Long-Term Mine Soil Weathering and Treatment Effects: Do Topsoil Substitutes Really Mimic Natural Soils?

2007/2008 Powell River Project Annual Progress Report

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Introduction and Background

The Surface Mine Control and Reclamation Act (SMCRA) of 1977 contained a number of contentious provisions including return to original contour (AOC), long-term liability bonding periods, and return to "equal or better" post-mining land use conditions. However, one of the more stealthy provisions was SMCRA's allowance for use of pre-selected overburden materials as topsoil substitutes when (A) the native A+E horizon materials are less than 6 inches thick, and (B) the physical and chemical properties of the proposed substitute spoil materials are deemed suitable for such use. Since native topsoil layers throughout the Appalachian coalfields are usually less than six inches thick, and removing them from steep slopes is difficult and expensive, the vast majority of coal mined lands in the region have employed topsoil substitutes.

In 1982, the USDI Office of Surface Mining and the Powell River Project co-funded the installation of the Controlled Overburden Placement (COP) experiment to objectively assess the viability of the topsoil substitute concept and to determine whether or not organic amendments would be beneficial. In one component of the COP experiment we are directly comparing five mixes of sandstone:siltstone (SS:SiS) overburden while in a separate experiment we are following the effects of topsoil return, sawdust addition and four incremental loading rates of biosolids. All treatments are replicated four times and the plots are split between herbaceous (dominantly tall fescue) and forest (red oak following pine) vegetation. We intensively monitored those two side-by-side experiments through the late 1980's, and our results can be reviewed at the PRP web site and at http://www.cses.vt.edu/revegetation/minereclam.html. In summary, we found that (A) properly selected and placed spoil materials provided an outstanding soil medium for tall fescue production and allowed vigorous invasion of native herbaceous species; (B) higher pH spoils such as the siltstone strata employed were deleterious to pine tree growth; and (C) higher rates of biosolids amendments drove high fescue production while suppressing the pines. The COP experiment remains the longest intact and continuously monitored study of mine soil genesis in the World. Follow-up studies by our group at other sites in the 1990's and early 2000's also characterized the wider effects of biosolids applications and the nature of inherent variability in mine soil properties in the Research & Education Center. However, very little detailed soil analyses have ever been performed on the native pre-mining soils in the Research & Education Center area for direct comparison.

Over the past decade, the concept of topsoil substitution has been directly and indirectly criticized from a number of perspectives. First of all, advocates of the return of Appalachian mined lands to native forest covers have pointed to the lack of topsoil salvage and the inclusion of higher pH unweathered spoils as directly inhibiting effective reforestation. These objections have been raised by citizens and certain well-trained scientists alike. Secondly, the fact that relatively unweathered spoils (such as those employed in the COP study) release significant total dissolved solids (TDS) loads to drainage waters over time has been implicated as a component of mining related surface water degradation under both low and moderate pH conditions. Finally, the ability of these mine soils to accumulate organic matter, maintain a stable and viable microbial biomass and available nutrient pools, and overall productivity potentials beyond the requisite five-year performance liability period is also questioned by many citizens' groups.

In 2007, we proposed to directly address a number of these challenges by initiating a new program of mine soil sampling and analysis utilizing our established baseline experiments at the Research and Education Center, and at other locations where long-term baseline data sets are available, that will allow us to study changes in mine soil properties and productivity relationships over prolonged periods of time. Furthermore, we will directly compare mine soil properties for a range of important parameters (e.g. pH, organic matter content, P-forms, microbial biomass) with a suite of unmined native soils forming out of the same rocks. Thus, by a combination of direct and differential analysis, we propose to meet the following objectives:

Research Objectives

1. To determine the long-term (20+ years) effects of overburden rock type and surface treatments on important mine soil morphological, physical, chemical and microbiological properties.

2. To directly compare the properties of weathering mine soils of varying age with unmined native soils formed from the same strata.

3. To measure the net TDS elution potential of a range of fresh, partially weathered and well-weathered topsoil substitute materials.

4. To predict the ability of selected overburden materials to weather and transform into mine soils suitable for the support of native hardwoods and hayland/pasture vegetation, and to estimate the rate of transformation.

Methods and Procedures

Overall Approach

We are fortunate to have an array of well-characterized, documented and "preserved" research sites throughout the Powell River Project Research & Education Center area and the surrounding region. These include the COP experiment, areas to the north of Powell River that have been minimally disturbed since 1990, and certain limited locations south of Powell River that have not been re-mined since 1990. While much of the 1990 aged mine soil surface received a uniform treatment of biosolids+compost, there are significant areas of that surface that did not. By differentially sampling across these contrasting treatment areas, we will be able to directly determine the net effect of organic matter additions on long term soil development process and important mine soil productivity parameters.

Furthermore, the recent re-mining activity to the south of Powell River will allow us to sample and "pair up" mine soil pedons that are very young (1 to 10 years) with much older mine soils (25+ years) to the north that formed out of identical parent materials. Finally, we also have access to a range of relatively intact native forest soils in the overall Powell River area that occur between mining disturbances.

We are now completing the first year (of three) of this study. In year one, we focused field work on a wide range of unweathered and weathered spoil types in the region and on sampling pedons within the immediate vicinity of the Research & Education Center as described above. In year two, we will work with Jim Burger, and other collaborators to locate pedons south of Powell River and across the region where we can be assured of good "control" of spoil age and type and treatments, and where we have access to archived original spoil samples (where possible) or original data sets to determine rates of change of various mine soil properties. In the final year, we will complete all laboratory work, sample or re-sample additional pedons to fill out the data set, and construct a qualitative model of how basic mine soil morphological, chemical, physical and microbiological properties respond to (A) initial spoil type and (B) initial surface treatments over extended periods of time.

As discussed below, we are sampling a range of mine soil and natural soil pedons in the area of the Research & Education Center and beyond. Each morphological horizon sample and selected depth increment samples will be analyzed for the following parameters:

pH and total titratable acidity
Saturated paste electrical conductance and solid salts species (cations + anions)
Total organic carbon and Walkley-Black organic matter
Organic matter fractions
Microbial biomass
Bulk microbial activity (incubation/CO_2 evolution)
Total-P and fractions (e.g. OM-P, Ca-P, Fe-P)
Total-N
Exchangeable cations
Dilute acid extractable nutrients and metals
Extractable Fe and Mn oxides
Total-S and S-forms if S $\geq$ 0.2%
Calcium carbonate equivalence
% Rock fragments
Particle size analysis
Aggregate stability
Moisture desorption/water holding capacity on < 2mm fractions

In addition, the incremental depth samples will all be subjected to the soluble salt and dilute acid extractable nutrients+metals analyses described above. This suite of extracts will also be run on the 1982 and 1990 archived samples for each matching pedon. This will allow us to determine both the mass leaching that has occurred over time within pedons and the net amount lost over 15 to 25 years.

Progress to Date (August 2008)

Our efforts over the first year of this study have focused on 1) collecting and characterizing spoil samples representing a variety of geologic materials and weathering extent, and 2) describing, sampling, and characterizing soil profiles developed in both undisturbed materials and in various spoil types.

Spoil Characterization and Leaching/Weathering Trials

Fifteen samples representing fresh, partially weathered and well-weathered topsoil substitute materials were collected from PRP and other mines in southwest Virginia and east Kentucky. These samples represent a variety of spoil types including sandstone, siltstone and shale in different proportions and at various degrees of weathering. The pH of these spoil samples ranges from 6.2 – 8.2, and all have low peroxide potential acidity (PPA) values (< 4 tons $CaCO_3$/1000 tons material) and low total S (< 0.25 %). A summary of some physical and chemical properties of these materials is presented in Table 1.

A leaching column study was established in July 2008 to characterize element release from a subset of the spoil materials. The leaching columns were built from PVC pipe with a diameter of 7.6 cm and a length of 40 cm (volume = 1200 cm^3). Three spoil samples (OSM 2, OSM 3, and OSM 11) were selected to be run in triplicate under saturated and unsaturated conditions (18 columns total). The columns will be leached and sampled twice a week for at least 6 months (until the leachate stabilizes) using a simulated rainfall solution (pH 4.8). To date, 4 leaching cycles have been completed. Leachate solution samples are analyzed for several constituents including total dissolved solids (TDS), total organic carbon (TOC), cations, metals, Cl and SO_4.

Intensive Sampling of COP Experiment

In 2008 we also initiated full plot-by-plot sampling of the Controlled Overburden Placement Experiment. Each plot (48 total in two experiments) is being volumetrically sampled from two random locations each under the herbaceous side and the forested side. The standing biomass and any litter layers are removed first from above each sampling quadrat (30 cm x 30 cm). Next, the mine soil is volumetrically excavated from 0-5 cm and 5 to 25 cm depths. Thus, we are sampling four total locations per plot with two bulk samples per location. These samples will be analyzed for a similar suite of parameters to the mine soil pedons as described above. This sampling is the first time since 1985 that these plots have been subjected to detailed volumetric sampling. The advantages of this intensive sampling protocol include that (A) we will be able to statistically determine the long term (25+ years) effects of rock type and surface treatments on mine soil properties and (B) plant growth response. By sampling both sides of each plot, we will (C) also be able to determine the differential effects of herbaceous vs. pine/hardwood vegetation and litter layers on surface soil properties after this extended period of time. Finally, (D) the volumetric sampling protocol employed will also allow us to readily calculate important changes in net C-sequestration and nutrient accumulation over this period of time.

Table 1. Some chemical and physical characteristics of topsoil substitute materials.

Lab-ID	Geologic Description	Coal Seam[1]	<1 cm	>1 cm	pH	EC	PPA[2]	S	C
			%	%		dS/m		%	%
OSM[3] 1	unweathered sandstone	to be determined	23	77	6.9	1.27	0.00	0.06	0.89
OSM 2	dark gray carbonaceous shale	Hazard #7, Hazard #8	60	40	7.0	3.48	0.00	0.23	4.73
OSM 3	highly weathered ss; unweathered gray siltstone	to be determined	87	13	6.9	0.94	3.58	0.07	3.25
OSM 4	weathered, reddish-brown shale	Clintwood/ Blair	85	15	6.5	0.29	0.22	0.03	1.48
OSM 5	weathered and unweathered sandstone	Clintwood/ Blair	79	21	6.2	0.90	0.15	0.04	1.48
OSM 6	minimally weathered gray siltstone	Clintwood/ Blair	79	21	7.3	1.40	0.00	0.14	1.89
OSM 7	weathered brown-gray siltstone	to be determined	62	38	7.7	0.20	0.12	0.03	0.28
OSM 8	unweathered gray siltstone	to be determined	69	31	7.6	0.47	0.24	0.19	4.28
OSM 9	weathered and unweathered sandstone; weathered and unweathered gray siltstone	to be determined	49	51	7.7	0.40	0.00	0.08	2.15
OSM 10	unweathered gray shale	Philips	72	28	7.8	0.66	0.00	0.10	2.92
OSM 11	weathered sandstone	Taggart	68	32	6.3	0.56	0.28	0.02	0.78
OSM 12	unweathered sandstone	Taggart	45	55	7.8	0.40	0.00	0.14	2.39
OSM 13	weathered and unweathered sandstone	Bolling (Imboden)	64	36	7.6	0.28	0.00	0.04	1.88
OSM 14	weathered sandstone	Clintwood/ Blair	65	35	7.5	0.36	0.12	0.02	0.85
OSM 15	unweathered siltstone	Clintwood/ Blair	47	53	8.2	0.67	0.00	0.09	1.78

[1] Coal seam information provided by mine representatives.
[2] PPA = Peroxide Potential Acidity: results expressed in tons of $CaCO_3$ lime demand per 1000 tons material.
[3] These samples are also being utilized in a parallel study funded by OSM to estimate long term weathering and element release rates.

Soil Profiles

Eight soil profiles, including 3 unmined native soils and 5 mine soils, were described in the field and sampled. All soil profile samples are undergoing full characterization (as described above) in the laboratory. Table 2 provides a summary of the types of soil profiles described and sampled to date. Three soil profile descriptions based on currently available information, and photos, are provided in Figures 1-3. These descriptions include a native profile developed over the Taggart sandstone and two different aged mine soils developed from Taggart spoil.

Table 2. Soil profiles described and sampled at Powell River Project (Nov 2007 to Jul 2008).

profile ID	**parent material**	**age (yrs)**	**relevant site information**
PRP 1 (native)	Philips shale		
PRP 2 (native)	Taggart sandstone		
PRP 3 (native)	Taggart sandstone		
PRPS 1 (mine soil)	Taggart sandstone (on Philips bench)	6	
PRPS 2 (mine soil)	Taggart sandstone (on Philips bench)	2	
PRPS 3 (mine soil)	Taggart sandstone (with Standiford shale)	18	no biosolids
PRPS 4 (mine soil)	Taggart sandstone (with Standiford shale)	18	"mine mix" biosolids applied to surface
PRPS 5 (mine soil)	Taggart sandstone	40	

A – 0 – 8 cm; dark brown (10YR 3/3) gravelly sandy loam; weak fine granular structure; very friable; common to many fine medium and coarse roots; 20% coarse fragments; extremely acid; clear smooth boundary

Bw – 8 – 38 cm; yellowish brown (10YR 5/6) sandy loam; weak fine and medium subangular blocky structure; very friable; common to many fine medium and coarse roots; 12% coarse fragments; extremely acid; clear smooth boundary.

CB – 38 – 51 cm; light yellowish brown (10YR 6/4) sandy loam; weak fine and medium granular and medium subangular blocky structure; friable; common fine and medium roots; 10% coarse fragments; extremely acid.

C – 51 – 69 cm; brownish yellow (10YR 6/6) sandy loam; massive; friable; few coarse roots; 14% coarse fragments; very strongly acid

Cr – 69+ cm.

Figure 1. PRP 2 – Unmined native soil over Taggart sandstone

^A – 0 – 10 cm; brown (10YR 4/3) loam; weak to moderate fine granular and subangular blocky structure; very friable; many fine and common medium roots; clear smooth boundary.

^AC – 10 – 29 cm; 50% dark yellowish brown (10YR 4/4), 30% gray (5YR 5/1), and 20% yellowish brown (10YR 5/8) gravelly loam; massive to weak moderate subangular blocky structure; friable; common fine and medium roots; clear wavy boundary.

^C1 – 29 – 62 cm; dark yellowish brown (10YR 4/4) and yellowish brown (10YR 5/8) very gravelly loam; massive; friable to firm; few fine roots; gradual wavy boundary.

^C2 – 62 – 95+ cm; very dark grayish brown (10YR 3/2) very gravelly loam; massive; friable.

Figure 2. PRPS 3 – Mine soil (18 years old) over Taggart sandstone.

^A1 – 0 – 10 cm; very dark grayish brown (10YR 3/2) and brown (10YR 4/3) loam; moderate fine and medium granular structure; very friable; many fine and medium roots; clear smooth boundary.

^Bw – 10 – 24 cm; brown (10YR 4/3) very channery loam; moderate medium subangular blocky structure; friable; common fine and medium roots; 40% siltstone channers; abrupt smooth boundary.

^2C – 24 – 60 cm; black (5Y 2.5/1), gray (2.5Y 5/1), and brown (10YR 5/3); massive (80%) and fine subangular blocky (20%) structure; few fine roots; 40% rock fragments; common coal; abrupt wavy boundary.

^3C – 60 – 148 cm; brownish yellow (10YR 6/8), light yellowish brown (2.5Y 6/4), black (5Y 2.5/1); massive; friable; 20% saprolitic sandstone boulders; common iron depletions and concentrations; abrupt smooth boundary.

^4Cr – 148 – 170+ cm; bluish gray (10B 5/1) siltstone; massive; very firm.

Figure 3. PRPS 5 – Mine soil (40 years old) over Taggart sandstone.

Summary Work Planned for Years 2 and 3

In year 2, we will expand sampling to areas near the Research & Education center that lie to the south of Powell River and to other more distant locations where we can develop adequate data base control on original spoil conditions, site/weathering age, and treatments applied. For example, we still have existing pine stands and small islands of undisturbed 1970's era mined lands in isolated pockets long the Taggart bench and certain higher levels. At several of these locations, our program described and sampled soil pits in 1980, and Dr. Burger's program has continuously monitored pine stand plantings. Directly adjacent to almost all these locations we can sample relatively young mine soils and/or raw spoils. In Year 3, we will complete any additional sampling needed to round out the data set across different spoil types.

Data Analysis, Synthesis and Expected Results

At the end of year two, we will be able to directly determine and report the relative effect of rock type and surface treatments in the COP experiment on 25 years of mixed herbaceous vegetation and tree growth. We will also be able to contrast the differential effects of the two different vegetative cover conditions on surface soil properties. Similarly, by comparing the properties of the biosolids treated/untreated 15 year-old Taggart mine soils, we will be able to confirm overall rates of important mine soil transformation such as pH reduction and organic matter accumulation in an initially high pH sandstone system. By the comparing the bulk salt and acid extractable nutrient+metal data for each pedon with depth, we will be able to calculate the mass "TDS leaching potential" of each mine spoil material and assess how much of the TDS load appears to have leached over 15 and 25 year time spans and from what depth. These data and findings will be reinforced by our spoil leaching column trials which were established in 2008 and will continue for at least six months. Finally, we will directly compare and contrast all mine soil pedons with nearby natural soils over the same strata.

At the completion of the study, we will integrate all data sets from all components of the study to specifically address and meet our first three objectives. The latter part of the final project year will be focused upon constructing a qualitative (but well quantified!) model of how SW Virginia mine soil properties change with time, and the relative effects of original spoil type and surface treatments on those processes.