Appendix A:

Final Cumulative Report

Ecoflo® Spent Peat Project

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Objectives

The primary goal of this research program was to determine the potential for reuse of spent peat from Ecoflo® biofiltration systems as a soil amendment under eastern US regulatory conditions.

The specific objectives of the first part of this project (2008-2009) were:

1.1. To prepare a detailed review of regulations and procedures for U.S. states of interest to Premier Tech (e.g. MD, MN, NC, PA, VA, VT, WV) with respect to permitting/approval of all modes of beneficial reuse of the spent peat materials, including land application as a soil amendment.

1.2. To characterize and test samples of the spent peat product from multiple locations to corroborate basic properties of the spent peat and their variability.

1.3. To conduct our standard bioassay laboratory & greenhouse trials of the composted peat product for use as a soil amendment or a conditioner.

Progress and results from these objectives was reported to Premier Tech in December of 2009 and then reviewed in a follow-up visit by W.L. Daniels to Montreal in March, 2010. At that time, we committed to a limited range of follow-up trials and analyses to (A) produce a stabilized peat product that clearly met USEPA Part 503 biosolids criteria for land application as a Class A material and (B) screen the stabilized/treated material(s) again with our greenhouse bioassay for suitability as a beneficial soil amendment.

The specific objectives of the second part of this project (2010-2011) were then:

2.1. To test two USEPA Part 503 approved methods (for Class A biosolids) for reducing pathogens in the spent peat to produce a viable soil amendment to be used following changeover of spent peat at field sites.

2.2. To conduct our standard bioassay laboratory & greenhouse trials of the lime stabilized spent peat product for use as a soil amendment or a conditioner.

Objective 1.1. Evaluation of State Regulations and Procedures

The review of regulations and procedures for U.S. states of interest to Premier Tech (MD, MN, NC, PA, VA, VT, WV) with respect to permitting/approval of all modes of beneficial reuse of the spent peat materials, including land application as a soil amendment, has shown that the material, as is, falls under a solid waste category in most states, but since its source is from domestic septic systems, it is classified as septage. Therefore, the beneficial re-use of spent peat is generally governed by the states by following the U.S. EPA 40 CFR Part 503 rules, primarily to assure proper handling with respect to pathogen reduction and reducing vector attraction.

This section of this report was originally submitted in December of 2009 and has been edited and modified slightly here to reflect new findings and insights derived over the past two years from our interactions with USEPA and Virginia agencies on related regulatory issues.

For a copy of 40 CFR Part 503 in a PDF format see:
http://yosemite.epa.gov/r10/water.nsf/NPDES+Permits/Sewage+S825/$FILE/503-032007.pdf

The U.S. government has also published "A Guide to the Federal EPA Rule for Land Application of Domestic Septage to Non-Public Contact Sites (Agricultural Land, Forests, and Reclamation Sites), Discussed in Relationship to Existing State Rules and Other Federal Regulations of Septage" at http://adph.org/environmental/assets/septage_guide.pdf.

The above cited federal regulations form the underlying basis of the various states' regulations. Given below is the state-specific information relevant to the handling/re-use of the spent peat material. As noted later, however, it is important to point out that the USEPA also allows spent peat to be treated as "biosolids" via approved pathogen and vector reduction strategies (e.g. lime stabilization with specified pH x time x temperature levels) and then land-applied per relevant restrictions based on the level of treatment (e.g. Class A or B, etc.).

MARYLAND

Classification of spent peat: Septage, same category as sewage sludge (biosolids)

Main factor: Based on EPA 40 CFR 503 regulations

For handling and processing of sewage sludge:
Hussain Alhija
Chief Design and Certification Division
Waste Management Division
MD Dept. of the Environment,
Phone: (410) 537-3315

For handling, distribution of finished product:
Phil Davidson
Product Registration Supervisor

Maryland Dept. of Agriculture
State Chemist Section
50 Harry S. Truman Pkwy.
Annapolis, MD 21401
phone: 410-841-2721
fax: 410-841-2740
DavidsPB@mda.state.md.us

Sewage sludge fact sheet:
http://www.mde.maryland.gov/assets/document/factsheets/sewagesludge.pdf

MINNESOTA

Classification of spent peat: Septage, same category as sewage sludge (biosolids)

Main factor: Based on EPA 40 CFR 503 regulations

Minnesota strongly supports re-use of waste products. Hence for any materials not listed/already approved for land applications, one may petition to have the material included in a standing list of approved materials. To submit a proposal for a case specific beneficial use determination one may contact:

Geoff Strack
Solid Waste Permitting (Beneficial use of waste materials)
Minnesota Pollution Control Agency
520 Lafayette Rd. N.
Saint Paul , MN 55155-4194
Phone 651-757-2759
Fax 651-297-2343
E-mail geoffrey.strack@pca.state.mn.us

State Agency responsible for oversight:
Minnesota Pollution Control Agency: http://www.pca.state.mn.us/waste/sw-utilization.html

Specifically for septage: http://www.pca.state.mn.us/programs/ists/septage.html#minnesota

NORTH CAROLINA

Classification of spent peat: Septage, same category as sewage sludge (biosolids)

Main factor: Based on EPA 40 CFR 503 regulations

General Info: North Carolina recently passed new rules to specifically include peat from septic system to be classified as septage. Domestic septage treated to meet the standard for Class A sewage sludge in accordance with the federal regulations for pathogen and vector attraction reduction in 40 CFR Part 503, Subpart D, may be permitted by the Division for application to public contact site, home lawns and gardens, or to be sold or given away in a bag or other container, provided pollutant limits in 40 CFR 503.13 are not exceeded.

Contact:
Mike Scott
Division of Waste Management – Head, Septage Management
Department of Environment and Natural Resources
401 Oberlin Rd., Suite 150, Raleigh, NC 27605
(919) 508-8508

Govt. websites: http://www.wastenotnc.org/swhome/cla.asp

Composting/recycling contacts: http://www.p2pays.org/compost/contacts.asp

PENNSYLVANIA

Classification of spent peat: Septage, same category as sewage sludge (biosolids)

Main factor: Based on EPA 40 CFR 503 regulations

Pennsylvania has a two-step process. First Step: Apply to PA Dept. of Environment Protection to declare the product as "safe". Second step: Apply to the PA Dept. of Agriculture for proper labeling of the product for use as a soil amendment or fertilizer.

Contact at the PA DEP:
Ron Furlan; Chief, Permits Division of Municipal and Residual Waste
(717) 787-8184
Division of Municipal and Residual Waste: http://www.depweb.state.pa.us/dep/site/default.asp

Application: http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-9705

Contact at the PA Dept. of Agriculture:
Erin Bubb
PA Dept. of Agriculture
2301 N. Cameron St.
Harrisburg, PA 17110
(717) 772-5216

Other relevant info: Pennsylvania Septage Management Association at http://www.psma.net/

VERMONT

Classification of spent peat: Could not determine
Main factor: Based on EPA 40 CFR 503 regulations from Appendix B (see below)

AGENCY OF NATURAL RESOURCES
DEPARTMENT OF ENVIRONMENTAL CONSERVATION
Waste Management Division
West Office Building
103 South Main Street
Waterbury, Vermont 05671-0407
(802) 241-3444

Contact person that assisted us:
Cary Giguere
Agrichemical Management Section Chief
Vermont Agency of Agriculture
Agricultural Resource Management & Environmental Stewardship
116 State St.
Montpelier VT 05620
Cary.Giguere@state.vt.us

SOLID WASTE MANAGEMENT RULES
http://www.anr.state.vt.us/dec/wastediv/solid/pubs/SWMRules.pdf
Appendix B specifies the pathogen reduction procedures consistent with 40 CFR 503 procedures.

VIRGINIA

New sewage and septage handling regulations were recently approved by the Virginia Dept. of Environmental Quality (DEQ) to assume authority from the Dept. of Health (VDH). Spent peat is not mentioned directly in draft regulations, but we presume it will be classified as septage from DEQ's perspective and would need to meet USEPA 503 criteria for land application as either septage or biosolids depending on the treatment protocols utilized.

DEQ Contact: Neil Zahradka: nrzahradka@deq.virginia.gov

Soil amendments, conditioners and fertilizer products are regulated by the Virginia Dept. of Agriculture and Consumer Services (VDACS). VDACS and Virginia Tech collaborate on screening, bioassay and field plot protocols to allow for municipal, industrial and miscellaneous residuals to labeled for use and thereby exempted from solid waste categorization by DEQ. That being said, it is important to note the Virginia Department of Health currently operates under an established policy that spent peat must be disposed of in a landfill until new regulations or policies are developed.

WEST VIRGINIA

State regulations concerning sewage (including septage) handling and disposal can be found at: http://www.wvdhhr.org/phs/sewage/. Despite repeated attempts, we were not able to identify an individual at the state level with clear authority over land application. The website given above indicates that authority is given to local health and sanitation districts for permits and regulatory interpretations.

Objective 1.2. Chemical Characterization of Spent Peat and Compost

Methods

Two barrels of each of six spent peat samples were collected on May 19-20, 2009. At the time of sampling, the fresh peat had high moisture contents, ranging from 83%-88%. The sampling was documented with extensive photographs (Appendix 1) that show that despite a certain decomposition level, most of the spent peat materials sampled maintained a fibrous and porous structure. Once the filtering media life span has been reached, the media has to be replaced. At that point while the media still retains key essential properties (physico-chemical and hydrological), the initial structure of the peat has been altered. Through the years of use, the initial, identifiable plant features, light fibrous structure, aggregates and associated inter-granular pore space, gradually give way to a more amorphous heavier earthy matter with a less distinct peaty structure.

As can be seen from the surface of the peat as portrayed in the photographs in Appendix 1, the peat at this time showed that initial identifiable peat features (i.e., light fibrous structure and high porosity) were transformed to less distinctive peat characteristics following decomposition and transformation as discussed above. Subsamples of each main sample were collected for biological, chemical and nutrient characterization.

Approximately 1.5 m^3 of the spent peat, comprised of subsamples from all six locations, were loaded into a rotating compost drum (Photo 1) and amended over two weeks with 300 kg of poultry litter (3-2-3 N-P-K analysis), 72 kg of wood shavings, 1 8-kg bale of straw, and 18 kg of urea (46-0-0) as complementary feedstock designed to optimize the composting process. Wood shavings and straw were added to adjust total moisture content to no greater than 60%, the maximum desirable composting conditions, and to provide additional palatable C substrate for compost microorganisms. The spent peat, poultry litter and urea were added to optimize the C:N ratio (30:1) upon the addition of the high carbon wood shavings and straw. The rotating mixture was composted for three months, during which period the highest temperature reached 94° Fahrenheit (35° C). Such a temperature is considerably lower than 105° Fahrenheit, suitable for thermophilic composting, or 131° Fahrenheit (55° C), required for pathogen reduction. A summary of the compost additions and temperatures by date is provided in Appendix 2 along with detailed daily notes. We believe that the carbon provided by the spent peat was too degraded and that the wood shavings and straw too stable to provide a high energy source for microbial metabolism. Successful composting of the spent peat should be readily achievable with a feedstock recipe that contains an appropriate moisture content (50-60%), C:N ratio (25:1 to 35:1), and fresh carbon.

The compost was analyzed for biological, physical and chemical properties following attainment of maximum temperatures and subsequent decrease to ambient air temperature. Maturity was determined on fresh moist samples with the SOLVITA® respiration test for CO_2-respiration and NH_3 volatilization (http://solvita.com/compost-information). Following air drying at 160° Fahrenheit, samples were ground and screened through a 2 mm sieve in preparation for chemical analysis. Mehlich-1 extractable nutrients were analyzed by the method described in Mullins and Heckendorn (2009) using a Thermo Elemental ICAP 61E (Inductively Coupled Argon Plasma Atomic Emission Simultaneous Spectrometer). For total C and total N, samples were further ground (<53 μm) and analyzed with an Elementar CNS analyzer. Saturated paste electrical conductivity (EC) and pH were determined by the method of Rhoades (1982). Total elemental analysis was performed using U.S. EPA method SW 846-3051. Fecal coliforms and Salmonella were enumerated and reported using the spread plate technique as described in method 9215 "Heterotrophic Plate Count" in APHA (1998). CHROMagar salmonella medium was used for *Salmonella* and mI agar medium was used for coliforms.

Photo 1. Rotating compost drum.

Results

Compost Maturity

The results for the SOLVITA® respiration test for CO_2-respiration and NH_3 volatilization were:

- ***Potential phytotoxicity*** (as assessed by NH_3 concentration)

  Result: 0.1 mg NH_3 which indicates slight phytotoxicity (on a scale of very high - high - medium - slight – none).

- ***Stability*** (as assessed by CO_2 concentration)

  Result: 1% CO_2 which (on a scale from ambient to 20%) indicates that the composting process was finished.

- ***Maturity*** (as a function of NH_3 and CO_2)

  Result: the combined levels of NH_3 and CO_2 indicate that the aeration requirement was reduced, the compost was ready for curing, which was at the boundary of "active" and "finished" compost when tested.

Proper composting conditions were not met. The highly degraded, high moisture-containing peat required an ample volume of compostable feedstock of appropriate C, N, particle size distribution, and solids content to ensure that optimum temperatures were achieved. Thus, the various substrates that we added in our trial were not adequate to optimize the composting process.

Biological Properties of Compost

The results for *Salmonella* and *E. coli* counts and total C and N are presented in Table 1.1. All six spent peat samples tested negative for *Salmonella*. The data showed moderate levels for *E. coli* in all samples, and it was expected that the composting process would largely eliminate this pathogen indicator. Separate analysis of the VT Compost conducted after the completion of the composting process showed that *Salmonella* and *E. coli* were not detectable.

Table 1.1. Results of pathogen and carbon/nitrogen analysis for six spent peat samples and VT compost subsequently made from those six peat samples.

Analyte	Spent Peat Sample Number						
	# 1	**# 2**	**# 3**	**# 4**	**# 5**	**# 6**	**VT Compost**
Salmonella	ND*	ND	ND	ND	ND	ND	ND
E. coli (MPN/g†)	109	120	129	154	114	163	ND
C (%)	45.1	45.4	43.2	44.9	43.8	40.8	36.5
N (%)	1.2	1.4	1.4	1.5	1.3	1.2	3.3
C:N ratio	36	32	31	29	34	35	11

*ND: None Detected

†Most Probable Number (of bacterial colonies) per g.

Chemical Properties of Spent Peat and Compost

The elemental analysis data of the six spent peat samples and the compost (VT) made from these six samples is given in Table 1.2. The data document that the six spent peat samples were fairly homogenous in their elemental composition. All samples contained macro-nutrient elements essential for plant growth at levels that could result in a fertilization benefit for plant growth. No micronutrients or elements of concern (Se, Hg, Cr, Cd, etc.) were present at levels that we would predict as problematic for plant growth or the environment.

Table 1.3 presents extractable nutrient content and saturated paste EC and pH of the #6 spent peat sample, the composting processed product, and the topsoil used in the greenhouse experiment. Of concern was the very high EC (27.3 dS m^{-1}) of the VT Compost. Such a high EC was likely due to the high rates of nutrient-rich poultry litter and urea fertilizer added to optimize the C:N ratio of the feedstock. Subsequently, the soluble salt content (as assessed by EC) was too high for the compost to be suitable as a plant growth substrate without dilution (Table 1.3). Such high EC would be expected to inhibit seed germination and seedling vigor. The analytical data also indicated that the spent peat sample (# 6) had good plant nutritional mineral content with a soluble salt content that was not too high (EC = 3.40 dS m^{-1}) and a near ideal pH of 6.71.

Table 1.2. Results of elemental analysis for six spent peat samples and the VT Compost (VT) made from a blend of the six spent peat samples.

Elements	Detect. Limit	Spent Peat Sample Number						
		# 1	# 2	# 3	# 4	# 5	# 6	VT Compost
	mg/ kg							
Nitrogen (Kjeldahl)	100	14,400	15,200	10,000	15,800	14,300	11,000	39,100
Phosphorus	10	1100	700	1200	1100	2600	1500	9600
Potassium	100	400	700	500	500	500	500	17900
Sulfur	100	4300	5700	4800	6600	7500	5300	7400
Calcium	100	24,300	22,000	31,800	20,700	72,500	33,500	44,200
Magnesium	100	3400	4400	2600	1500	7700	6900	6900
Sodium	100	600	4200	4600	3500	900	2600	5600
Iron	1	1610	1460	1300	1500	3440	8690	18000
Aluminum	10	1560	650	920	1490	5480	3310	2090
Manganese	1	69	68	39	77	43	1290	795
Copper	1	75	66	215	425	202	45	497
Zinc	1	41	133	186	263	115	187	509
Cadmium	1	BDL*	BDL	BDL	BDL	BDL	BDL	BDL
Chromium	5	12	BDL	9	13	12	17	26
Nickel	5	7	BDL	9	6	6	10	16
Lead	5	BDL	BDL	8	8	6	BDL	BDL
Arsenic	1	BDL	BDL	1.1	1.5	1.3	BDL	2.3
Mercury	0.4	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Selenium	1	1	3	2.5	1.4	1.3	1.1	2.4
Molybdenum	5	BDL	BDL	BDL	BDL	BDL	BDL	12

*BDL: Below Detection Limit

Table 1.3. Saturated paste EC and pH, and Mehlich-1 extractable plant nutrients in the topsoil substrate, VT Compost, and spent peat # 6. Note the moderate nutrient levels in the prime farmland topsoil.

Material	Saturated Paste		Mehlich-1 extractable					
	EC	pH	P	K	Ca	Mg	Mn	Fe
	-dS/m-		mg/kg					
Topsoil	1.25	6.14	30	74	332	38	12	17
Spent peat # 6	3.40	6.71	55	655	3312	443	38	62
VT Compost	27.3	7.37	985	4974	1643	679	42	5

Previous proprietary trials conducted by Premier Tech in Quebec in 2002-03 indicated that spent peat can be successfully composted, achieving the proper thermophilic conditions (55°C) via the use of a 3:1 mix of spent peat and fresh chicken manure. They also reported that several commercial operations in Canada are successfully integrating spent peat into their compost blends. While, the composters claim to use the spent peat as a bulking structural agent, the highly decomposed form and the high moisture content of the peat which we attempted to compost would require a high volume of a dry carbon source of variable particle size distribution and a complementary nitrogen source to optimize moisture and C:N ratio.

Objective 1.3. Bioassay trials

Methods

The bioassay trial was designed to test for beneficial effects of Ecoflo® spent peat as a surface-applied amendment to agricultural soils and to observe any potential negative effects on soil properties and plant growth. The soil used as a substrate was the Old Hickory topsoil; a loamy sand Coastal Plain prime farmland topsoil (Dinwiddie County Virginia; Orangeburg series) with a pH of 6.5. The trial was conducted using snap beans (*Phaseolus vulgaris* L.) as an indicator plant sensitive to substrate chemical conditions (EC, pH, elemental toxicity) and tall fescue [*Schedonorus phoenix* (Scop.) Holub.] as a test crop that exhibits relative tolerance to low/high pH, metals, and salts.

Germination Trial Experimental Design and Treatments

Trials were conducted separately for fescue and snap beans. The treatments used were four peat application rates: 0%, 10%, 20%, and 30% (volume basis, but measured on a weight basis to reduce variability) of each of 2 amendment materials: VT Compost (made from a mixture of the 6 peat samples) and spent peat sample # 6 (stored in plastic sampling barrel). Control pots containing 100% topsoil were also used for each crop. The statistical design was a completely randomized block (CRB) with 4 replications per treatment combination.

Petri dishes were half filled with the respective treatment blend and seeded at 10 seeds per tray for snap beans and 20 seeds / tray for tall fescue. Trays were moistened and covered with a clear lid. Seed germination counts were taken 7 days after initial moistening of trays.

Greenhouse Bioassay Trial Experimental Design & Treatments

Greenhouse trials were conducted separately for fescue and snap beans. The treatments used were four peat application rates: 0%, 10%, 20%, and 30% (volume basis, but measured on a weight basis to reduce variability) of each of 2 amendment materials: VT Compost (made from a mixture of the 6 peat samples) and spent peat sample # 6 (stored in plastic sampling barrel). Control pots containing 100% topsoil were also used for each crop. The control pots were not fertilized but the topsoil used did contain residual nutrients. The statistical design was a completely randomized block (CRB) with 4 replications per treatment combination.

The total volume of substrate per pot was 700 ml / pot (900 g). Standard 12 cm diameter pots were used. Snap beans were seeded at 5 per pot and tall fescue at 50 seeds per pot on Oct. 17, 2009. During the experiment, soil moisture was maintained at approx. 80% of container capacity.

Data collection was as follows:

- General observations on seed germination and vigor of plants (see attached pictures.)
- After one month, pots were allowed to equilibrate at field capacity for 24 hours and then eluted with excess water to obtain 50ml (± 5ml) of leachate. This is a modification of the "pour-through" method of Wright (1986).
- Snap beans were harvested on Nov. 16, 2009. Tall fescue was clipped to 1 cm on Nov. 30, 2009. Total dry matter yield was determined after drying in a 60° C oven and weighing.

Results

Germination Bioassay Trial

The results from the germination trial were evident from the seed-count results (Fig. 1) and visual inspection (Photos 2 & 3). The spent peat (# 6) showed no adverse effects on the germination and emergence of tall fescue and snap bean seeds. The germination and emergence of snap bean and tall fescue seeds placed directly into the VT compost were reduced at the 10% amendment rate and higher. A more appropriate feedstock recipe could likely have improved the plant growth media value of the compost.

Overall, the negative effect on germination was surprisingly stronger for the tall fescue seed than the snap bean seed. This, however, does not mean that the effect was necessarily carried over to the actual growing phase of the plants. Inhibited or delayed germination will generally translate into reduced plant size/biomass yield at any given growth period compared to the control treatment. However, if the amendment actually supplies more essential nutrition to the surviving plants than the control treatment, plant biomass production may surpass that of the control treatment despite a lower initial plant count. This appears to be evident in the results of the greenhouse bioassay trial discussed below.

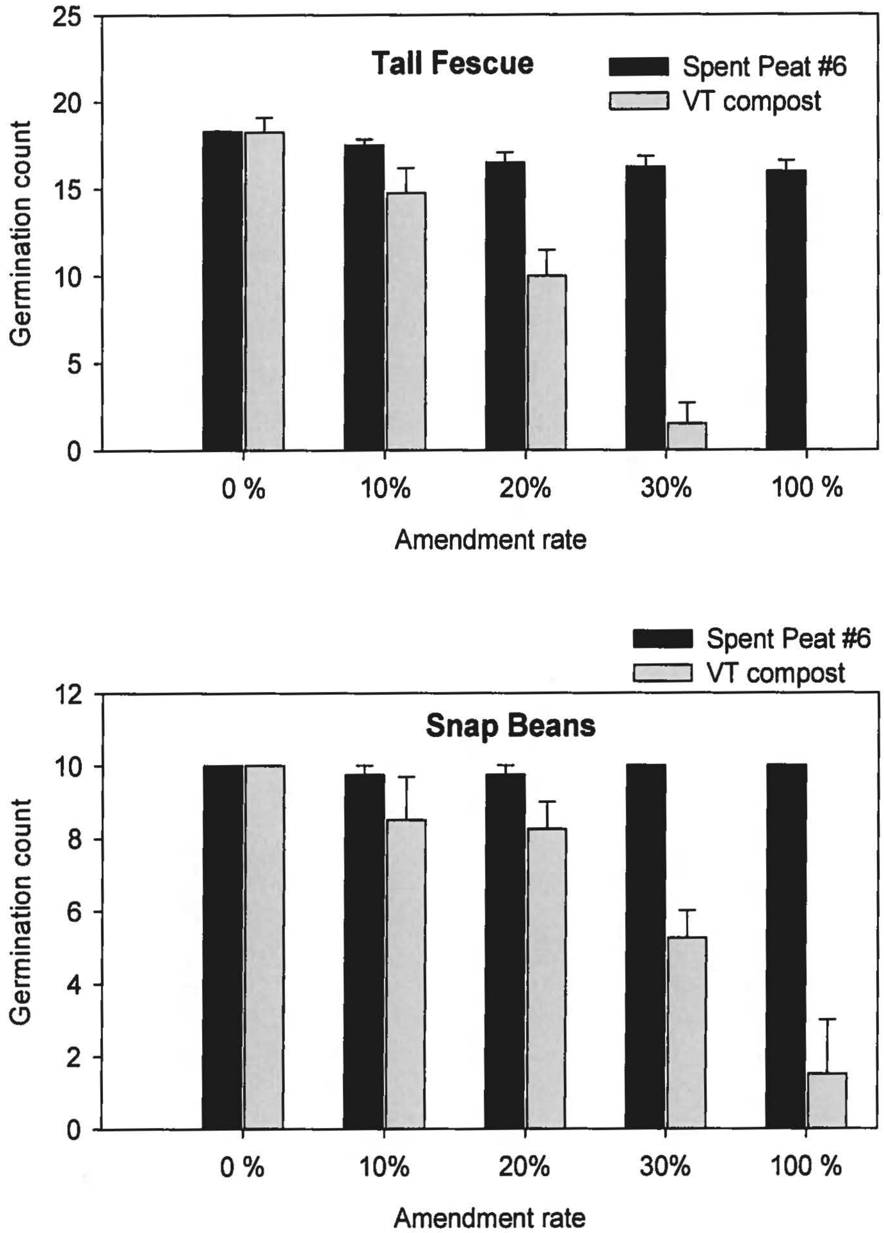


Figure 1. Seed germination trial: Effect of amendment material and rate on the germination of tall fescue and snap bean seed.

Photo 2. Tall fescue seed germination trial.

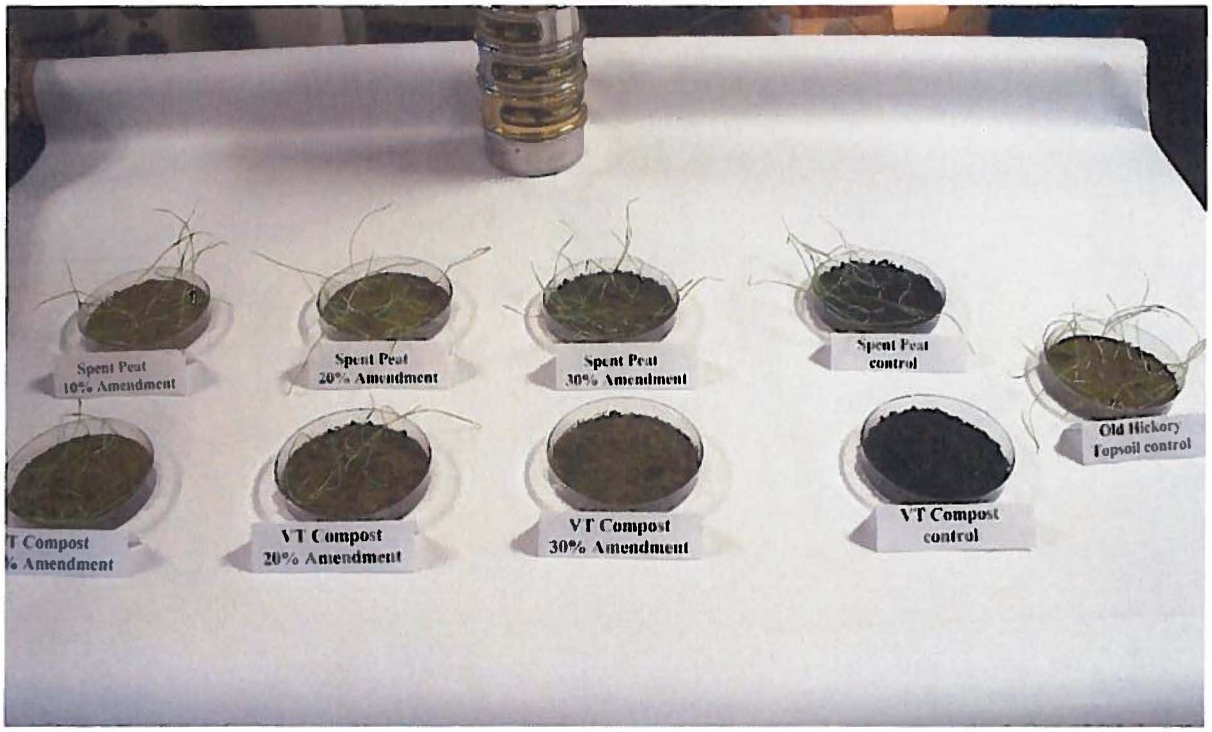
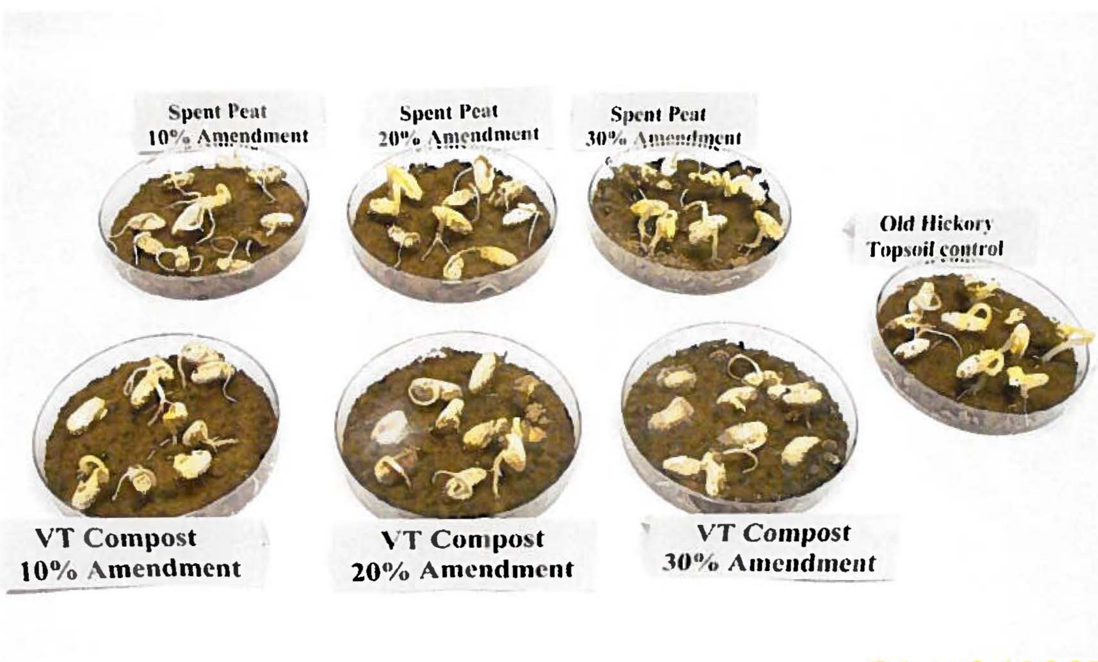


Photo 3. Snap beans seed germination trial.



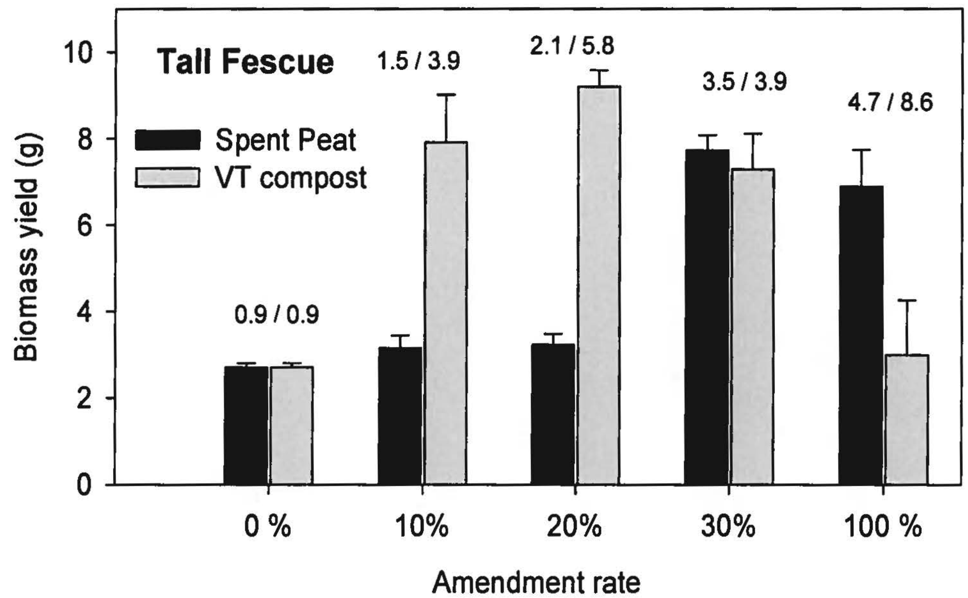
Greenhouse Bioassay Trial

Greenhouse bioassay trials provide important information regarding the potential effect of soil amendment materials on seedling establishment and plant growth. The loading rates utilized in this study were decided upon under the assumption that the materials would be used at relatively high rates (e.g. 10 to 30% by volume) as a soil conditioner and soil amendment rather than a fertilizer per se. We also intentionally used higher rates in this study to attempt to induce any phytotoxicities that might occur due to over-application of the materials.

As shown in Figure 2, tall fescue showed a significant growth response to both the VT compost and spent peat #6 but with different loading rate responses. While seed germination observed on the greenhouse pots was clearly inhibited (delayed) by excessive salts in the VT Compost, the plants that established grew quite well due to the very high nutrition supplied by the VT compost. The tall fescue (as expected) tolerated the high EC values. Contrary to the lab germination trial, some seed did germinate in the 100% VT compost material. It did appear that the surviving plants increased in growth after the leaching of those pots (for the determination of the EC) and subsequent lowering of the bulk EC in the soil substrate. However, the results from those pots are highly variable as indicated by the large standard error bar (Fig. 2). Tall fescue response to the spent peat was entirely positive and increased at higher loadings rates, particularly > 20%. Photos 4 and 5 depict the actual fescue response observed in the greenhouse.

Snap beans responded positively to VT compost addition at 10%, but were clearly suppressed or killed at higher loading rates due to soluble salt stress (Fig. 2). The snap beans exhibited a strong positive response to spent peat #6 with increasing biomass yield due to increasing amendment rates (Photos 6 and 7). Biomass yield was highest for beans grown in 100% spent peat #6. We attribute this response to the high fertility of the spent peat without raising the substrate EC to levels that would be detrimental to plant growth.

Figure 2. Biomass yield of tall fescue and snap beans in response to topsoil amended at different rates with spent peat # 6 and VT Compost along with respective pour-though leachate EC values.



NOTE: Values above bars are EC values (dS m-1) of pour-through leachates

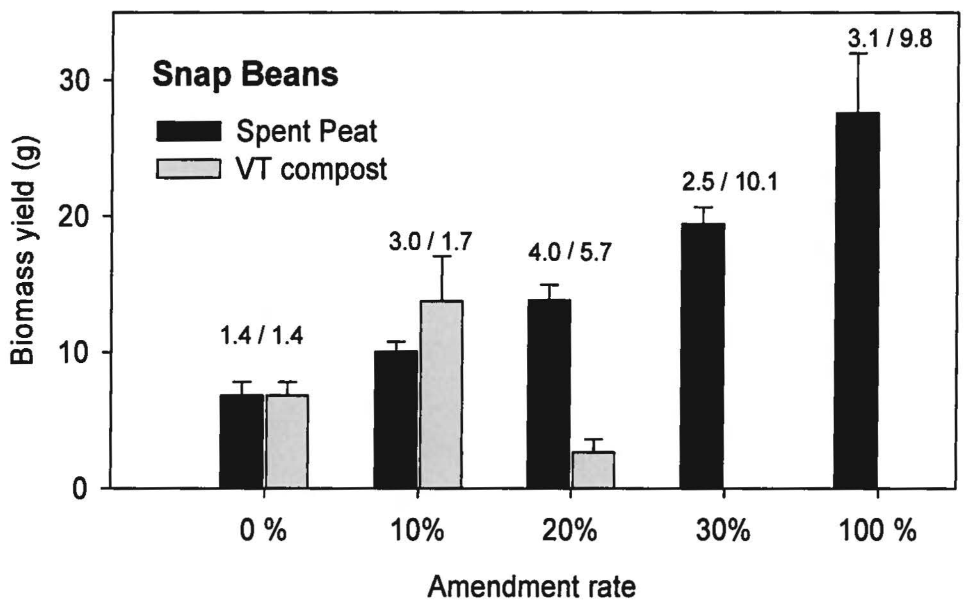


Photo 4. VT Compost amendment rate effects on tall fescue. Treatments from left to right are topsoil control, 10%, 20%, 30% and 100% VT Compost by volume.

Photo 5. Spent peat # 6 amendment rate effect on tall fescue. Treatments from left to right are topsoil control, 10%, 20%, 30%, and 100% spent peat # 6 by volume.

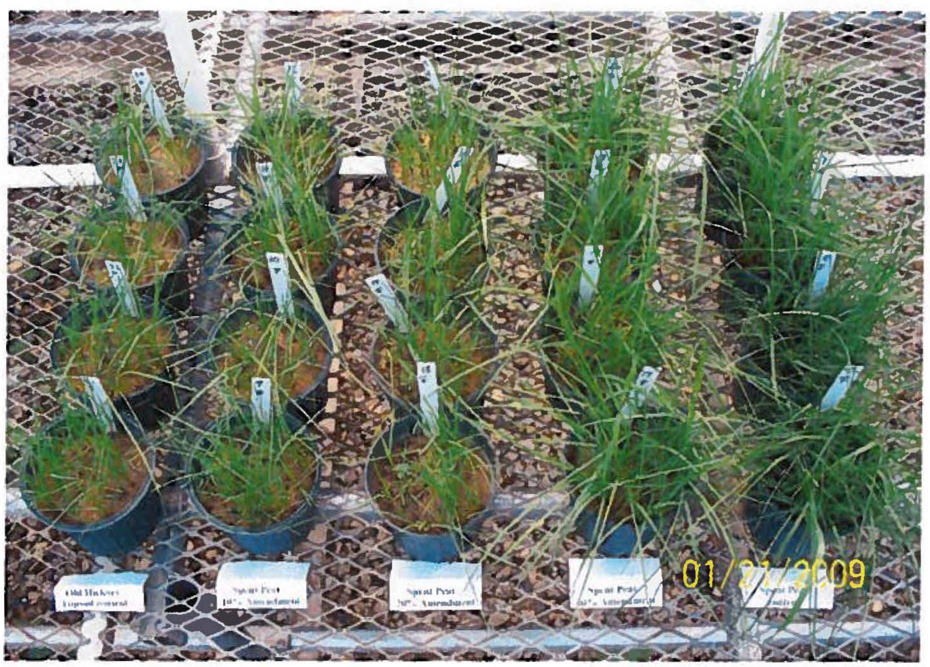
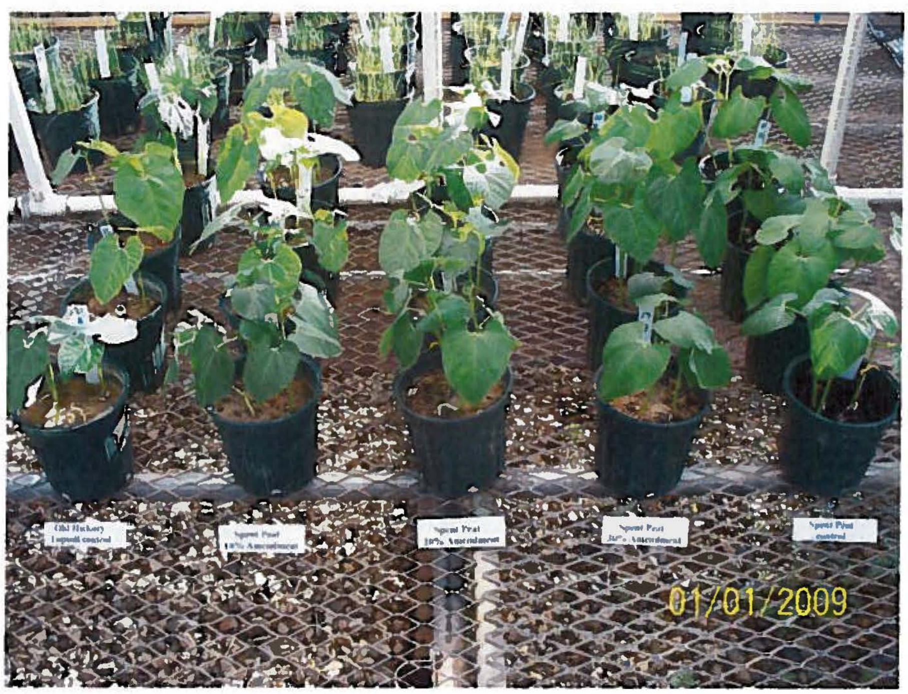


Photo 6. VT Compost amendment rate effect on snap beans. Treatments from left to right are 10%, 20%, 30% 100% VT Compost by volume and topsoil control.

Photo 7. Spent peat # 6 amendment rate effect on snap beans. Treatments from left to right are topsoil control, 10%, 20%, 30%, and 100% spent peat # 6 by volume.



Objective 2.1. Phase II Spent Peat Treatment and Pathogen Reduction Method Testing

Overview and Background

As discussed in the introduction, by the end of our primary work effort on this project (December, 2009) it was clear that any land application of spent peat in the USA would need to meet applicable USEPA Part 503 treatment standards for either septage (e.g. on-site lime treatment and soil incorporation within 24 hours) or via one of the approved part 503 protocols for biosolids for generation of either Class A or Class B materials. In addition, since the compost process that we (Virginia Tech) employed in our earlier work did not generate high enough temperatures to meet Class A criteria and contained considerable levels of soluble salts, we agreed to perform a follow-up research trial to (A) generate a treated/stabilized material that clearly met USEPA standards and criteria to be land-applied as a Class A biosolids material and then (B) to repeat our standard greenhouse bioassay on the produced material(s).

After subsequent communication and considerations, we agreed that we would generate two additional stabilized materials for greenhouse bioassay work under the assumption that Premier Tech would conduct sufficient in house process development work to specify the appropriate "recipes" for the procedures that we would then implement at Virginia Tech. Premier Tech did run a limited number of trials in Canada on the selected lime treatment protocols as discussed below and provided us with several proposed recipes. Thus, as described below, we conducted multiple process development trials in Blacksburg.

By the spring of 2011, we (Virginia Tech) and Premier Tech had reviewed the possible treatment alternatives available for the production of a Class A stabilized material that would then be suitable for local land application near the locations of their dispersed Ecoflo systems in the field. The USEPA (2003) lists six alternative methods for demonstrating Class A pathogen reduction in biosolids and the following two were selected:

Alternative 2 involves treatment of the sewage sludge with a high pH and high temperature process as described in [see Part 503.32(a) (4)]. According to the U.S. EPA (2003) "This alternative describes conditions of a high temperature-high pH process that has proven effective in reducing pathogens to below detectable levels. The process conditions required by the Part 503 regulation are:

- Elevating pH to greater than 12 and maintaining the pH for more than 72 hours.
- Maintaining the temperature above 52°C (126°F) throughout the sewage sludge for at least 12 hours during the period that the pH is greater than 12.
- Air drying to over 50% solids after the 72-hour period of elevated pH."

Alternative 5 involves the use of one of the Processes to Further Reduce Pathogens, or PFRP [see Part 503.32(a)(7)] listed in Appendix B of the Part 503 regulations. One of the PFRPs listed in Appendix B of 40 CFR Part 503 is pasteurization, in which the temperature of the sewage sludge is maintained at 70°C (158°F) or higher for 30 minutes or longer. This is the method used for Alternative 5 in the following studies.

Stabilization Trial Methods

Spent peat was collected from a single Ecoflo system located in Saluda, VA and taken to our facilities at Virginia Tech for testing of the U.S. EPA's Alternative 2 and 5 methods. The spent peat was far more decomposed than expected (see Photo 8). This filtering media had reached its overall lifespan, if not exceeding it. As can be seen in the photo below, there was limited fibrous structure remaining, the material was amorphous, non-aggregated, dense, and high in moisture content. On a larger operational scale, such material would have been blended with less decomposed material from different sites (as reflected in the first phase of our trials), providing a less decomposed and a better structured blend. However, due to operational and time constraints, it was decided to retain the current spent media for the lime stabilization trials, even if the degraded status of the material may have required higher than normal mixing and lime doses. A split of the raw peat product was taken at the time of field sampling and submitted for complete lab analysis and those data are reported later in Table 2.7 along with the properties of the two final lime stabilized peat products.

Spent peat samples collected at time = 0 were analyzed for pH, subsampled for determination of gravimetric water content, and placed in containers for delivery to the CSES Soil Microbiology lab for analysis for fecal coliforms and *Salmonella.* Fecal coliforms and Salmonella were enumerated and reported using the spread plate technique as described in method 9215 "Heterotrophic Plate Count" in APHA (1998). CHROMagar salmonella medium was used for *Salmonella* and ml agar medium was used for coliforms.

Photo 8. Degraded peat material sample in March, 2011, from Ecoflo unit in Saluda, VA.

Two trials of both alternatives were performed. Trial 1 began on March 29, 2011 and Trial 2 began on April 4, 2011. A rotating cement mixer (approximately 140 L volume) was used for mixing. Temperature, pH, and moisture content readings/samples were taken, the spent peat was placed into the rotating concrete mixer, and then either lime kiln dust (LKD) and quick lime (CaO) was added to the various trial runs as specified below and mixed for 5 minutes. The type and amount of liming agent added varied per trial and is specified in the results section.

For both methods, the material was placed back into the barrels. For Alternative 2, barrels were left open to allow evaporation. Temperature, pH, and moisture content were then monitored regularly. For alternative 2 (LKD), samples for measurement of fecal coliforms and salmonella were taken before lime addition, after 5 minutes of lime mixing, 2.5 hours after lime addition, and 72 hours after lime addition. An air-dry sample was taken at the end of the experiment. For alternative 2(CaO) samples for measurement of fecal coliforms and salmonella were taken before lime addition, after 5 minutes of lime mixing, 30 minutes after lime addition, and 72 hours after lime addition. An air dry sample was taken at the end of the experiment.

Material pH was determined with ATI Orion perPHecT LogR meter, model 370 with a glass electrode. The meter was calibrated to pH 7-10 and was periodically checked (to confirm stability of the calibration) with the pH 10 standard solution. Samples were collected at the times specified in the methods. Twenty cubic centimeters (cc) of material was retrieved from the top of the sample barrel and placed in a plastic beaker. Twenty cubic centimeters of de-ionized water was added and the mixture stirred with a glass stir bar for approximately one minute. Samples were tested again after 10 to 20 minutes to assure accuracy of the one minute readings. After a few seconds of settling, the probe was placed in the supernatant and a reading taken when the pH stabilized (indicated by the meter). Replicates were analyzed every few samples or when there was a question regarding a reading.

Immediately following the trials, concerns were raised by Premier Tech regarding the effect of higher than normal temperatures on the pH meter and electrode combination used. In response, we tested our meter+electrode in a pH 10.00 buffer solution across the full temperature range between 20 and 80° C and found a maximum variance of less than 0.05 pH units. Thus, we believe that all temperature values reported in the following tables are accurate.

Results

Trial 1: March 29, 2011

1. Alternative 2 - Attainment of high temp and pH with LKD

The spent peat was far more decomposed than expected, so LKD was added to the peat at higher rates than originally estimated by Premier Tech's preliminary work. We added 10.95 kg LKD to 58.08 kg peat, or approximately 188 g LKD/kg spent peat. The mixture did not immediately heat in the cement mixer, leading us to conclude that either (a) the LKD was not as alkaline as expected or (b) the mixture rate was inadequate to offset the high peat moisture content. The pH increased to 12.25 after 5 minutes of mixing, but the temperature did not increase during the two subsequent hours of monitoring (Table 2.1). Thus, we deemed the use of the LKD as an amendment to meet Alternative 2 under these mixture ratio conditions was not viable. The LKD apparently did not have the alkalinity required to achieve Alternative 2 minimum temperatures and we decided to terminate this trial.

Table 2.1. Temperature, pH, and pathogen data for Trial 1 of Alternative 2 on March 29, 2011, in which 10.95 kg LKD was added to 58.08 kg peat. The material did not reach the temperature required for Alternative 2, so the trial was aborted.

Time (minutes)	Temp. (°C)	pH	Fecal Coliforms (CFU/100ml)	Salmonella (CFU/100ml)
Initial (no lime addition)	11	7.12	3960	10600
0 (5 min of lime mixing)	19	12.25	3100	10200
10	23			
20	23			
30	23			
720 (12 hr)	30			

2. Alternative 5 - PFRP pasteurization with CaO

Because of the decomposed state of the spent peat, CaO was also added to the peat at higher rates than originally specified. We added 12.4 kg of CaO to 74.36 kg moist spent peat (86% moisture), or approximately 166 g CaO/kg spent peat.

Upon addition of the newly calculated lime rate and blending in a cement mixer for 5 minutes, the rapidly heating spent peat-lime mixture was transferred into a barrel in a greenhouse for continual monitoring. The temperature rose to 57° C within 15-30 minutes but did not surpass 62° C throughout the next 12 hours (Table 2.2). The pH of the mix surpassed 12.0 within the first 15 minutes and remained above 12 during the entire initial (i.e. 12-hr) period. We continued to monitor pH for 72 hours because we believed this that treatment, while not meeting the requirements for Alternative 5, would achieve Alternative 2 standards. After 12 hours, the temperature had dropped to 52.2° C and the pH was still >12, confirming our expectations.

Table 2.2. Temperature, pH, moisture content, and pathogen data for Trial 1 of Alternative 5 on March 29, 2011, in which 12.4 kg CaO was added to 74.36 kg peat. The material did not reach the temperature required for Alternative 5, so the trial was continued as Alternative 2.

Time (minutes)	Temp. (°C)	pH	Additional pH reading	% Water	Fecal Coliforms (CFU/100ml)	Salmonella (CFU/100ml)
Initial (no lime addition)	10	7.25		86	3960	10600
0 (5 min of lime mixing)	49	12.13			3100	10800
10	51	12.12				
20	55	12.22				
30	56	12.23			2800	8000
120 (2 hr)	58	12.18				
720 (12 hr)	52	12.05	12.11	68		
1440 (24hr)	41	12.01	12.02			
2280 (48hr)	22	12.06	12.08			
4320 (72hr)	22	11.79		65	<10	<10
End of Experiment (Air Dry)				54	<10	<10

Trial 2: April 4, 2011

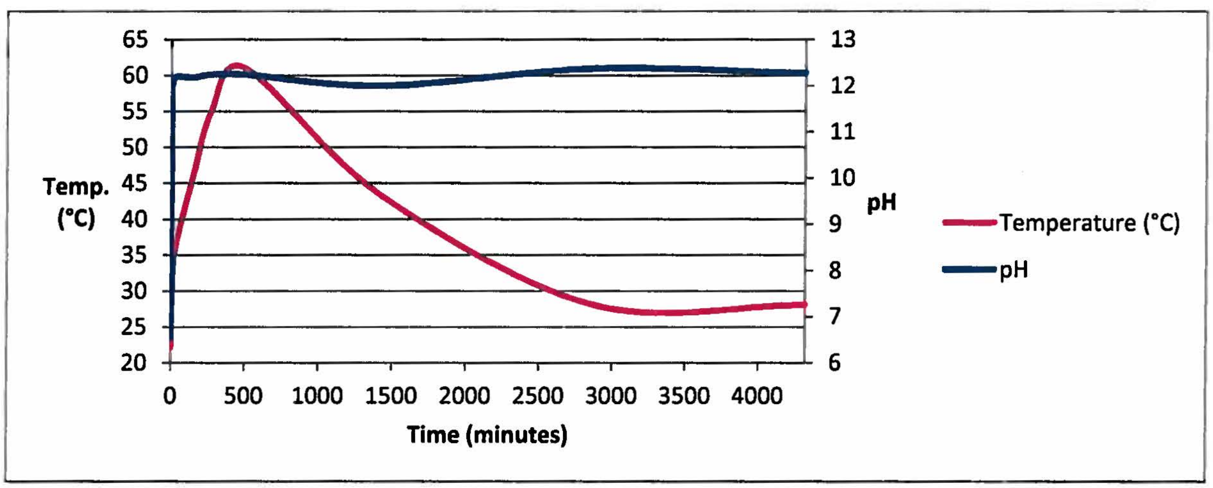
1. Alternative 2 - Attainment of high temp and pH with LKD

For Trial 2 of Alternative 2, we added 19.61 kg LKD to 63.01 g spent peat or approximately 311 g LKD/kg spent peat. The mixed materials began to heat up significantly at 30 minutes and continued to heat progressively for 8 hours (Table 2.3 and Figure 3), and maintained a pH of ≥12 during the same period. This trial was deemed a success because the CaO was alkaline enough at the rate calculated to achieve Alternative 2 pathogen reduction criteria as based on temperature and pH values.

Table 2.3. Temperature, pH, moisture content and pathogen data for Trial 2 of Alternative 2 on April 4, 2011, in which 19.61 kg LKD was added to 63.01 kg peat.

Time (minutes)	Temp. (C)	pH	% Water	Fecal Coliforms (CFU/100ml)	Salmonella (CFU/100ml)
Initial (no lime addition)	22	6.58	86	1860	1000
0 (5 min of lime mixing)	27	12.06	59		
10	31	12.04			
20	31				
30	36	12.19			
150 (2.5 hr)	46	12.18		<10	<10
270 (4.5 hr)	55	12.24			
495 (8.25hr)	61				
720 (12hr)	53				
1230 (20.5hr)	49				
1440 (24hr)	43	12.00	56		
2880 (48hr)	28	12.37			
4320 (72hr)	28	12.27		<10	<10
End of Experiment (Air Dry)			56	<10	<10

Figure 3. Graphic representation of temperature and pH for Trial 2 of Alternative 2 on April 4, 2011, in which 19.61 kg LKD was added to 63.01 kg peat. Mixed materials heated progressively and maintained a temperature of >52° C for at least 12 hours (720 minutes), and maintained a pH of ≥12.0 for 72 hours (4,320 minutes), thus meeting the requirements for the U.S. EPA's Alternative 2.



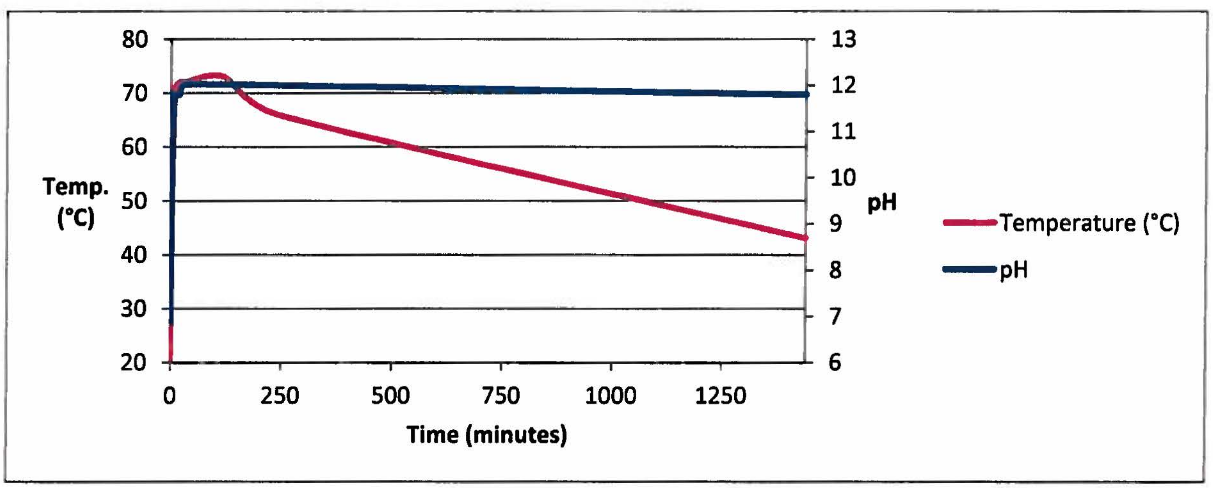
2. Alternative 5 - PFRP pasteurization with CaO

For Trial 2 of Alternative 5, we added 13.78 kg CaO to 55.12 kg peat, or approximately 250 g/liter. The higher rate of CaO drove the temperature well above 70° C for over 30 minutes (Table 2.4 and Figure 4), which met the requirements for Alternative 5. However, measured pH did not quite reach 12.0. Regardless, we viewed this trial as successful due to the high temperature achieved, the low final pathogen count data and the fact that the measured pH was above or very close to 12.0 for an extended period of time.

Table 2.4. Temperature, pH, moisture content and pathogen data for Trial 2 of Alternative 5 on April 4, 2011, in which 13.78 kg CaO was added to 55.12 kg peat.

Time (minutes)	Temp. (°C)	pH	% Water	Fecal Coliforms (CFU/100ml)	Salmonella (CFU/100ml)
Initial (no lime addition)	20	6.92	86	1860	1000
0 (5 min of lime mixing)	60	11.81	55.3	<10	<10
10	71	11.80			
20	72	11.81			
30	72	12.01		<10	<10
120 (2 hr)	73	12.02			
240 (4 hr)	66				
720 (12hr)	46				
1440 (24hr)	43	11.80	54	<10	<10
End of Experiment (Air Dry)			54	<10	<10

Figure 4. Graphic representation of temperature and pH for Trial 2 of Alternative 5 on April 4, 2011, in which 13.78 kg CaO was added to 55.12 kg peat. The temperature was over 70° C for at least 120 minutes, which met the requirements for the U.S. EPA's Alternative 5.



Thus, at the close of this portion of the follow-up peat stabilization research program, we were satisfied that either LKD or CaO could be used with the appropriate dose rates to achieve the specified Part 503 time x temperature and pH criteria for Alternative 2, but Alternative 5 most likely requires CaO. Both April 4 treated materials approached the 50% solids criteria immediately after the end of the process runs and both were more than 90% solids following several weeks of air-drying in our greenhouse. Thus we see no issues with meeting all of the combined pH, temperature, time and solids contents requirements of Alternatives 2 and 5.

We selected the two last materials generated (April 4 runs) for the follow-up detailed characterization and greenhouse bioassay work discussed below.

Objective 2.2. Greenhouse Bioassay of Lime Stabilized Spent Peat Materials

The greenhouse bioassay trial was designed to document the effects of lime stabilized spent peat on plant growth and soil properties. The trial was conducted using soybeans (*Glycine max* (L.) Merr.) as an indicator plant sensitive to substrate chemical conditions (EC, pH, elemental toxicity) and tall fescue [*Schedonorus phoenix* (Scop.) Holub] as a test crop that exhibits relative tolerance to low/high pH, metals, and salts.

Methods

Residuals testing and soils analysis

The lime kiln dust-treated peat (LKD peat) and the quick lime-treated spent peat (CaO peat) used in the bioassay were derived from the pathogen reduction trials described in part 2.1. The Piedmont soil used as the substrate for the "wet-dry" incubation and the bioassay was collected in Appomattox, VA, and was the 0-15 cm layer of a Cecil/Pacolet series (Typic Hapludults; fine, kaolinitic, thermic). This soil is a typical Virginia Piedmont soil with native levels of whole soil acidity requiring periodic liming. As described below, the loading rates of the lime-stabilized peat will be most likely limited by their high pH and total lime content (CCE), thus we decided to run this trial on an acidic soil that would require lime additions.

Percent solids, total elemental analysis, alkalinity, nutrient content, pH, and volatile solids for data for both the CaO and LKD stabilized spent peat was determined by AWS Laboratories, Inc., Richmond, VA. Electrical conductivity (EC) and pH was determined on saturated paste extracts of the LKD peat and the CaO peat with an Oakton con 100 series EC probe and an ATI Orion perPHecT LogR meter, model 370 with a glass electrode. The Calcium Carbonate Equivalence (CCE) of each lime stabilized peat material was determined by the AOAC method (2002). This technique involves reaction of the material with a fixed quantity of strong HCl and back-titration of the unreacted acid. A parallel analysis is run with pure $CaCO_3$ and then results expressed as % CCE.

As a laboratory check to confirm the actual liming efficacy of the amendments, "wet-dry" incubation pH and EC data was determined on the LKD peat and the CaO peat applied at 0.5x, 1x, and 2x CCE to the Piedmont soil (lime requirement = 3.5 g CCE/1000 g soil) with an additional treatment of reagent grade $CaCO_3$ at 1x CCE. Each mixture was moistened to approximate field capacity and then dried in a 55° C oven. The wetting and drying were repeated 4 times and then pH and EC were determined on a 1:1 subsample/water mix filtered through Whatman 42 filter paper. Each mixture went through five wetting and drying cycles. Solution EC was determined with an Oakton con 100 series EC probe and pH with a Fisher Scientific Accumet pH meter with a glass electrode.

Bioassay methods

The Piedmont soil used in the greenhouse bioassay were dried and sieved to approximately 1.2 cm. Amendments (Table 2.5) were then added to 800 grams of the Piedmont soil, mixed thoroughly, and placed into 15 cm wide plastic pots lined with filter paper.

The following treatments were used:

- Control - no added lime
- Control 1x CCE $CaCO_3$
- Lime Kiln Peat 0.5x CCE
- Lime Kiln Peat 1x CCE
- Lime Kiln Peat 2x CCE
- Quick Lime Peat 0.5x CCE
- Quick Lime 1x CCE
- Quick Lime Peat 2x CCE

The statistical design was a completely randomized block (CRB) with 4 replications per treatment combination.

Table 2.5. Amount of lime or lime-stabilized peat added per pot by treatment in the greenhouse bioassay. Each pot contained 800 g Piedmont soil (lime requirement = 3.5 g CCE/1000 g soil). The amount of peat added was corrected to account for percent moisture: 4.8% for the LKD peat and 3.8% for the CaO peat.

Treatment	**Lime or Lime-stabilized Peat per pot (g)**
Control - no added lime	0
Control - 1x CCE $CaC0_3$	2.80 g
LKD Peat - 0.5x CCE	2.15 g
LKD Peat - 1x CCE	4.30 g
LKD Peat - 2x CCE	8.20 g
CaO Peat - 0.5x CCE	1.81 g
CaO -1x CCE	3.62 g
CaO - Peat 2x CCE	7.24 g

Both the soybeans and tall fescue were planted on Sept. 20, 2011. Soybeans were pre-treated with Seedmate® Isotox Seed Treater and soybean inoculant before planting. Soybeans were seeded at 3 seeds/pot, and thinned to 2 plants per pot on Sept. 30, and 1 plant per pot on Oct. 4. Tall fescue was seeded at 2 grams/pot. Pots were placed under mist irrigation during germination and growth with supplemental hand watering as necessary.

After germination, Peters Professional 20-20-20 fertilizer to equal 112 kg/ha N, P, and K was applied in two separate applications on Sept. 25 and Oct. 12. Tall fescue was clipped to 5 cm once on Oct. 4. These clippings were saved and weighed with final yields. On Oct. 24, soybeans and fescue were clipped to 1 cm, and dried in 60 degree oven, and weighed to get a total plant weight per pot.

The soil from each pot was then dried and subsampled for analysis for pH, extractable nutrients, and total C and N. Mehlich-1 extractable nutrients on the soils from the bioassays were analyzed by the method described in Mullins and Heckendorn (2009) using a Thermo Elemental ICAP 61E (Inductively Coupled Argon Plasma Atomic Emission Simultaneous Spectrometer). For total C and total N on the bioassay soils, samples were powder-ground (<53 μm) and analyzed with an Elementar CNS analyzer.

Results

Peat and Soil Characterization

The total analysis data for the original peat and the two lime stabilized samples are presented in Table 2.6 and reveal no levels of concern for heavy metals or other elements and corroborates our lab determinations for % solids, expected Ca content etc. The LKD was slightly higher in certain metals (e.g. Al, Cd and Fe), but not at levels of regulatory concern.

Table 2.6. Percent solids, total elemental analysis, alkalinity, nutrient content, pH, and volatile solids in LKD and CaO stabilized spent peat (Analyzed by AWS Laboratories, Inc.).

Parameter	Spent peat before stabilization	LKD-stabilized spent peat	CaO-stabilized spent peat	Method
Solids (%)	15.5	91.3	93.2	SM18/2540G
Al (mg/kg)	657	8600	1720	SW6010C
As (mg/kg)	<3.2	15.2	2.86	SW6010C
Cd (mg/kg)	<3.2	0.648	<0.536	SW6010C
Ca (mg/kg)	22,188	298,000	405,000	SW6010C
Cr (mg/kg)	<3.2	10.4	2.92	SW6010C
Cu (mg/kg)	48.1	37.7	29.5	SW6010C
Fe (mg/kg)	735	4790	1290	SW6010C
Pb (mg/kg)	26.1	20.6	34.0	SW6010C
Mg (mg/kg)	961	3640	3680	SW6010C
Mn (mg/kg)	29.7	30.4	28.8	SW6010C
Hg (mg/kg)	0.058	0.057	0.026	SW7471C
Mo (mg/kg)	<16.1	4.33	3.10	SW6010C
Ni (mg/kg)	<3.2	12.2	2.10	SW6010C
K (mg/kg)	657	2020	440	SW6010C
Se (mg/kg)	<16.1	<2.74	<2.68	SW6010C
Na (mg/kg)	5688	1720	1570	SW6010C
Zn (mg/kg)	112.9	46.3	42.1	SW6010C
Alkalinity (mg/kg)	13,352	515,000	526,000	Calculated
NH_4-N (mg/kg)	489	<10.9	<10.7	SM18/2320B
NO_3-N (mg/kg)	<64	<10.9	<10.7	EPA350.1/R2.0
NO_2+NO_3-N (mg/kg)	<64	<10.9	<10.7	SM18/4500F
NO_2-N (mg/kg)	<13	<2.2	2.2	SM18/4500B
Organic N (mg/kg)	6450	200	682	Calculated
pH (mg/kg)	47.1	12.3	12.2	SW9045D
Total P (mg/kg)	485.7	163	58.0	SM18/4500-P E
Total Kjeldahl N (mg/kg)	6966	202	682	EPA351.2/R2.0
Volatile solids (mg/kg)	580, 5000	148,000	128,000	SM18/2540E

The wet-dry lime incubation clearly confirmed our estimate that the LKD stabilized peat contains approximately 70% CCE and the CaO stabilized materials contains approximately 80% CCE (Tables 2.7 and 2.8). Thus, these materials' land application will more than likely be limited by their liming efficacy as predicted by CCE.

Table 2.7. Calcium Carbonate Equivalent (CCE), saturated paste pH and EC, and percent C and N in LKD and CaO stabilized spent peat.

Sample ID	CCE	Saturated Paste		C	N
		pH	EC		
	-%-		--mS/cm--	----%----	
LKD Peat	68.69	12.19	9.92	15.00	0.254
CaO Peat	80.27	12.09	9.63	15.06	0.269

Table 2.8. Soil pH for Piedmont soil with 0.5x, 1x, and 2x CCE LKD peat, 0.5x, 1x, and 2x CCE and the CaO peat applied at to the Piedmont soil with an additional treatment of 1X $CaCO_3$ before, during and after four wetting and drying cycles.

Treatment	pH				
	27-Jul	3-Aug	9-Aug	16-Aug	22-Aug
Control (no amendment)	4.53	4.48	4.58	4.55	4.53
Control (no amendment)	4.54	4.34	4.84	4.60	4.55
Control (no amendment)	4.48	4.66	4.60	4.53	4.57
1x CCE $CaCo_3$	6.47	6.43	6.68	6.62	6.59
1x CCE $CaCo_3$	6.29	6.19	6.59	6.69	6.65
1x CCE $CaCo_3$	6.28	6.43	6.49	6.60	6.62
0.5x CCE LKD Peat	5.09	5.05	5.54	5.52	5.57
0.5x CCE LKD Peat	4.80	5.22	5.43	5.43	5.54
0.5x CCE LKD Peat	5.22	5.07	5.54	5.53	5.53
1x CCE LKD Peat	6.19	6.74	6.63	6.60	6.62
1x CCE LKD Peat	6.72	6.64	6.73	6.72	6.66
1x CCE LKD Peat	6.36	6.70	6.89	6.84	6.71
2x CCE LKD Peat	7.16	7.56	7.56	7.55	7.49
2x CCE LKD Peat	7.00	7.61	7.58	7.56	7.55
2x CCE LKD Peat	7.16	7.53	7.56	7.62	7.54
0.5x CaO Peat	4.75	5.18	5.52	5.61	5.69
0.5x CCE CaO Peat	4.98	5.29	5.51	5.58	5.55
0.5x CCE CaO Peat	5.33	5.25	5.35	5.41	5.37
1x CCE CaO Peat	5.24	5.75	6.52	6.73	6.66
1x CCE CaO Peat	5.19	6.56	6.53	6.76	6.71
1x CCE CaO Peat	5.06	6.30	6.41	6.68	6.84
2x CCE CaO Peat	6.30	7.44	7.46	7.59	7.53
2x CCE CaO Peat	5.98	7.42	7.54	7.69	7.69
2x CCE CaO Peat	6.53	7.52	7.56	7.74	7.65

Greenhouse bioassay

The soybean plants in the bioassay showed no phytotoxic symptoms that could be attributed to treatment (Photos 9 and 10). Germination rates were similar among treatments (Table 2.9), and soybean yields were not significantly different among treatments (Figure 5).

Photo 9. Soybean plants growing in soil amended with LKD-stabilized peat, and limed and unlimed controls. Photo was taken just before harvest on Oct. 24, 2011.

Photo 10. Soybean plants growing in soils amended with CaO-stabilized peat, and limed and unlimed controls. Photo was taken just before harvest on Oct. 24, 2011.

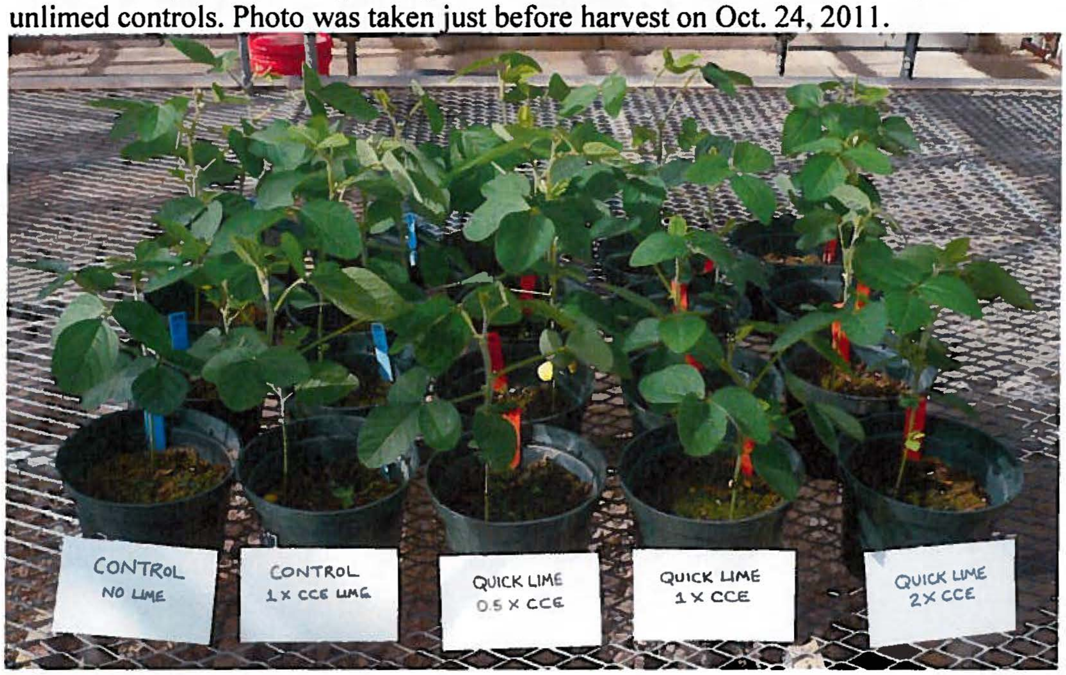
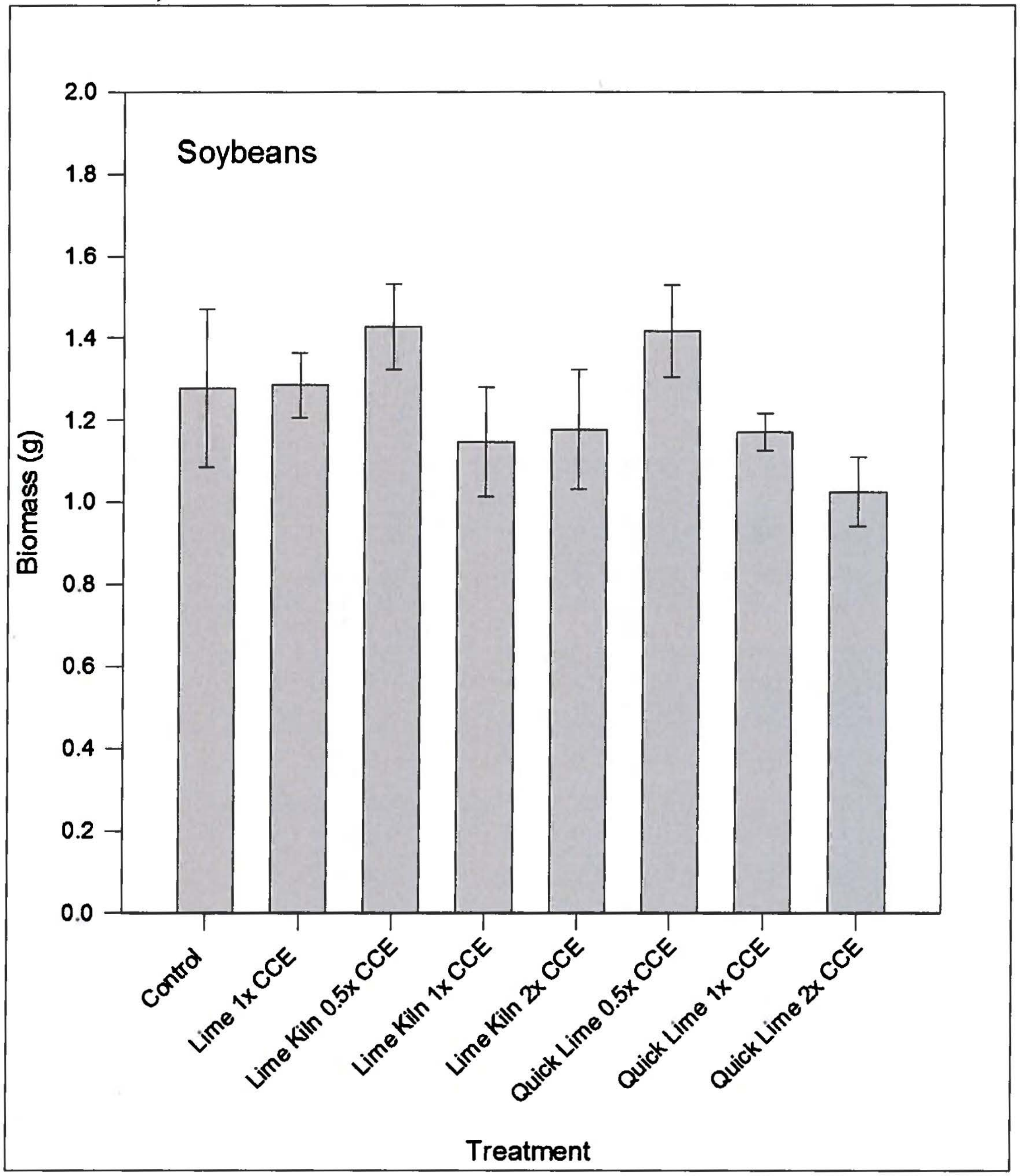


Table 2.9. Soybean germination count from greenhouse bioassay on 2 October 2011. Three soybean seeds were planted in each pot.

Treatment	Rep	Number of soybean seeds germinated
Control - no added lime	1	3
Control - no added lime	2	2
Control - no added lime	3	2
Control - no added lime	4	1
Control 1x CCE $CaC0_3$	1	2
Control 1x CCE $CaC0_3$	2	3
Control 1x CCE $CaC0_3$	3	1
Control 1x CCE $CaC0_3$	4	2
Lime Kiln Peat 0.5x CCE	1	2
Lime Kiln Peat 0.5x CCE	2	2
Lime Kiln Peat 0.5x CCE	3	2
Lime Kiln Peat 0.5x CCE	4	3
Lime Kiln Peat 1x CCE	1	2
Lime Kiln Peat 1x CCE	2	2
Lime Kiln Peat 1x CCE	3	2
Lime Kiln Peat 1x CCE	4	2
Lime Kiln Peat 2x CCE	1	2
Lime Kiln Peat 2x CCE	2	3
Lime Kiln Peat 2x CCE	3	3
Lime Kiln Peat 2x CCE	4	1
Quick Lime Peat 0.5x CCE	1	2
Quick Lime Peat 0.5x CCE	2	2
Quick Lime Peat 0.5x CCE	3	1
Quick Lime Peat 0.5x CCE	4	1
Quick Lime Peat 1x CCE	1	2
Quick Lime Peat 1x CCE	2	3
Quick Lime Peat 1x CCE	3	3
Quick Lime Peat 1x CCE	4	1
Quick Lime Peat 2x CCE	1	2
Quick Lime Peat 2x CCE	2	3
Quick Lime Peat 2x CCE	3	3
Quick Lime Peat 2x CCE	4	1

Figure 5. Mean and standard error of the mean for soybean dry weights from greenhouse bioassay, by treatment. There was no significant difference among treatment means ($P \leq 0.01$; Fisher's LSD).



Fescue biomass weights (Figure 6) were highest in the LKD stabilized peat 2x CCE treatment, and lowest in the CaO stabilized peat 0.5 and 1.0x CCE treatments. None of the treatments, however, had biomass weight that was significantly different than either the unlimed or limed control soils, or both. Fescue visual appearance did not differ among treatments (Photos 11 and 12).

Figure 6. Mean and standard error of the mean for tall fescue dry weights from greenhouse bioassay, by treatment. Means with different letters are significantly different ($P \leq 0.01$; Fisher's LSD).

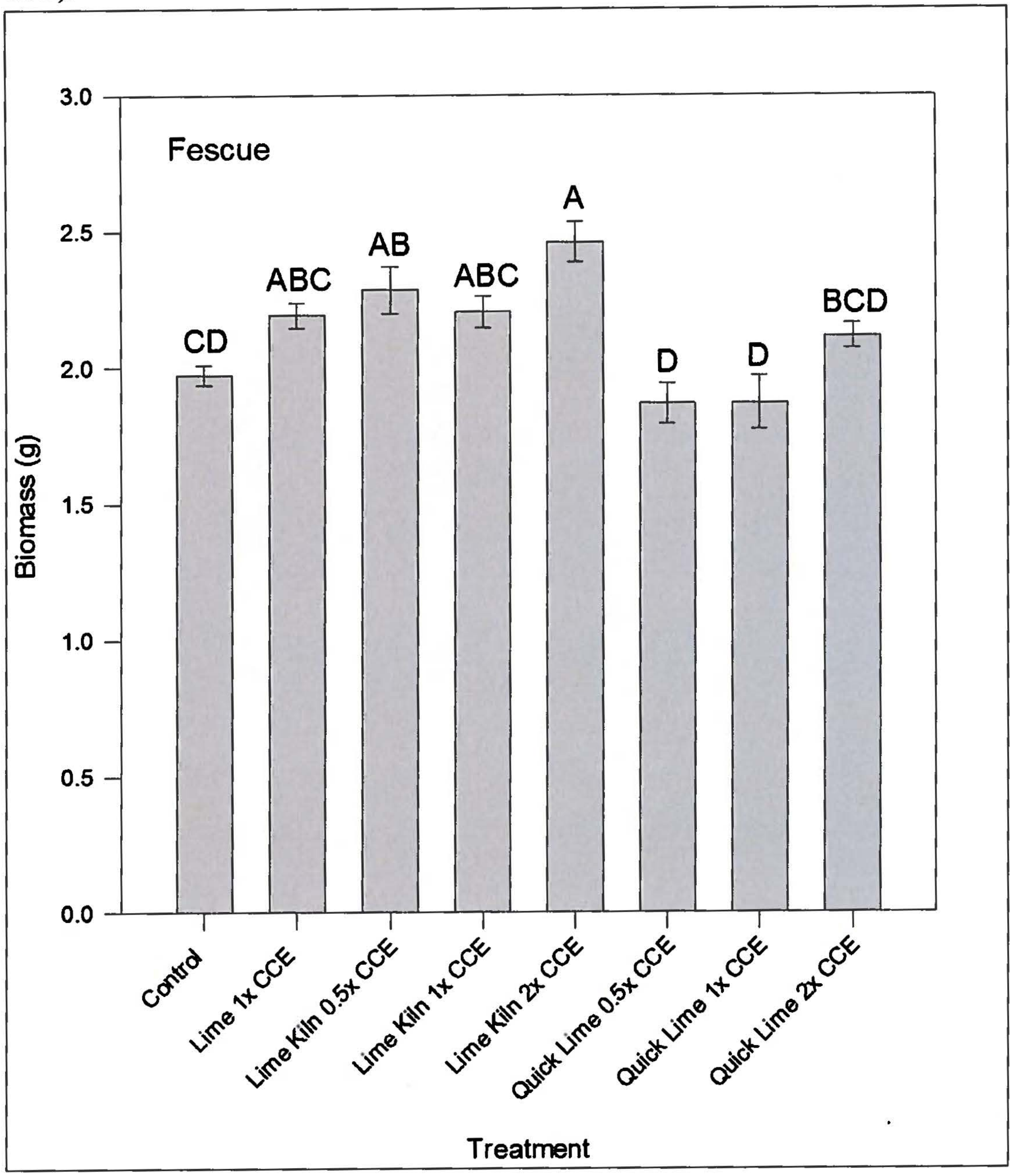


Photo 11. Tall fescue growing in soil amended with LKD-stabilized peat and limed and unlimed controls. Photo was taken just before harvest on Oct, 24, 2011.

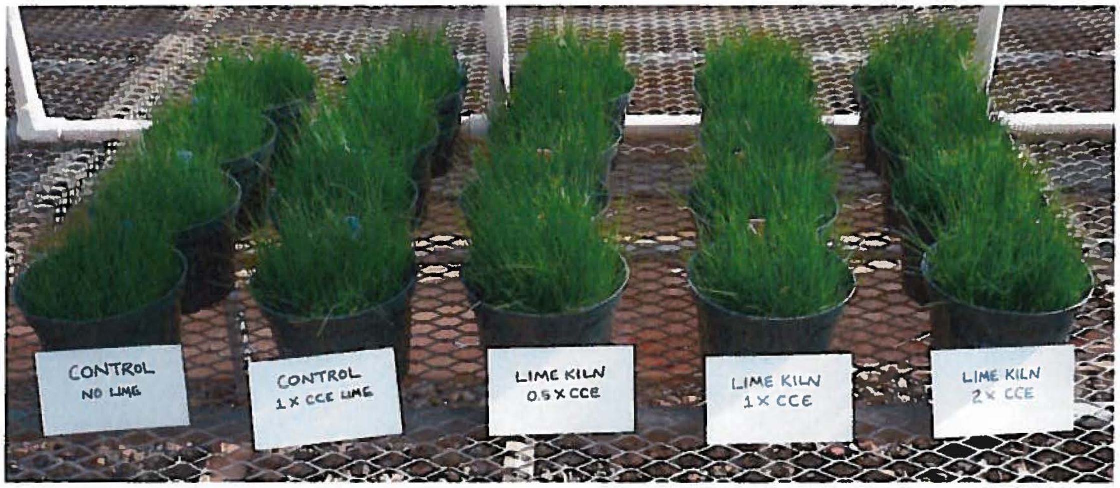
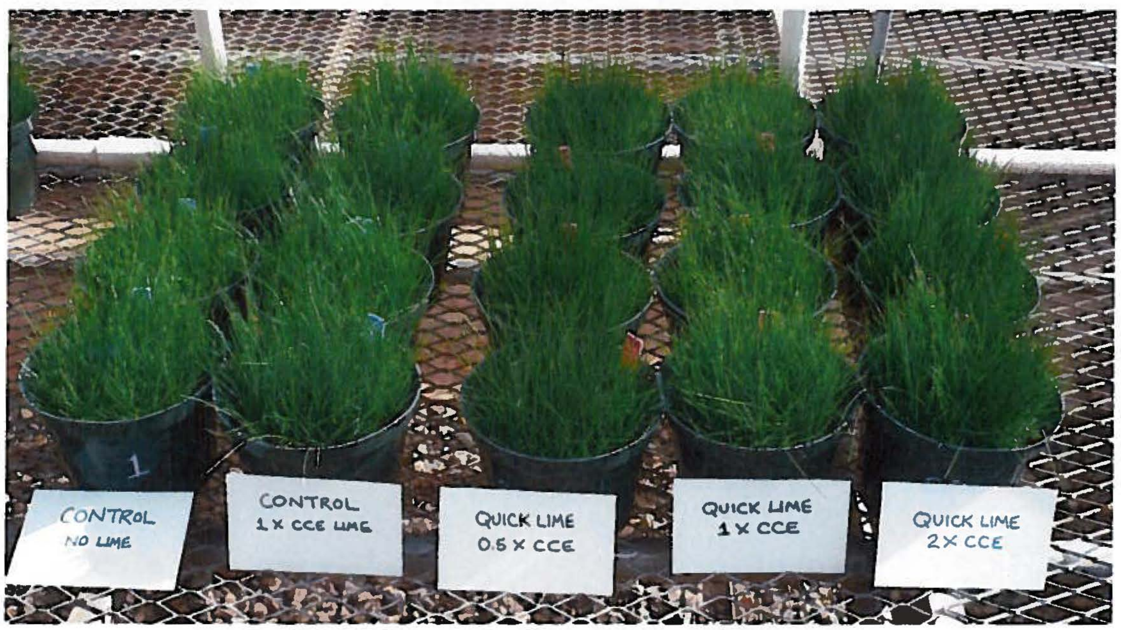


Photo 12. Tall fescue growing in soil amended with LKD-stabilized peat and limed and unlimed controls. Photo was taken just before harvest on Oct, 24, 2011



Analysis of the soil from the tall fescue and soybean pots showed that soil pH varied with liming material rate (Table 2.10). The unlimed control had the lowest pH under both types of vegetation. As expected, highest pH levels were found in the 2x CCE LKD-stabilized peat 2x CCE CaO-stabilized peat amended pots. The pH from pots where $CaCO_3$, LKD-stabilized peat, and CaO-stabilized peat were applied at a 1x CCE rate were not significantly different, as expected.

Table 2.10. Soil pH in tall fescue and soybean pots containing Piedmont soil amended with lime, lime kiln dust-stabilized spent peat, and quick lime-stabilized spent peat.

Treatment	pH	
	Tall Fescue Soil	Soybean Soil
Control - no added lime	5.33e*	5.09d
Control 1x CCE $CaCO_3$	7.18b	7.10b
Lime Kiln Peat 0.5x CCE	6.20d	6.04c
Lime Kiln Peat 1x CCE	7.11b	7.04b
Lime Kiln Peat 2x CCE	7.63a	7.57a
Quick Lime Peat 0.5x CCE	6.59c	6.28c
Quick Lime 1x CCE	7.19b	6.85b
Quick Lime Peat 2x CCE	7.81a	7.70a

*means followed by the same letter are not significantly different (Fisher's LSD, $P < 0.01$)

Soil C and N in the tall fescue pots varied slightly, but was not significantly different from either control in any treatment (Table 2.11). Soil C and N levels in the soybean pots also did not vary significantly among treatments.

Table 2.11. Soil C and N in tall fescue and soybean greenhouse pots containing Piedmont soil amended with lime, lime kiln dust-stabilized spent peat, and quick lime-stabilized spent peat.

Treatment	Tall Fescue Soil		Soybean Soil	
	C	N	C	N
	--- % ---		--- % ---	
Control - no added lime	2.36abc*	0.106ab	2.51a	0.105a
Control 1x CCE $CaC0_3$	2.44abc	0.104ab	2.30a	0.097a
Lime Kiln Peat 0.5x CCE	2.56a	0.111a	2.45a	0.107a
Lime Kiln Peat 1x CCE	2.34bc	0.099b	2.21a	0.098a
Lime Kiln Peat 2x CCE	2.53ab	0.103ab	2.44a	0.104a
Quick Lime Peat 0.5x CCE	2.27c	0.100b	2.24a	0.100a
Quick Lime 1x CCE	2.28bc	0.098b	2.30a	0.101a
Quick Lime Peat 2x CCE	2.33bc	0.101b	2.21a	0.096a

*means followed by the same letter are not significantly different (Fisher's LSD, $P < 0.01$)

The only variation in Mehlich-1 extractable nutrients in both the tall fescue soils and soybean soils that was attributable to treatment was in extractable Ca and Fe levels (Tables 2.12 and 2.13). Extractable Ca increased with increasing liming material rate. Extractable Fe levels were somewhat variable with pH: in the fescue soils, they were lowest in the higher liming rates, and in the soybean soils, they were significantly higher in the unlimed control. Extractable K in the soybean soils was also slightly higher in the control. In the tall fescue soils, extractable Mn levels were slightly higher than both the limed and unlimed control in the two highest CaO-stabilized peat rates, but this same trend was not observed in the soybean soils.

Table 2.12. Mehlich-1 extractable nutrients from tall fescue greenhouse pots containing Piedmont soil amended with lime, lime kiln dust-stabilized spent peat, and quick lime-stabilized spent peat.

Treatment	P	K	Ca	Mg	Zn	Mn	Cu	Fe	B
	------------------------- mg/kg -------------------------								
Control - no added lime	5.2bc*	28a	302f	42abc	0.8a	11.3e	0.38ab	52a	0.2b
Control 1x CCE $CaCO_3$	5.8abc	24ab	1157d	31d	1.0a	13.4cde	0.35b	36b	0.2b
Lime Kiln Peat 0.5x CCE	5.0c	22b	782e	39c	1.0a	11.1e	0.40ab	47a	0.2b
Lime Kiln Peat 1x CCE	6.0abc	28a	1306cd	41abc	1.0a	14.3bcd	0.45a	36b	0.3a
Lime Kiln Peat 2x CCE	6.3ab	29a	2230b	41abc	0.9a	15.6abc	0.42ab	37b	0.3a
Quick Lime Peat 0.5x CCE	5.5bc	29a	924e	44a	0.8a	12.8de	0.40ab	36b	0.2b
Quick Lime 1x CCE	6.8a	29a	1352c	40bc	0.8a	16.1ab	0.40ab	33b	0.3a
Quick Lime Peat 2x CCE	6.3ab	27ab	2518a	43ab	0.8a	17.6a	0.38ab	24c	0.3a

*means followed by the same letter are not significantly different (Fisher's LSD, $P < 0.01$)

Table 2.13. Mehlich-1 extractable nutrients from soybean greenhouse pots containing Piedmont soil amended with lime, lime kiln dust-stabilized spent peat, and quick lime-stabilized spent peat.

Treatment	P	K	Ca	Mg	Zn	Mn	Cu	Fe	B
	------------------------- mg/kg -------------------------								
Control - no added lime	7.0ab	62a	342d	50a	0.9a	14.3abc	0.40a	60a	0.2b
Control 1x CCE $CaCO_3$	8.0b	44cd	811c	39d	0.7a	16.7a	0.40a	39c	0.2b
Lime Kiln Peat 0.5x CCE	7.2ab	49bcd	1187b	48ab	0.7a	12.7c	0.42a	42b	0.2b
Lime Kiln Peat 1x CCE	6.0a	44cd	1299b	45c	0.9a	16.2ab	0.40a	39c	0.3a
Lime Kiln Peat 2x CCE	7.0ab	53b	2222a	45c	0.9a	16.3ab	0.42a	35c	0.3a
Quick Lime Peat 0.5x CCE	7.2ab	53b	891c	47abc	0.8a	14.5bc	0.40a	39c	0.2b
Quick Lime 1x CCE	7.5ab	43d	1222b	44c	0.8a	15.2ab	0.40a	34c	0.2b
Quick Lime Peat 2x CCE	7.5ab	50bc	2357a	46c	0.9a	16.2ab	0.38a	25c	0.3a

*means followed by the same letter are not significantly different (Fisher's LSD, $P < 0.01$)

In summary, both of the lime stabilized peat products (LKD and CaO) performed as expected in the greenhouse bioassay. In other words, both of these products behaved as predicted with respect to liming efficacy and also contributed minor amounts of Ca to the soil:plant system. Other than their expected liming effects, we noted no other major positive or negative impacts of the two amendments on the soils or plant growth in either bioassay trial. This essentially "soil neutral" effect was expected due to the relatively low mass loading rates of the materials that were employed due to their high CCE levels.

Conclusions

Overall, the combined data sets from all components of our research program support the utilization of spent peat materials as soil amendments under a wide range of potential beneficial utilization scenarios. Our original greenhouse trials indicated that either the raw peat or a composted peat product were quite beneficial at relatively high loading rates. The only limiting factor noted was that our compost was high enough in soluble salts to limit sensitive plants (e.g. soybeans) at rates above 10% by volume. Similarly, our second round of bioassay trials with the USEPA (Class A) Alternative 2 and 5 lime-treated peat materials proved that these materials are quite beneficial as liming materials with no adverse secondary effects on plant growth as long as liming rates are correctly specified to avoid potential over-liming effects in the receiving soil-plant system.

From a practical field utilization standpoint, our review of the relevant state and federal regulatory programs indicates that Premier Tech would have the following primary options and associated compliance restrictions for land application of these materials at a given site in the USA:

1. **Treat the materials as septage** which would automatically qualify it is "Class B" for land application and allow it to be utilized locally following lime-treatment and incorporation into the soil within 24 hours. Data on time x pH of the lime treatment would be required, but no batch specific pathogen testing. Loading rates would be constrained by the materials' pH and lime content and potentially by local nutrient management regulated N and P loadings.

2. **Compost the material** via an approved USEPA Part 503 procedure to meet Class A time x temperature requirements. Each batch would need to be tested for pathogen reduction according to local state program requirements. Spent peat should be considered as a filler, an organic bulking agent, that could be integrated into existing compost facilities where proper expertise can be found, enabling the production of a well-balanced (with respect to micro & macro nutrients) Class A compost with suitable agronomic value to the market.

3. **Lime treat the materials via addition of CaO or LKD** to meet Alternative 2 or 5 time x temperature x pH criteria for Class A process pathogen reduction. Each batch would need to be tested for pathogen reduction according to local state program requirements. Land application rates would be controlled by the CCE content of the material vs. local soil liming requirement.

The density and water content of the well decomposed spent peat material used in our lime stabilization trials may have led to higher lime doses than necessary. Further trials and cumulative database development would allow for improved lime addition rate prescriptions.

One of the objectives of this study was to obtain a proper labeling for the spent peat material if it were to be used as a soil amendment or conditioner. While soil amendment and conditioner labeling requirements vary widely from state to state in the USA, our research clearly supports label development in Virginia for an appropriately composted or lime-stabilized product. Such labeling is important to distinguish and separate these materials from septage or many biosolids products found on the market.

While the second phase or our work ended up using a spent peat with properties closer to those of municipal biosolids, we believe that the overall pool of spent peat removed after its typical lifespan would still carry many key attributes of the initial distinct peat structure; low density, fibrous, aggregated, and with good porosity and water holding capacity.

Acknowledgment of Support and Future Commitment

Finally, we appreciate Premier Tech's long term support of this research program. We will be willing to support their efforts to develop appropriate and compliant land application programs for their spent peat materials in any state of interest via supporting memoranda or phone calls as needed. We will also be willing to support the development of a soil amendment label with the Virginia Department of Agriculture and Consumer Services (VDACS).

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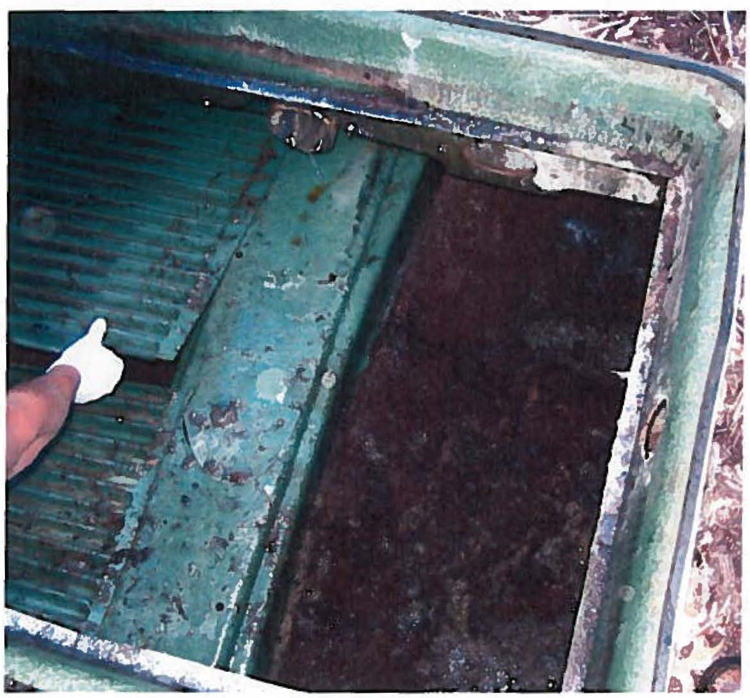
Appendix 1 – Photos of Ecoflo units sampled on 19 and 20 May 2009

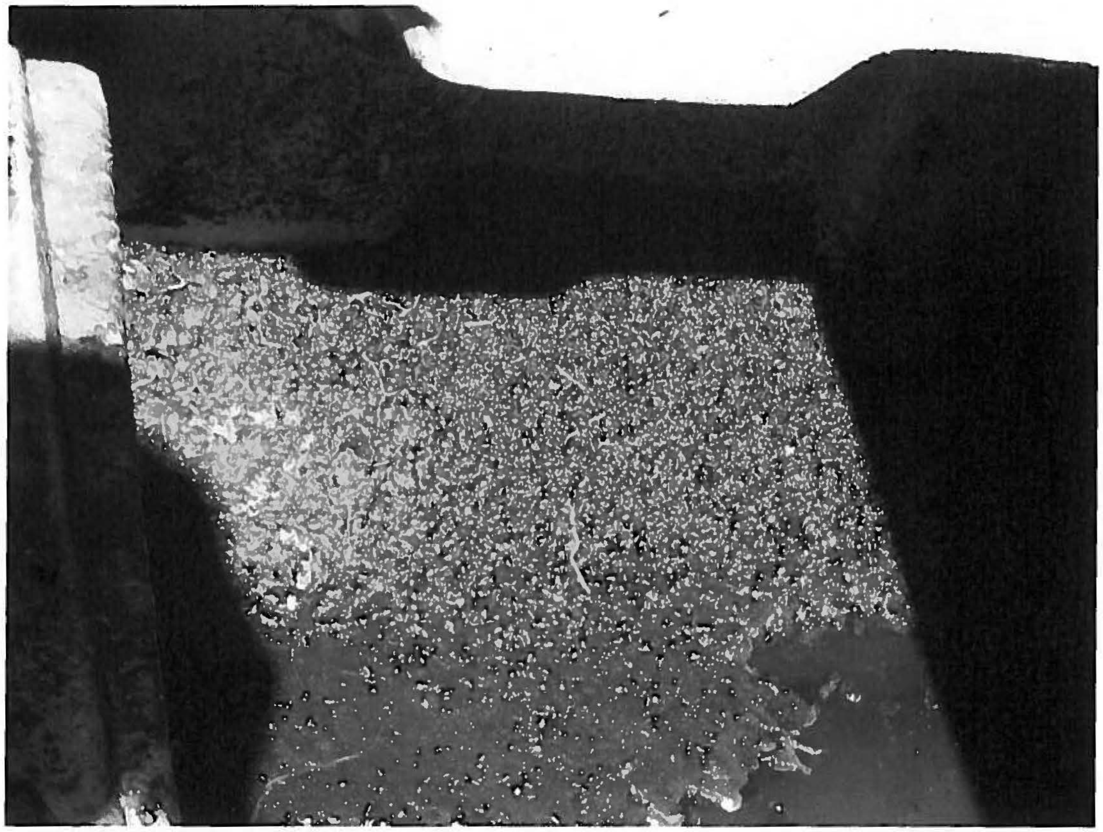
A1 -- Ecoflo unit 2 as sampled on May 19, 2011.

A2 -- Interior of Ecoflo unit 4 sampled on May 20, 2011. Image shows white crust accumulated on surface of spent peat.

A3 – Deeper interior of same unit (4) as depicted in A2. This image shows primary peat structures and fibrous nature still intact after years of use.



A4 – Interior of unit 5 sampled on May 20, 2009.



A5 – Interior of unit 6 as sampled on May 20, 2009. This material was the wettest and most degraded of those sampled.

Appendix 2

Daily Notebook Entries from Drum Composter Operations

Misc Info inside front cover:

Tractor Farm Supply	wood shavings	standard 20lbs/bale
Urea	40lbs/bag	46.0.0 analysis
Chicken manure	60 lbs? 3% ttl N 2% P_2O_5	Harrisonburg processor Glen Hill Farm Harrisonburg VA
13 drums	put in 10 drums	

Data log

Date	Notes	Temp F	Initials
6/2	loaded material Greg fixed chain	64	DKJ
6/3, 10am	chain loose, unplugged	64	DKJ
6/3, 4pm	chain fixed, running	64	DKJ
6/4, 8am	chain OK water stopped dripping out	64	DKJ
6/4, 4pm	chain OK	64	DKJ
6/5, 8am	chain OK	64	JCB
6/5, 3:30pm		65	JCB
6/6, 3:30pm	chain bouncing, losing material out the front water dripping out back	64	JCB
6/7, 2pm	still losing material out front, dripping in back	64	JCB
6/8, 8am	lid off, lots of material on ground, still looks v. wet	64	JCB
6/9, 10am	closed lid, shoveled ground material into drum "39 Stone Lane A & B" H_2O still dripping	64	DKJ
6/10, 9am	checked temp slow drip	64	DKJ WTP
6/11, 12pm	checked temp	64	DKJ
6/12	checked temp	64	DKJ
6/13, 12pm	checked temp	65	DKJ
6/14, 4pm	checked temp	65	DKJ
6/15, 12pm	checked temp	65	DKJ
6/16, 12pm	checked temp	65	DKJ
6/17, 1pm	checked temp	65	DKJ
6/18, 11am	checked temp opened lid	65	DKJ
6/18, 3pm	added 6 bags of chicken litter (3 front, 3 rear)	65	DKJ, JCB, WTP
6/19	lost some material out front, balling up inside	65	JCB
6/20, 3:30	looks good	70!	JCB

6/21, 3:30	looks good	76	JCB
6/22, 10:30am	looks good	82	JCB
6/23	added 2 bags	81	DKJ, NLT
11am	poultry litter		
3pm	closed lid	80	NLT
6/24, 7:30am	checked temp	80	NLT
6/24	added 3	80	DKJ, GE
	bags wood chips		
6/25	added 3/4 bag wood shavings	79	NLT
	when shoveling somehow it tipped on its end		
	turned the off switch (by the timer) and unplugged		
	called Greg E. -will check it tonight		
6/26, 10am	righted machine	80	DKJ, GE
	added 1/4 bag of chips Nicole left		
6/27, 11am	checked temp, looks OK	84	NLT
6/28, 7pm	checked temp	94	NLT
6/29, 8am	checked temp	94	NLT
6/30, 8am	checked temp got grab sample	94	NLT
7/1, 4pm	checked temp	94	NLT
7/2, 7:30am	checked temp	94	NLT
10am	added 2 bales wood shavings, 12 bg litter		GE
11am	check temp	94	GE
7/6	check temp added 1 bag litter + 1 bale shavings	90	GE
7/7, 8:30am	checked temp	92	NLT
7/8, 12pm	checked temp	93	DKJ
	added 1 bale of straw		
	straightened up site		
	shoveled up ground material		
7/9, 9am	checked temp	93	NLT
7/10, 8am	checked temp	92	NLT
	periodically squeaking but can't tell what's making the noise		
	will email GE		
7/10	add 1 bale straw/wood chips (?) & 1 bag litter	93	GE
7/11, 4pm	checked temp	93	NLT
7/12, 4pm	checked temp	93	NLT
	Never mind :) I thought the arms weren't square but then measured them and they are		
7/13, 8:30am	checked temp	93	NLT
7/14, 8:30am	checked temp	93	NLT
7/14, 3pm	added 1 bag urea and		
	1 bag wood shavings per G.E. email	93	NLT
7/15, 8:30am	chain had slipped and barrel stopped moving. Adjusted (L) all thread at 1/2" and tightened lockout on left side. Squeaks a bit so oiled bottom sprocket and seems to be fine.	93	NLT
	Note: '(R) all thread adjusted all the way out and (L) all thread still isn't adjusted all the way out.		
	(can be adjusted another ~1/4")		
7/16, 12pm	checked temp, squeaks but seems/starts(?) ok	92	NLT
7/17, 10am	came out 7:30 to find the blue(?) rubbermaid ok.	89	NLT
	emptied out the blue lid (into the pile already below the opening) and reattached the lid.		

	Restarted drum - squealing much worse today		
7/18, 12pm	checked temp	89	NLT
	squealing almost gone. Looks good.		
7/20, 8:30am	checked temp	86	NLT
	put tarp over pile of overflow		
	will shovel when not raining		
	squealing stopped. Looks good		
7/21, 12pm	checked temp	86	DKJ
7/22, 3:45pm	cked temp; repaired cap collar & band off	87	WTP
7/23, 3:45pm	cked temp, tighten band	87	WTP
7/24, 1pm	check temp, shoveled ground material into barrels	86	DKJ
7/25, 6pm	check temp	86	DKJ
7/26	check temp	86	DKJ
7/28	check temp	88	JCB
7/29	ck temp	87	WTP
7/30	" "	87	JCB
7/31	" "	87	JCB
8/1		87	JCB
8/2		87	JCB
8/3	checked temp	86	JCB
8/4	checked temp	86	JCB
8/5, 3:20pm	" " & collar/cap	87	WTP
8/6	" "	87	JCB
8/7	" "	87	JCB
8/8	" "	87	JCB
8/10		87	JCB
8/11	checked temp	87	JCB
8/11, 3:45	" "	87	WTP
8/12, 4:40	" "	87	WTP
8/13		87	JCB
8/14		87	JCB
8/15		87	JCB
8/16		87	JCB
8/17	checked temp	87	JCB
8/18	checked temp	87	NLT
9/3	emptied compost drum for curing		