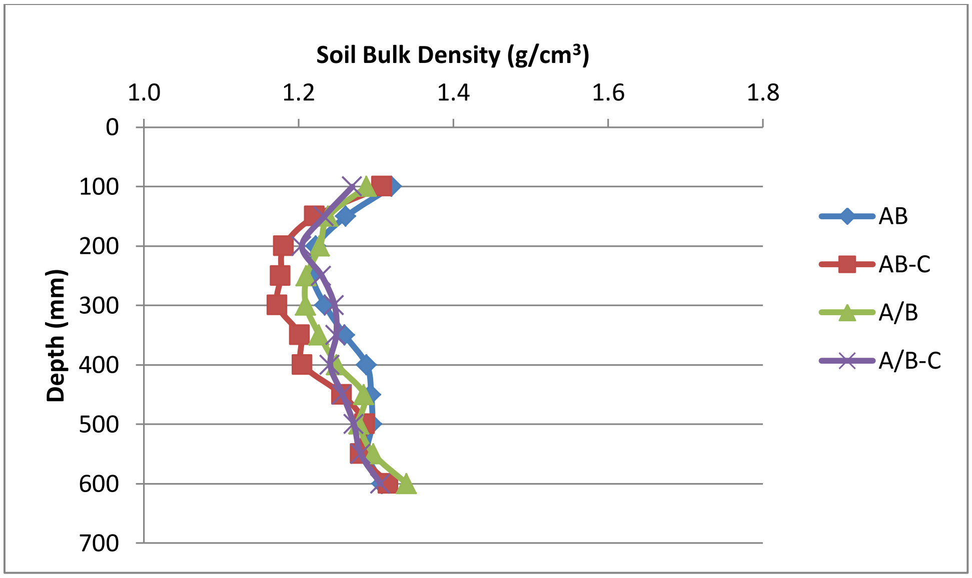

Figure 7. Soil bulk density versus depth measured in reconstructed plots, May 2008.

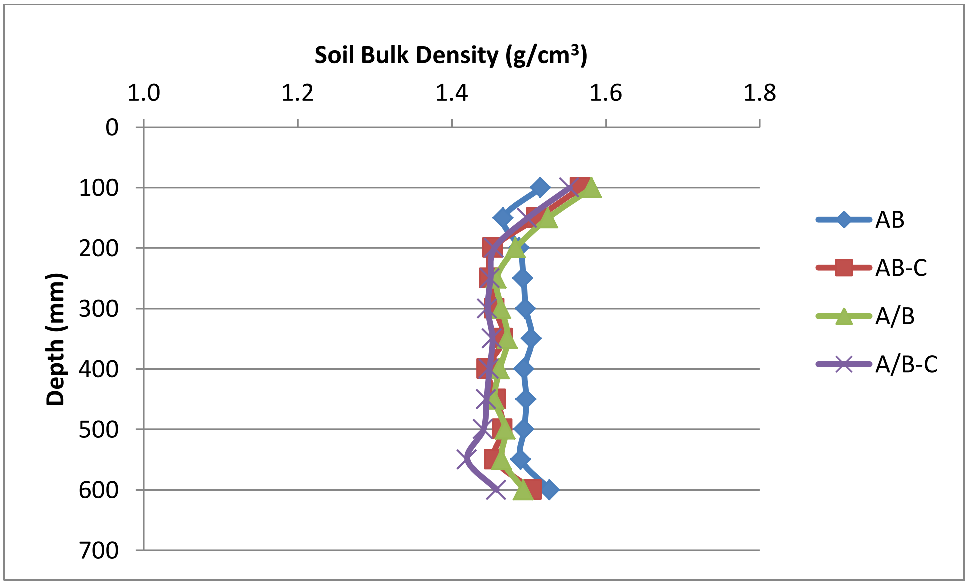

Figure 8. Soil bulk density versus depth measured in reconstructed plots, March 2009.

There is an apparent decrease in bulk density for the A/BC treatment for 200 mm < z < 400 mm. These measurements will be repeated during 2012 to determine if this trend persists. A possible explanation may be enhanced formation of soil microstructure arising from beneficial microbial activity.

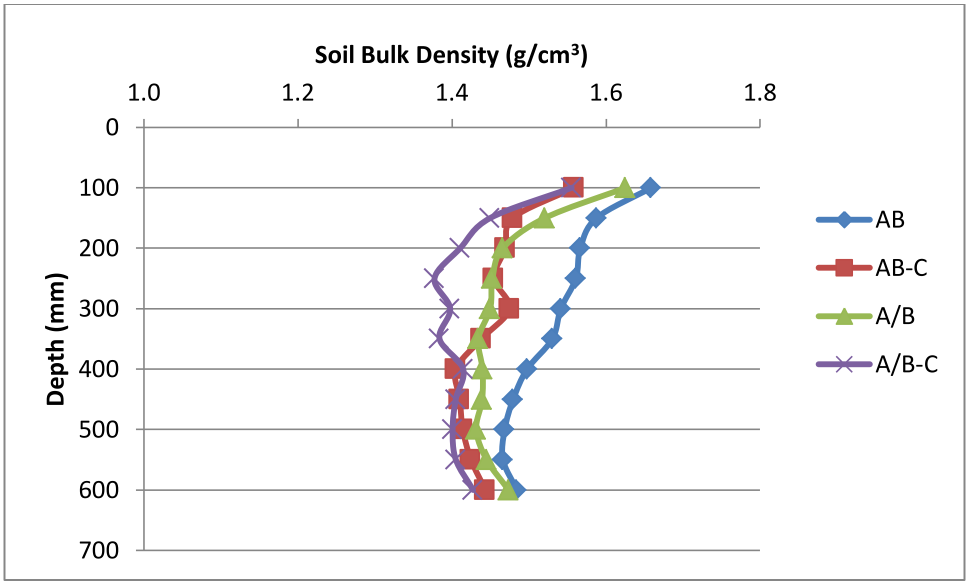

Figure 9. Soil bulk density versus depth measured in reconstructed plots, June 2011.

Soil Cone Index

Figure 10 shows soil cone index (CI) measured in the plots during May 2008. Again, these measurements were recorded prior to any equipment traffic occurring on the plots. Soil cone index $\geq$ 2 MPa (300 psi) is generally recognized as sufficient to restrict root growth in soil and thus is considered as severely compacted (Schwab et al., 2004). Clearly, CI measurements in all plots were substantially less than 2 MPa and therefore not indicative of adverse compaction. These results, along with bulk density shown in Fig. 7, demonstrate that the *Soil Regenerator* is capable of reconstructing soil with negligible compaction.

Figure 11 shows CI measurements recorded in the plots in May 2009. These measurements were made immediately following planting of the first corn crop on the plots. Natural consolidation and equipment traffic during the first planting has caused CI values to increase compared to those measured in 2008. However, the levels for all plots remain well below the critical level of 2 MPa and indicate no apparent detrimental compaction. It is interesting to note that the AB-C and A/B-C treatments showed slightly higher levels of CI compared to the non-compost plots. This may indicate a moderate increase in soil fabric and strength resulting from microbial activity. CI versus depth measurements will be repeated in these plots during 2012 to determine any possible adverse compaction resulting from equipment traffic associated with producing and harvesting the three corn crops.

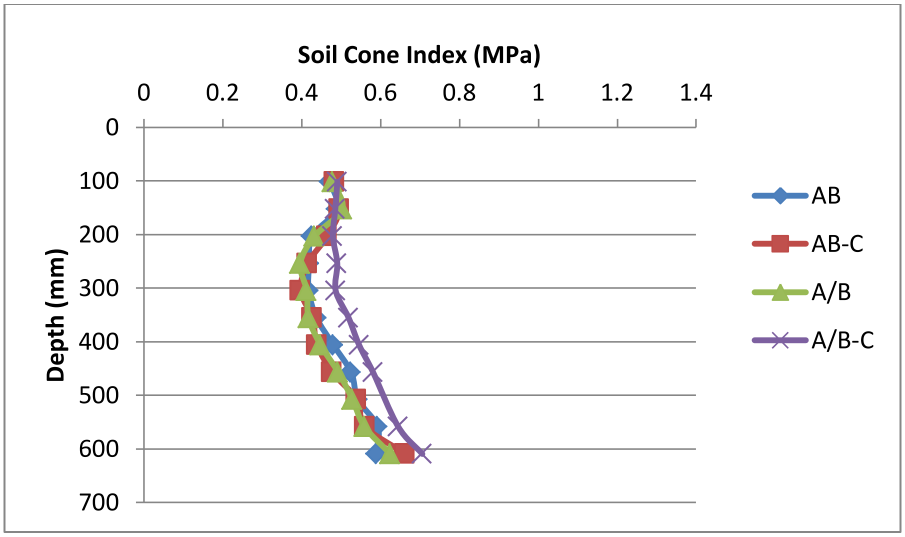

Figure 10. Soil cone index versus depth measured in reconstructed plots, May 2008.

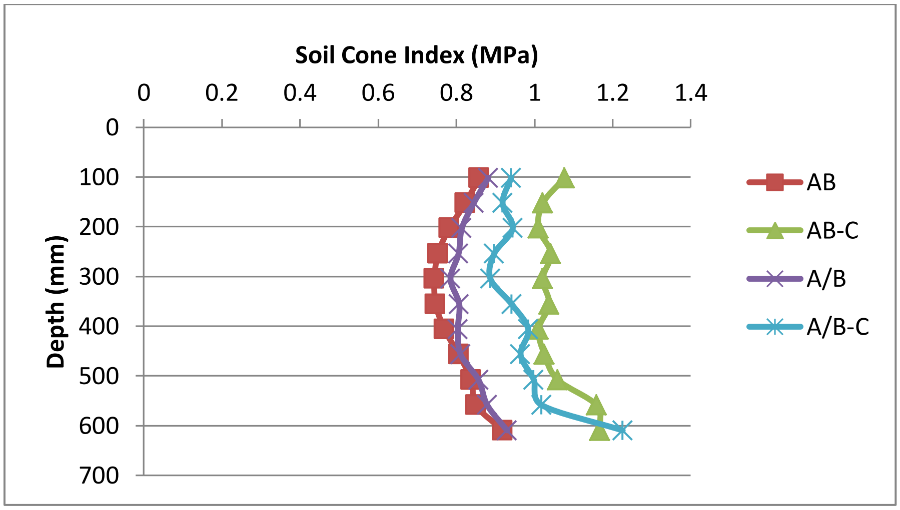

Figure 11. Soil cone index versus depth measured in reconstructed plots, May 2009.

Corn Yield

Table 1 shows corn yield as measured in the plots for 2009, 2010 and 2011. Yield appears to be greater in the A/B and A/B-C treatments in 2009 but this trend did not continue in 2010 and 2011. Table 1 indicates that all reconstructed plots produced yield which was numerically greater than the overall average yield for the research farm in 2009 and 2010. In 2011, only the A/B-C treatment produced yield numerically greater than the overall farm average. Unfortunately, the selection and harvesting of conventional 'control' plots in undisturbed soil adjacent to the study plots was not possible as this would have required substantial disruption of harvesting operations in adjacent fields planted in corn. Thus, we can only compare average plot yield to the average corn yield measured in undisturbed fields proximate to the location of our plots.

Table 2 shows analysis of variance results for the measurements recorded in Table 1. There was no significant treatment effect ($\alpha = 0.05$) upon measured yield in any year. However, when yield data from all three years were pooled, treatment 1 yield was significantly less than the average yield of treatments 2, 3 and 4 ($\alpha = 0.05$).

These results appear to indicate that segregation of A and B soil horizons is not necessary. In fact, the highest average yield for all three years was measured for the mixed A and B horizons with compost added. Further inspection of the results indicates no apparent benefit from adding compost when soil horizons were segregated, especially in 2010 and 2011.

Conclusions

The conclusions of the study are:

1. The University of Kentucky *Soil Regenerator* was used to successfully reconstruct soil while completely avoiding traffic compaction.
2. Soil reconstructed with the *Soil Regenerator* maintained acceptable levels of soil bulk density and soil strength throughout the entire depth of reconstructed soil profiles (600 mm) for four years.
3. Reconstruction of soil by mixing soil horizons without adding compost produced significantly lower corn yield ($\alpha = 0.05$) than the average yield of the other reconstruction methods. Average corn yield measured in reconstructed plots was numerically greater than the average yield measured on the University of Kentucky north research farm in two of three years, however, this difference could not be confirmed statistically.
4. There was no apparent effect of soil reconstruction method upon soil strength or bulk density, however, a statistical analysis will be completed after measurements are repeated in 2012.

Table 1. Corn grain yield (Mg/ha) measured in reconstructed plots during 2009-2011. Reconstruction treatments were: A and B horizons mixed, no compost (AB), A and B horizon mixed, 50 Mg/ha compost (AB-C), A and B horizons segregated, no compost (A/B), and A and B horizons segregated, 50 Mg/ha compost (A/B-C)

Year	**Rep**	**Treatment**			
		AB	**AB-C**	**A/B**	**A/B-C**
2009	1	13.49	14.98	15.96	14.61
	2	12.08	14.36	14.31	14.90
	3	14.03	14.74	15.32	16.65
	Mean	13.20	14.69	15.20	15.39
				Grand Mean	14.62
				North farm average	11.62
2010	1	11.22	13.29	11.34	10.98
	2	11.67	13.36	11.01	10.37
	3	12.72	11.59	11.01	11.07
	Mean	11.87	12.75	11.12	10.81
				Grand Mean	11.64
				North farm average	10.68
2011	1	10.15	12.77	12.01	10.68
	2	11.61	13.43	10.81	10.99
	3	12.31	11.52	10.15	10.78
	Mean	11.99	12.57	10.99	10.81
				Grand Mean	11.44
				North farm average	11.55

Table 2. Analysis of variance of corn yield (bu/ac) measured in reconstructed plots during 2009-2011. Results are presented for each crop year (α = 0.05).

Year	**Source of Variation**	**Sum of Squares**	**dof**	**Mean Squared**	**F**	**P-value**	**F critical**
2009	Between treatments	856.6	2	428.3	1.323	0.314	4.256
	Within treatments	2913.9	9	323.8			
	Total	3770.5	11				
2010	Between treatments	7.852	2	3.926	0.0136	0.9865	4.256
	Within treatments	2598.3	9	288.7			
	Total	2606.2	11				
2011	Between treatments	136.576	2	68.288	0.215607	0.810097	4.256
	Within treatments	2850.514	9				
	Total	2987.1	11				

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