

UPLAND PLACEMENT AND MANAGEMENT OF ACID-FORMING DREDGE MATERIALS¹

A.F. Wick², W.L. Daniels, Z.W. Orndorff, and C.H. Carter III

Abstract: Harbor and ship channel maintenance dredging by the Maryland Port Administration has historically presented a dredge disposal and utilization challenge due to metals and the potential acidity of their sediments. Post-placement low pH (<4.0) has been problematic for vegetation establishment and also reduces the pH of water moving through or over the sediment disposal or utilization facility. To determine best management practices for one material (Cox Creek; H₂O₂ potential acidity - PPA = - 10 Mg CCE per 1000 Mg material; Total S = 1.31%; calcium carbonate equivalent - CCE = 7.13%) proposed for upland placement, we conducted lab and field experiments. In the lab, a series of liming rates (0.00, 0.50, 0.75, 1.00, and 1.25x of required lime additions as CCE) were evaluated through 32 wet-dry cycles. The pH of the 0.00x liming rate treatment remained between 4.10 and 4.20 throughout the experiment, while the effects of the lime rates on bulk sediment pH were not evident until after four wet-dry cycles were completed. The lack of development of pH lower than 4.10 was unexpected. Based on the PPA results, we predicted the pH of the unlimed treatment to drop below 4.0 over more extended periods of time. By the end of the experiment, the 1.25x liming rate sediment pH was 6.22 and the 0.50x pH was 5.11. Salinity of the material is clearly an additional issue. The EC of the 0.00x liming rate increased from 5.9 dS m⁻¹ at the start of the experiment to 7.9 dS m⁻¹, while the 1.25x rate EC increased from 7.0 to 8.9 dS m⁻¹, presumably due to sulfate release. In the field, two lime application methods were tested (bulk blending and layering) against an unlimed control treatment. Three zero-tension lysimeters were installed under each plot to monitor pH and EC of leachates. First-year results indicate that the pH of both the bulk-blended lime and layered treatments remained between 4.4 and 5.5 after four sampling events. The unlimed control pH was slightly lower, between 4.2 and 4.5. The EC of the leachate samples (6 to 17 dS m⁻¹) again indicated an issue with soluble salts across all treatments. The salts initially originate from entrained chlorides, but are enhanced by sulfates over time as sulfides react and are neutralized. Thus, managing these materials for plant growth and water quality in an upland environment will be limited by pH and the need to develop strategies for leaching soluble salts and predicting their ground- and surface water impacts. The PPA technique for estimating potential acidity was superior to a more conventional acid-base-accounting technique based on Total-S and CCE determinations.

Additional Key Words: acidity, dredging, potential peroxide acidity, salinity

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² Abbey F. Wick, Post-doctoral Research Associate, W. Lee Daniels, Professor, Z. Orndorff, Post-doctoral Research Associate, Dept. of Crop and Soil Environ. Sciences, Va. Poly. Inst. and State University, Blacksburg, VA 24061. Charles H. Carter III, Weanack Land LLLP, Charles City, VA. Proceedings America Society of Mining and Reclamation, 2011 pp 734-750

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Introduction

Maintenance of navigational channels from the Baltimore Harbor to the mouth of the Patapsco River by the Maryland Port Administration produces approximately 765,000 cubic meters of material per year with an additional 380,000 cubic meters per year for modifications to channels (Jackson, 2010). As of April 2010, the Maryland Port Administration used three existing locations for placement of dredge material, including the Poplar Island, the Cox Creek and the Masonville Storage Facilities with the recent closure of Hart Miller Island. Poplar Island is a restoration project for an eroding shoreline, with the capacity to hold 23.3 million cubic meters, while Cox Creek and Masonville Storage facilities are primarily holding cells for 16 million cubic meters of material (Jackson, 2010). Historically, Maryland Port Administration facilities have encountered periodic management problems with acidic runoff and leachates from emplacement of sulfidic materials. An additional operational goal of the Cox Creek Facility is to be a source of dredged material for beneficial re-use projects. Hart Miller Island was a restoration project to create shore bird habitat, which reached capacity at 76.5 million cubic meters of material in December of 2009. The days are “numbered” as to when the remaining three facilities will reach capacity and alternative placement locations will be needed (within 40 years at the current dredging rates). Therefore, Maryland Port Administration is making an effort to identify alternative placement locations as well as beneficial re-use options, especially for the Cox Creek material. One location which has been identified for upland placement of dredge material followed by beneficial re-use is the Shirley Plantation in Charles City, VA (managed by Weanack LLP; capacity 1.5 million cubic meters). This location has a history of conversion of dredge sediments to productive agricultural uses (Daniels et al., 2007).

Locating storage facilities is only one facet to understanding the long-term management needs of the Maryland Port Administration maintenance dredge material from the Cox Creek Facility. This sediments depositional history and mineralogy has created an additional management issue primarily due to the potential acidity (from sulfides) of the sediment. Once the material is dredged and exposed to oxygen, pyrite within the sediment reacts with oxygen and water to produce H_2SO_4 , which reduces the pH of the sediment. Low pH material (≤ 4.0) can be problematic for vegetation establishment, genesis of soil structure, and can drastically reduce the pH of water moving through the sediment. Drainage and runoff waters from

oxidizing sulfidic sediments (Orndorff et al., 2008) and coal mine spoils (Skousen et al., 2002) are usually enriched in Fe, Mn, and other metals and pose major risks to local groundwater and receiving streams. Adverse soil and water quality effects associated with sulfide weathering in closely related dredge materials in the Baltimore area have also been widely noted in the literature (Fanning and Fanning, 1989; Fanning and Burch, 2000; Demas et al., 2004). Due to these combined risks, particularly those associated with sulfide oxidation reactions, careful planning and pilot field studies need to be conducted to determine appropriate treatment and reclamation strategies, best management practices and to ensure compliance with local and state permit requirements.

Remediation solutions and best management practices for the Maryland Port Administration Cox Creek materials are currently being evaluated at the Shirley Plantation/Weanack research facility. First, the Cox Creek material was fully characterized (i.e. heavy metals, pesticides, organics, nutrients, potential acidity, salinity, pH, and particle size). Second, based upon those results, necessary amendments and/or remedial treatments were determined to stabilize the materials for upland use. An upland placement pilot study was designed and installed which is being monitored for soil and water quality. Our material characterization and first-year monitoring results are reported here. Our primary original objectives were to: (1) measure the effects of two liming procedures (e.g. blending vs. layering) on acid production and associated soil and water quality parameters and (2) document the effects of sulfide oxidation and lime application on water quality immediately below the emplaced dredge sediments. As the study progressed, we noted a divergence in soil and water pH from what was predicted and thus another objective became (3) to compare the relative accuracy of conventional acid-base-accounting (ABA) versus H_2O_2 oxidation procedures.

Materials and Methods

Study Sites and Field Sampling

Approximately 150 m³ of de-watered maintenance dredge from the Cox Creek Facility was transported to Port Tobacco, Weanack, Charles City, VA via truck in November of 2009 (Fig. 1). The material was placed onto pavement and immediately covered with a tarp to limit water/rainfall additions and oxidation. Five representative composite samples were collected

in January of 2010 and analyzed for soil properties necessary to determine a management strategy (i.e. dredge sediment characterization). As described below, we determined that these materials (as received) would require a net liming rate of 12.5 Mg CaCO₃ per 1000 Mg, which was 125% of their predicted acid-forming potential. We also decided to test two alternative lime management strategies, bulk blending vs. layering lime with the sediment.



Figure 1. Maryland Port Administration Cox Creek Facility dredge material being placed at Port Tobacco, Shirley Plantation, Charles City, VA, in November of 2009. The materials were immediately covered with a tarp to limit rainfall additions and oxidation.

By May 2010, three research cells (4.5 x 8 x 1.2 m) were constructed to test the two different lime addition treatments (bulk-blend and layered) with respect to an untreated control (Fig. 2). The research cells, engineered by Marshall Miller and Associates, have a compacted clay liner and controlled drainage to a collection tank for excess water moving through the Cox Creek material. Zero-tension lysimeters (3 per cell) were also installed for sampling of any saturated flow that passes the interface of treated sediment and the compacted soil liner.

At Port Tobacco, the Cox Creek material was separated into three piles for plot construction in May and June, 2010. The first pile was for placement in the west research cell as the control (no lime). The next pile was bulk-blended with 381 kg of pelletized agricultural

lime based on its assumed potential acidity using a Komatsu 750 and hauled to the middle research cell. The bucket on the equipment was rinsed to avoid cross contamination during loading. The third pile was hauled to the east research cell in lifts (17 cubic meters per lift), with 127 kg of lime placed between each lift. A total of three lifts were placed in the research cell (in the sequence from bottom to surface: dredge material - lime - dredge material - lime-dredge material - lime). The surface of each plot was roto-tilled (starting with the control, again to avoid cross contamination) and hydroseeded (with mulch and fertilizer) to *Setaria italica* (German millet) at a rate of 44 kg ha⁻¹ (Fig. 3).

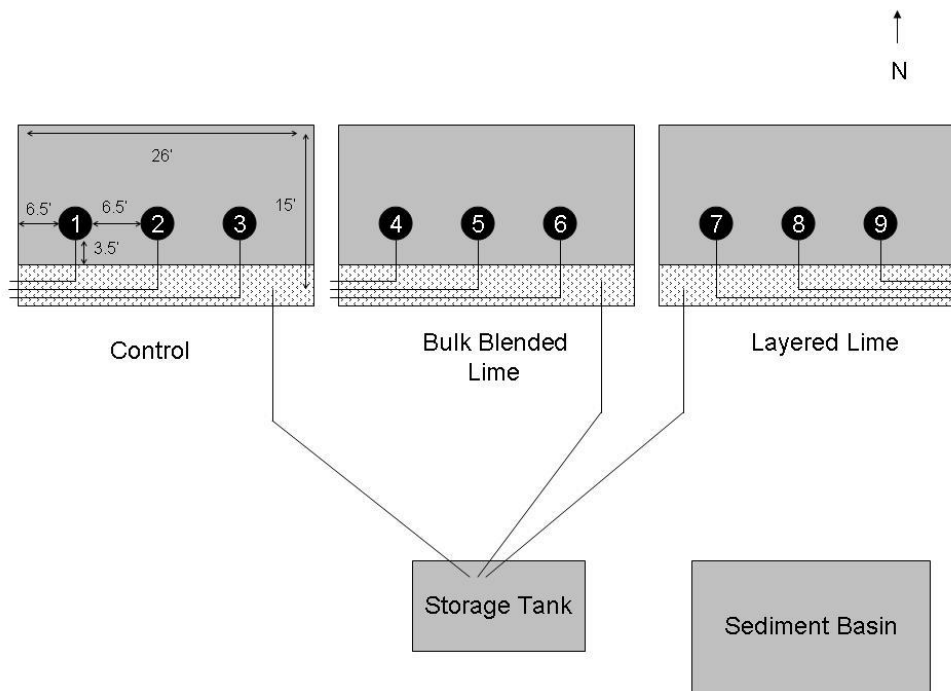


Figure 2. Schematic diagram for lysimeter locations within each treated (control, bulk blended lime and layered lime) cell at the Maryland Port Administration Cox Creek dredge material study, Shirley Plantation, Charles City, VA.

In July, 2010, the first lysimeter samples were collected and analyzed (as described below). A low pH of the leachates was observed in cells containing lime additions (Fig. 4; similar the control), therefore in September, 2010, all three cells were roto-tilled and an additional 20 kg of lime was tilled into the surface 15 cm of the blend and layered plots to assist revegetation. Fertilizer (90 kg N and 224 kg P ha⁻¹) were also roto-tilled to a depth of 20 cm in all three cells at this time. Plots were then seeded to a diverse assemblage of acid-

tolerant species utilized for direct seeding of acid-forming coal wastes (Daniels and Stewart, 2000) at a (combined seeding rate of 112 kg ha⁻¹. These species included, *Eragrostis curvula* (weeping lovegrass), *Festuca arundinacea* ‘bronson’ (tall fescue), *Festuca brevipila* ‘stonehenge’ (hard fescue), *Lotus corniculatus* ‘norecen’ with inoculant (birdsfoot trefoil), *Lespedeza cuneata* with inoculant (lespedeza), and *Secale cereale* (grain rye). Plots were mulched with straw post-seeding and berms around the cells were again stabilized with erosion control matting. The zero-tension lysimeters have been sampled three times (September, November, and December 2010) since the additional lime incorporation.



Figure 3. Research cells for the Maryland Port Administration Cox Creek dredge material study at the Shirley Plantation, Charles City, VA.

Dredge Sediment Characterization

There were two separate sampling dates, January 2010 (pre-plot installation) and June 2010 (post-plot installation). Acid-producing potential (PPA) was determined using a modified H₂O₂ oxidation method based on Barnhisel and Harrison (1976) and O’Shay et al. (1990) as recently documented for use on Coastal Plain sediments by Orndorff et al. (2008). To approximate a more conventional approach to acid-base-accounting we also determined calcium carbonate equivalent (CCE; AOAC, 2002) on samples collected from both sample dates. Total sulfur, electrical conductivity (EC), and pH were determined on the January 2010

samples. Total sulfur analysis was determined on a ground sample (<53 μm) with a Leco S632 analyzer. Electrical conductivity and pH were determined on a saturated paste extract with an Oakton con 100 series EC probe (Vernon Hills, IL) and a Fisher Scientific Accumet Basic pH meter with a glass electrode (Pittsburgh, PA).

Leachate Analyses

Leachates from the lysimeters were analyzed for EC and pH using the same techniques described above. Leachate samples were filtered through a 0.45 μm mixed cellulose filter and analyzed for Al, Fe, Mn, and S using a Thermo Elemental ICAP 61E equipped with a TJA-300 autosampler.

Lab Experiment

Because of differences between PPA and ABA predictions and soil pH results observed between the January and June 2010 samples, a wet-dry lime equilibration experiment was also conducted in the lab to test the effects of various liming rates (0.00, 0.50, 0.75, 1.00, and 1.25% of the anticipated liming rate of 12.5 Mg CaCO_3 per 1000 Mg of material) on soil EC and pH over a series of wet-dry cycles for material directly removed from the control field cell. Each treatment was wetted to field capacity and dried in a 65°C oven to constitute one wet-dry cycle. After four cycles, 40 g of each sample was removed and a 1:1 soil:DI water mixture was prepared. Electrical conductivity and pH analyses were conducted on each extract as described above. Samples were again wetted and dried for four more cycles and again tested for EC and pH. This was completed for a total of 32 cycles.

Statistical Analyses

One-way analysis of variance was used to determine differences among treatments followed by t-tests for separation of means for both the field and lab experiments (SigmaPlot, 2008). Statistical analyses were accomplished at $P < 0.05$.

Results and Discussion

Dredge Sediment Characterization

An average liming rate of 10.6 Mg CaCO_3 per 1000 Mg material was determined on the January 2010 samples via the PPA method which was significantly ($P < 0.10$) higher than the June 2010 values (9.04 Mg CaCO_3 per 1000 Mg material). Calcium carbonate equivalency values were also higher on the January 2010 sample (7.13%) vs. the June 2010 samples

(2.54%; $P < 0.05$). Total-S in the January 2010 samples averaged 1.31% and the saturated paste pH was 7.80 and the EC was 10.38 dS m^{-1} . If we make conservative assumptions that the original total-S in January 2010 was all pyritic, the maximum potential acidity (MPA) of this material in January was approximately - 41 Mg CCE per 1000 Mg of sediment. Similarly, if we assume that our lab determined CCE approximated the actual neutralization potential (NP), the material contained approximately +71 Mg per thousand NP, and thus had a net surplus of +30 Mg CCE per thousand Mg and a MPA/NP ratio of 1.73. Thus, under common assumptions of the conventional acid-base-accounting approach, this material would not be expected to be net acid-forming over time (Skousen et al., 2002). However, as noted above, the PPA procedure that we routinely employ in our laboratories did predict these materials would be net acid-forming and those results were used as the basis for the lime rates utilized in the field experiment and the lab wet-dry cycles.

By looking at the combined leachate plus sediment data from June 2010, it is clear that a significant component of the total-S in this material was highly reactive as the bulk sediment and leachate pH dropped from 7.8 in January into the low 4.0's by June. This appears to have occurred in-situ within the sediment stockpile over that six-month period, but may have been accelerated by the mixing and oxidation involved with building the treatment cells in May and June. Similarly, the CCE of the bulk sediment appeared to decrease from 7.13% to 2.54%, which may have been due to internal neutralization reactions or perhaps sampling error due to the presence of numerous carbonate-bearing shells in the sediments. That being said, we do need to point out that the sediments were screened to $< 2\text{mm}$ before further crushing for analysis, so any carbonate/shell fragments that might have contributed to this would have necessarily been in the sand or silt fractions. Based on our experience with other mid-Atlantic region sediments via the PPA procedure, we expected this material to produce soil:water pH values < 4.0 , but that did not occur here. Presumably, the significant carbonate content of this sediment is sufficient to keep the pH buffered above 4.0, but not reactive or soluble enough to quickly neutralize the acidity and keep the pH any higher.

Surprisingly, the PPA values determined in June (- 9.04 Mg CCE demand per 1000 Mg) were still similar to those determined in January (- 10.6 Mg CCE), indicating that a significant portion of the sulfidic-S either had not reacted or that large amounts of total acidity reaction products remained entrained in the sediments that subsequently influenced the final titration

step of the PPA procedures. As mentioned earlier, a conventional acid-base-accounting interpretation of this material would not have predicted it to be acid-forming due to the abundance of CCE inferred NP values over MPA. However, much of the CCE in this material is contained in sand and silt sized shell fragments, which may not be highly reactive under field conditions but are accounted for in the CCE procedure due to the grinding employed. In this instance, the PPA prediction that the material would be net acid-forming was correct, but the large amount of CCE that these materials contain was keeping the pH just above 4.0 despite the apparent high reactivity of the sulfidic components. Another potential explanation for the differences observed between the two procedures may be that the sand-sized carbonate fragments may not dissolve into the PPA reaction solutions quickly enough to offset the acid released by the rapid oxidation of the sulfides.

Field Lysimeter Leachate

Leachate pH was similar across sampling dates for the control treatment (ranging from 4.16 to 4.46) and increased significantly with time for the bulk-blended treatment (4.43 to 5.53; Fig. 4abc). The layered treatment leachate pH showed a gradual increase (4.98 to 5.41), although this was not significant. This difference between the layered treatment versus the control and the bulk-blended treatments may be due to the presence of a layer of lime immediately under the bottom of the emplaced sediment and immediately around and above the lysimeter. Across treatments, the pH of leachate samples collected in December was significantly lower in the control vs. both lime-amended treatments. Leachate EC declined significantly for all treatments, from 13.0 to 6.4 dS m⁻¹ for the control, 12.8 to 6.6 dS m⁻¹ for the blend and 16.7 to 9.5 dS m⁻¹ for the layer treatment (Fig. 4def), presumably due to net Cl⁻ leaching from the saline source sediments since the total-S component of the leachates did not decline significantly (Table 1). The EC of the leachates was significantly higher for all sample dates in the layered-lime treatment.

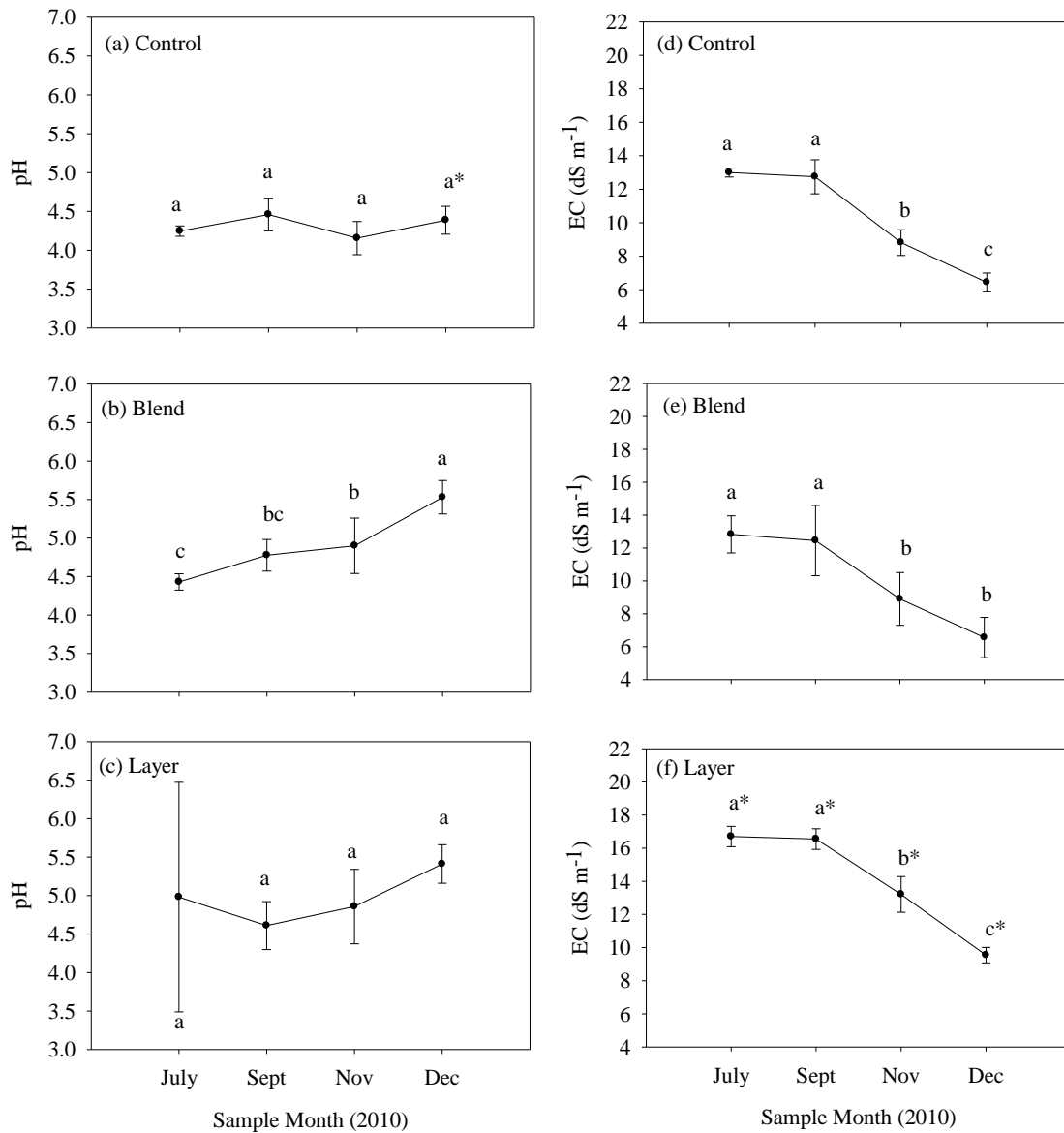


Figure 4. Maryland Port Administration Cox Creek dredge sediment cell leachate pH and electrical conductivity (EC) for three different treatments: control (a, d), bulk blended lime (b, e), and layered lime (c, f). Different letters indicate significant differences among sample month in 2010 within each treatment and asterisk indicates a significant different among treatments within each sample month at the $p < 0.05$ level. Bars indicate standard deviation.

Aluminum, Fe, Mn, and S concentrations for the leachate samples collected were similar across all sample dates for the control (Table 1). Overall Fe and Mn levels in these leachates were quite high relative to typical groundwater protection or surface discharge standards and

are certainly due to the sulfide oxidation reactions and associated low pH in the weathering sediments. Aluminum and Mn decreased with sample date for the bulk-blended treatment, while Fe and S remained similar. Leachates collected from the control were generally higher in Al and Fe relative to the limed treatments, while Mn and S were consistently higher in the layered treatment relative to the other two. Manganese and S concentrations were lower in the bulk-blended treatment than the layered, while for most sample dates, while Al and Fe were similar. Interestingly, leachate Fe, Mn and S levels under the layered cells were considerably higher than the control and somewhat higher than under the blended treatment. Furthermore, both limed treatments appear to have accelerated Fe, Mn and S leaching while simultaneously limiting Al solubility. This is counterintuitive since we typically assume that lime will slow sulfide oxidation by keeping the pH higher and reducing Fe and Mn solubility. However, these systems are clearly actively oxidizing (high S elution) and far from equilibrium which may partially explain this incongruity. Evangelou (1995) also points out that Mn directly oxidizes pyrite in systems where present in abundance and this mechanism may be partly responsible for the very high Mn levels observed. Regardless, the reduced efficacy of the layered treatment at limiting sulfide oxidation and associated Fe, Mn and S levels in leachates versus the blended treatment indicates that the applied layered lime is not actively neutralizing the un-limed layers immediately below.

Table 1. Maryland Port Administration Cox Creek dredge sediment cell leachate Al, Fe, Mn, and S concentrations for treatments (control, blended and layered). Lower case letters indicate significant differences among dates within a specific treatment and upper case letters indicate significant differences among treatments within a specific date for each element at the $p < 0.05$ level.

Element/Date	Treatment		
	Control	Blended	Layered
	mg L ⁻¹		
Al			
7/15/10	11.50 a, A	7.15 a, B	3.27 a, C
9/10/10	1.83 a, A	1.07 b, A	1.02 b, A
11/11/10	4.20 a, A	0.40 b, B	0.40 b, B
12/15/10	10.30 a, A	0.10 b, A	0.30 b, A
Fe			
7/15/10	8.9 b, A	23.1 a, A	71.4 a, A
9/10/10	79.4 a, A	81.4 a, A	153.8 a, A
11/11/10	13.0 b, B	30.4 a, B	170.3 a, A
12/15/10	2.4 b, A	21.3 a, A	133.7 a, A
Mn			
7/15/10	182.5 a, B	146.8 a, C	301.7 a, A
9/10/10	149.6 a, B	116.1 ab, B	249.2 ab, A
11/11/10	155.0 a, B	105.2 b, B	230.3 b, A
12/15/10	178.5 a, A	97.1 b, B	191.2 b, A
S			
7/15/10	2199 a, B	2226 a, B	2921 a, A
9/10/10	1935 a, B	2025 a, B	2703 a, A
11/11/10	1830 a, B	1964 a, B	2673 a, A
12/15/10	1936 a, B	1948 a, B	2462 a, A

Lab Equilibration Experiment

As expected, the pH of the Maryland Port Administration Cox Creek material was low (approx. 4.0) in the 0% treatment relative to the limed treatments (Fig. 5) and remained low throughout the experiment. The effect of lime additions was first observed after four wet-dry cycles with significant increases in pH with increased additions of lime. These differences were consistent throughout the experiment with the greatest separation of values observed

after 24 wet-dry cycles. Trends in EC were not as clear as pH; however, there was an interesting increase in EC observed in the control treatment after 20 wet-dry cycles.

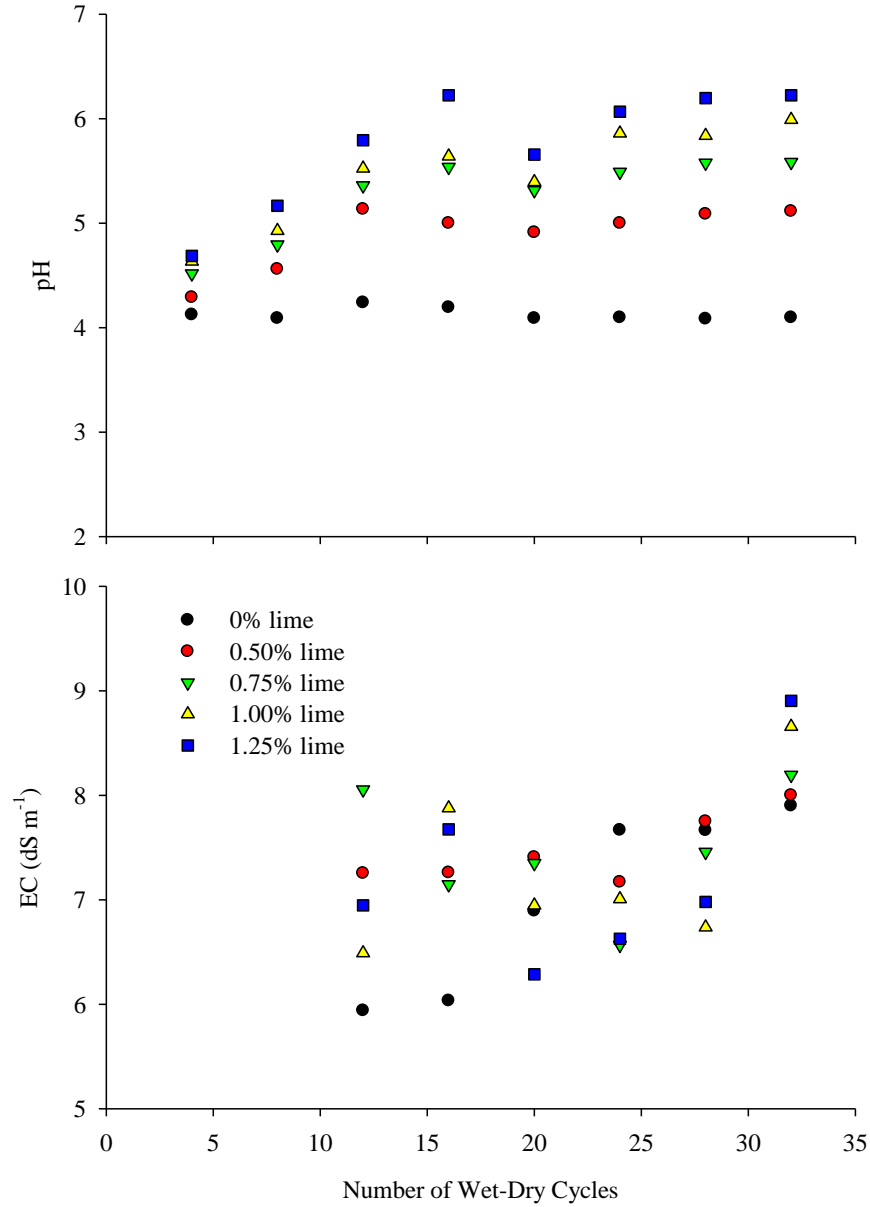


Figure 5. Soil pH and electrical conductivity (EC) for a series of wet-dry cycles conducted on lime-treated (0, 0.5, 0.75, 1.0, 1.25% dry weight of calcium carbonate equivalent) Maryland Port Administration/Cox Creek dredge material.

In the 0% treatment, soil pH remained unchanged throughout the experiment (Table 2), while there were significant increases in soil pH with number of wet-dry cycles for lime treatments at all rates. The highest soil pH was achieved with the 1.25% CCE rates which was also approximately 125% of PPA determined CCE field addition rate. Soil EC increased with the number of wet-dry cycles for all treatments, except the 0.50 and 0.75% of CCE treatments.

Table 2. Soil pH and electrical conductivity (EC) for a series of wet-dry cycles conducted on lime treated (0, 0.5, 0.75, 1.0, 1.25% of calcium carbonate equivalent) Maryland Port Administration Cox Creek dredge material. Lower case letters indicate significant differences within treatment across the number of wet-dry cycles at the $p < 0.05$ level. Standard deviation in parentheses.

Number of Cycles	pH				
	Treatment (% of CCE)				
	0.00%	0.50%	0.75%	1.00%	1.25%
4	4.12 (0.1) a	4.29 (0.1) c	4.51 (0.1) d	4.63 (0.0) e	4.69 (0.1) d
8	4.09 (0.1) a	4.56 (0.1) bc	4.79 (0.1) c	4.93 (0.1) d	5.17 (0.1) c
12	4.24 (0.1) a	5.13 (0.6) a	5.36 (0.1) b	5.52 (0.4) c	5.79 (0.2) b
16	4.19 (0.0) a	5.00 (0.2) a	5.54 (0.1) a	5.64 (0.1) bc	6.22 (0.0) a
20	4.09 (0.1) a	4.91 (0.2) ab	5.31 (0.1) b	5.39 (0.1) c	5.66 (0.0) b
24	4.10 (0.0) a	5.00 (0.1) a	5.49 (0.1) ab	5.86 (0.2) ab	6.07 (0.1) a
28	4.08 (0.0) a	5.09 (0.1) a	5.58 (0.0) a	5.84 (0.0) ab	6.20 (0.1) a
32	4.10 (0.0) a	5.11 (0.1) a	5.58 (0.0) a	5.99 (0.0) a	6.22 (0.1) a

Number of Cycles	EC (dS m ⁻¹)				
	Treatment (% of CCE)				
	0.00%	0.50%	0.75%	1.00%	1.25%
4	NA	NA	NA	NA	NA
8	NA	NA	NA	NA	NA
12	5.94 (0.2) b	7.25 (0.5) a	8.05 (0.3) a	6.49 (1) c	6.95 (0.4) bc
16	6.03 (0.6) b	7.26 (0.9) a	7.15 (1) a	7.88 (0.7) ab	7.67 (1) b
20	6.89 (0.9) ab	7.41 (1) a	7.35 (0.5) a	6.95 (0.2) bc	6.29 (0.7) c
24	7.67 (1) a	7.17 (0.5) a	6.57 (0.3) a	7.01 (0.1) bc	6.63 (0.7) bc
28	7.66 (0.5) a	7.75 (0.5) a	7.46 (0.6) a	6.74 (0.2) c	6.98 (0.5) bc
32	7.90 (0.8) a	8.00 (0.6) a	8.19 (0.1) a	8.65 (0.4) a	8.90 (0.5) a

Summary and Conclusions

While not shown here, the two revegetation efforts on the surface of the field experimental cells both failed regardless of the fact that: (1) we added a moderate amount of additional surface-incorporated lime to the two limed treatments, (2) used a proven acid/salt tolerant seeding mix with a combination of fiber and straw mulch. Field visual evidence points to excessive salts and possibly high surface temperatures (this material is gray/black) as being the primary reasons for revegetation failure. It is clear that between the times these materials were sampled in January versus June of 2010 that a significant portion of their sulfides oxidized, dropping soil pH from near 8.0 to just above 4.0, while the measured CCE appeared to drop from 7.1 to 2.5%, presumably due to carbonate neutralization of the acid-sulfate weathering products. The fact that the PPA values remained close to original estimates indicate that either (A) some portion of the sulfides remain in reduced form, (B) acidic reaction products were retained in the sampled sediments over time, or (C) that we have problems with the application of that technique to these carbonate rich materials. Regardless, it is important to point out that the PPA technique did predict these materials to be significantly acid-forming while a more conventional approach to acid-base-accounting did not.

Once placed and lime-treated in the field, these materials did show a gradual and consistent liming response. A similar response was observed in the laboratory wet/dry study that confirmed that the necessary liming rate predicted by the PPA technique was appropriate and should be effective over an extended period at offsetting sulfide oxidation. It does appear that bulk blending the lime is more effective than layered approaches, but more time will be needed to adequately address this alternative. Regardless, the bulk sediment and leachate EC of these materials remains high due to sulfates produced internally even though the originally entrained Cl salts do appear to leach relatively quickly. The limed materials also continued to elute very levels of Fe, Mn and S, which would be of concern with respect to groundwater contamination during active curing and oxidation.

Thus, over long periods, it appears that while the potential acidity in these materials can be successfully neutralized via addition of appropriate rates of agricultural limestone, that revegetation efforts will be hindered by soluble salt effects, which will not diminish until after

the sediment's sulfides have been completely neutralized and the bulk solution sulfates leach completely. The net groundwater effects of the combined leaching of Cl and sulfates will need to be addressed.

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