RELEASE OF NUTRIENTS FROM BROWN AND GRAY SANDSTONE SOIL SUBSTITUTES IN SOUTHERN WEST VIRGINIA[1]

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Abstract: For forestry post-mining land uses, native topsoil is the preferred rooting media. When insufficient volumes of native soil are present, which is very common in the surface mining region of southern West Virginia, topsoil substitutes are allowed. Two commonly used topsoil substitutes are weathered brown sandstone, which is found at 0 to 10 m below the land surface, and unweathered gray sandstone, which is brought from much lower depths in the overburden column. Questions exist about the suitability of these two substitute materials to provide adequate amounts of nutrients and to supply these nutrients at a rate sufficient for optimum tree growth after placement and as they weather. The objective of this study was to evaluate the release of selected elements from these materials when repeatedly leached with a weak acetic acid extracting solution (Morgan's Extract). Since brown sandstone is generally composed of finer-sized particles than gray sandstone, samples were sieved into two particle size fractions to eliminate the inherent differences in natural particle size distribution. Samples from these two materials at two size fractions were leached with Morgan's extract (0.62*M* NH_4OH + 1.25*M* CH_3COOH) by two extraction methods to examine the concentrations of Mg, Ca, P, and K released during four leaching events. The two extraction methods were a shaking procedure and an extractor apparatus procedure. Release of total amounts of Ca, Mg, K, and P were not significantly different between brown and gray or between particle sizes (sieve sizes). Comparison of extraction methods showed the extractor method leached more K and P out of samples than the shaking method. However, more Ca was leached using the shaking method compared to the extractor procedure.

Additional Key words: substrate composition, substrate depth, compaction, tree survival, tree volume, hardwoods

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Introduction

The Appalachian Regional Reforestation Initiative (ARRI) is a cooperative effort by the states of the Appalachian Region with the Office of Surface Mining and universities to encourage restoration of high quality forests on reclaimed coal mines in the eastern USA. ARRI's goals are to encourage the planting of more high-value hardwood trees on reclaimed lands, improve survival and growth rates of planted trees, and expedite forest development through natural succession. These goals can be achieved by using the Forestry Reclamation Approach (FRA) (Angel et al., 2005).

The FRA is a method for reclaiming coal-mined land to forest, which is based on knowledge gained from both scientific research and experience. The FRA can be summarized in five steps:

1. Create a suitable rooting medium for good tree growth that is no less than 4 feet deep and comprised of topsoil, weathered sandstone and/or the best available material.

2. Loosely grade the topsoil or topsoil substitute to create a non-compacted growth medium.

3. Use ground covers that are compatible with growing trees.

4. Plant two types of trees—early successional species for wildlife and soil stability, and commercially valuable crop trees.

5. Use proper tree planting techniques (Burger et al., 2005).

Due to the scarcity of topsoil in the Appalachian coal mining region, topsoil substitutes often replace topsoil when reclaiming surface mines in West Virginia (Emerson et al., 2009). The surface mining laws allow the use of weathered brown sandstone or other suitable material as topsoil substitutes, and many operators prefer to use unweathered gray sandstone to place at the surface. This desire stems from the fact that the last material encountered as the mining operation reaches its maximum depth is unweathered gray sandstone, and it is this material that is easiest and cheapest to be placed on the surface of the adjacent reclaimed area.

Unweathered gray sandstone has proven to be a suitable growth media when grasses and legumes are used to reclaim the site to pasture and hay land (Johnson and Skousen, 1995; Sobek et al., 2000). With rapid weathering of these sandstones, a mine soil profile can start to develop in as little as three years and form a soil-like material (Sencindiver and Ammons, 2000). This material often produces a very acceptable growth media because of its high pH and sufficient content of nutrients that are released rapidly upon exposure to weathering conditions (Bendfeldt et al., 2001; Haering et al., 1993; 2004). However, the high pH of this material is not conducive to the survival and growth of all hardwood tree species and research has shown that hardwood tree growth is significantly better in the weathered brown sandstone compared to the unweathered gray sandstone soil substitutes (Angel et al., 2009; Emerson et al., 2009).

The objective of this study was to determine the release of nutrients from these two types of soil substitutes. Brown sandstone substrates tend to be finer in particle size than the gray sandstone substrates, so we attempted to remove the inherent differences in particle size by sieving these materials to specific particle sizes. Therefore, two different particle sizes were used for leaching of each substrate.

Materials and Methods

Soil samples were collected from five random locations in constructed plots containing each of the substrates. The plots were established at the Catenary Coal Company's Samples Mine in Kanawha County, WV, in 2005 (see Emerson et al., 2009). Soil sampling for this study was done in 2007 so these soils had been in place and weathered for three years. The samples came from the top 15 cm and each was bagged and labeled. Dried samples of weathered brown sandstone and unweathered gray sandstone were sieved separately through an ASTM standard #10 (<2 mm) sieve. All soil material passing through this sieve was then sieved through an ASTM standard #270 (50 µm) sieve (ASTM, 1985; Soil Survey Staff, 1975). The fraction that passed through the #270 sieve was considered the silt and clay-sized fraction, and the portion that stayed on top of the #270 sieve was considered the sand-sized fraction. These two fractions were separated because sand-sized particles have little nutrient-holding capacity compared to silt and clay sized particles (Mortland and Kemper, 1965).

Two extraction methods were employed: a shaking method and an extractor procedure. The shaking method used 10 cm^3 of soil and 50 mL of extracting solution. The extracting solution was Morgan's Extract, which is composed of 0.62*M* NH_4OH + 1.25*M* CH_3COOH. This extraction solution is a weak acid solution and was developed to mimic chemicals that are contained in root exudates. Morgan's Extract is considered to extract nutrients that are biologically available in acid soils (Morgan, 1941). The soil and extractant were shaken in beakers for 15 min at 180 oscillations per min. After shaking, the soil solution was filtered through a 0.8 μm filter (Whatman 42 filter paper) and the filtrate was analyzed. After each filtration, the sample material not passing through the filter was allowed to dry, removed and weighed. The amount of extractant solution added for the next extraction was then adjusted to maintain a soil:solution ratio of 1:5. The same sample was then prepared, shaken, and filtered in the same way as described. This process was repeated four times. Four times was considered adequate because samples released no further nutrients for two of the four nutrients examined.

The second method used to extract nutrients from the sandstone substitute materials was an extractor apparatus. The same amount of sample (10 cm^3) was placed in an extraction tube on top of a cotton pulp filter and the same amount of Morgan's Extract (50 mL) was put in the reservoir attached to the top of the extraction tube. The extractor slowly pulled the extract through the sample over 12 hours and into a collection tube. This allowed the soil sample to remain in the tube and could be leached repeatedly by simply adding more extractant to the reservoir tube. This process was repeated four times and the solution was collected after each extraction. Solutions from each extraction event were then analyzed by ICP (Perkin Elmer Plasma 400 Emission Spectrometer) for P, K, Ca and Mg.

Soil pH (1:1 soil:water mixture) of a the 50-μm size class was measured with a Beckman 43 pH meter and electrical conductivity (2:1 soil:water mixture) was determined with a Microprocessor Conductivity Meter LF 3000.

Results and Discussion

The solution pH of the sample substrates was significantly different with the brown sandstone having a pH of 5.0 and the gray sandstone having a pH of 8.0 (Table 1). Oxidized brown sandstone has weathered over time removing many of the exchangeable bases and leaving H, Fe, and Al on exchange sites. The un-oxidized or unweathered gray sandstone is from deeper within the geologic column and has not undergone nearly as much weathering. Therefore, it still reflects its high pH, carbonate parent material characteristic.

Electrical conductivity (EC) was not different between the two sandstone materials. Electrical conductivity has been linked to productivity on minesoils and EC values greater than 0.5 ds m^{-1} are considered detrimental to plant growth (McFee et al., 1981; Rodrigue and Burger, 2004). In our samples, EC values ranged from 0.2 to 0.4 ds m^{-1}, within the range found by

Rodrigue and Burger (2004) in western Virginia mines, which ranged from 0.3 to 1.7 ds m^{-1}. The authors of this study associated higher EC values with finer textured unoxidized spoils, whereas more coarse textured oxidized materials had lower EC values.

Table 1. Soil pH and electrical conductivity of brown and gray sandstone topsoil substitute materials in Kanawha County, West Virginia.

Property	Brown SS	Gray SS
pH (s.u.)	5.0 b*	8.2 a
EC (ds m^{-1})	.35 a	.25 a

*Means with the same letter are not significantly different at $p \leq 0.05$.

Since brown sandstone has been exposed to weathering and oxidation processes for very long time periods, it would follow that these materials would contain fewer amounts of nutrients than fresh unweathered materials if they were composed of the same parent minerals. However, the opposite trend was observed with the brown sandstone materials having generally higher extractable concentrations, with Mg and P being significantly higher (Table 2). Both materials were fertilized with N-P-K at low levels during the first growing season, which means that after three years there should have been little to no residual nutrient concentrations from fertilization in these soils. In fact, due to the coarse nature of the soil materials, it is highly likely that the nutrients not utilized by plants were leached from the upper 5 to 15 cm. Exchange capacity of these substitute soil materials was <10 $cmol_c$ kg^{-1} (data not shown), and evidence of this low exchange capacity is found in other studies examining these materials (Emerson et al., 2009). While finer textured materials would be expected to release higher concentrations of elements than more coarse textured materials, this was not evident in the experiment. Soil materials sieved into these two different sized particle fractions (2 mm–50 µm vs <50 µm) showed no difference in elemental concentrations (Table 2).

Comparison of the two extraction methods showed that there were significant differences in extracted concentrations for three of the four elements examined (Table 2). Potassium and phosphorus were significantly higher with the extractor method, while calcium was greater in the shaker method. Magnesium also showed a higher trend of nutrient release with the extractor method but the differences were not significant between methods.

Table 2. Mean concentrations of Morgan-extractable Mg, Ca, K, and P from brown and gray sandstone leached by two extraction methods.

	Mg	Ca	K	P
	------------------------ $mg\ L^{-1}$ ------------------------			
Soil Substitute				
Brown SS	8.4 a*	16.9 a	10.7 a	0.02 a
Gray SS	7.3 b	15.5 a	9.2 a	0.01 b
Sieve Size				
10 (2 mm – 50 µm)	8.1 a	16.2 a	10.4 a	0.02 a
270 (< 50 µm)	8.0 a	16.0 a	10.1 a	0.01 a
Extraction Method				
Shaker	7.4 a	18.7 a	8.1 b	0.01 b
Extractor	8.7 a	13.3 b	12.4 a	0.02 a
Leaching Event				
1	4.7 c**	7.2 c	6.6 c	0.01 b
2	5.5 c	8.7 b	8.1 b	0.01 b
3	7.7 b	15.8 a	10.0 a	0.015 a
4	8.0 a	16.1 a	10.0 a	0.015 a

*Means for each factor for each element with the same letter are not significantly different at $p \leq 0.05$.

**Leaching concentrations are cumulative.

Significant differences in nutrient concentrations were found for solutions of different leaching events. The leachate from the first leaching event contained the highest concentrations of all events (Table 3). Concentration declined for the second event, but increased for the third. The final leaching event had the lowest concentrations.

Table 3. Mean concentrations for the total amount of each nutrient released at the end of each leaching event.

Leaching Event	Mg	Ca	K	P
	-------------------	mg L^{-1}	-------------------	
1	58	45	66	66
2	10	9	15	0
3	28	43	19	34
4	4	3	0	0
Total	100	100	100	100

Conclusions

Brown and gray sandstone substitute topsoil materials were leached with Morgan's extract to determine the release of Mg, Ca, K, and P. Comparison between materials showed no significant difference, and different particle size fractions also did not show a significant difference. Comparison of extraction methods showed the extractor method leached more K and P out of samples than the shaking method. The shaker method probably released more Ca because the shaking of the samples could have physically caused degradation of particles thereby releasing more Ca. It was expected that brown sandstone would release lesser amounts since it has been exposed to leaching and oxidation (more weathered) for a longer time period, while the gray sandstone was less weathered.

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