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EVALUATING PEATS FOR THEIR CAPACITIES TO REMOVE ODOROUS COMPOUNDS FROM LIQUID SWINE MANURE USING HEADSPACE "SOLID-PHASE MICROEXTRACTION"

Key Words: Peat, liquid swine manure, odor removal, solid-phase microextraction, hogs

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ABSTRACT

This paper reports on research designed to investigate the capacities of different highly characterized peats to remove odorous compounds from liquid swine manure (LSM). Peat types representing a wide range of properties were tested in order to establish which chemical and physical properties might be most indicative of their capacities to remediate odors produced by LSM. Eight percent slurries (of peat/LSM) were measured for odor changes after 24 hours using odor panel and GC/MS-Solid-phase microextraction (GC/MS-SPME) analysis.

The GC/MS-SPME and odor panel results indicated that, although all peats tested in this study were found to be effective at removing odor-causing compounds found in LSM, some peats tended to work better than others. Overall, the peats that were the most effective at removing odor-causing compounds tended to have lower bulk densities, ash contents, fulvic acids contents, and guaiacyl lignins contents,and higher water holding capacities, hydraulic conductivities, "total other lignins" contents, hydrogen contents, carbon contents, and total cellulose contents.

GC/MS-SPME analysis was found to be a reasonably inexpensive and efficient way of conducting this type of research. It allows one to identify a large number of the odor-causing compounds found in LSM, and more importantly, to detect with some precision specific differences in the amounts of these compounds between peat types.

INTRODUCTION

Odors produced from liquid swine manure (LSM) have resulted in major air pollution problems and significant complaints from local inhabitants in areas near to intensive livestock production (Willrich and Miner, 1971; Jongebreur, 1977; Waston and Friend, 1987). A wide variety of medical complaints have also been attributed to these emissions (Satchell. 1996).

Various methods have been studied to reduce these air pollution problems. Fenlon and Mills (1980) reported that addition of lime to LSM could reduce certain odors. Stevens and Cornforth (1974), Chen et al. (1994), Copelli et al.

(1986), and Williams and Evans (1981b) found that aeration of stored LSM also tended to reduce odors. MacKenzie and Tomar (1987) reported that mixing triple superphosphate fertilizer with LSM reduced emissions of ammonia, a significant odor-causing compound. Bourque, et al. (1987) identified and tested aerobic microorganisms that exist in LSM and found that some can degrade various malodorous substances. However, their studies as well as those of others (e.g. Ritter, 1981) have shown that microorganisms selected from a given swine waste will not necessarily work for another swine waste .

Several studies have indicated that peats and peat extracts are effective removers of odor from animal waste. For example, peat has been used as a litter in milking cow barns, where it was found to outperform rice straw and sawdust in adsorption of ammonia and odor removal (Peltola, 1986). Peat has also been used effectively in biofilter applications for odor remediation in livestock buildings (e.g. Zeisig et al., 1977; Zeisig and Kreitmeier, 1982; Noren, 1986; Valentin, 1986; Williams and Miller, 1992). In these biofilters, ventilation air is blown through a bed of Sphagnum moss peat (or Sphagnum moss peat and heather) and the natural microorganisms within these beds degrade the odors. In a related study, Namkung and Rittmann (1987) showed that biodegradation of taste and odor-causing compounds in drinking water could be enhanced by addition of fulvic acid extracts from peat to biofilm reactors. Additionally, Mathur et al. (1990) reported significant reductions in odors of animal manures that were mixed with Sphagnum moss peats during composting, and Al-Kanani et al. (1992) showed that Sphagnum moss peat slurried in LSM could eliminate a great number of the odor-causing compounds under either aerated or nonaerated conditions. In the latter study, the peat amendment was found to work better than several chemical treatments, including 1.5 M H_2SO_4, 1.7 M H_3PO_4, monocalcium phosphate monohydrate, elemental S, $CaCO_3$, and CaO.

In nearly all of the previous studies, only Sphagnum moss peat was tested. Although Sphagnum peat is available commercially in many parts of the country, it is not necessarily the indigenous or cheapest peat type in regions where swine production is common. In North Carolina, for example, where swine production has increased dramatically in recent years, many kinds of peat are found. However, Sphagnum moss peat is not a particularly common one of these (Cohen, 1979; Ingram, 1987). Additionally, previous studies with a variety of other contaminants have shown that the type of peat used can strongly affect its sorption/desorption properties (e.g., gasoline-derived hydrocarbons [Cohen et al., 1991b, 1995a, 1996; Rizzuti et al., 1996; Stack et al., 1993,], metals [Stack et al., 1994; Cohen et al., 1995a; Cohen et al., 1995b; Cohen and Stack, 1995c; Rizzuti et al., 1996], and nitrates [Cohen and Stack, 1995c; Cohen et al., 1996]). Lastly, a previous preliminary study by us (Rizzuti et. al., 1998) using both odor panel and GC/MS techniques has shown that, although all peat types tested reduced LSM odors, different peat types varied in how much they reduced these odors. Additionally in this preliminary study we identified a technique, GC/MS, headspace, solid-phase, microextraction (GC/MS-SPME), that allowed us (in a relatively inexpensive and precise manner) to identify which specific odor-causing compounds were present and how much these were reduced.

The purpose of this study was thus to evaluate a wide variety of highly characterized peats in order to establish which chemical and physical properties might be most indicative of their capacities to remediate odors produced by LSM. The GC/MS-SPME technique that was identified in our previous study was used to determine which odor-causing compounds were being reduced. This information is needed for future follow-up studies, which will include larger scale tests using one or more of the best peat types identified in this study to design and implement controlled field tests at a swine farm.

MATERIALS AND METHODS

Selection of Peat Samples

The University of South Carolina's Geology Department has a unique collection of peat samples, which consists of a large assortment of bulk samples of natural peats from various parts of the United States (including the southeastern states). Representative splits of these samples have already been analyzed in great detail for their chemical, physical, and biological properties (Cohen et al. 1991). Some of these measured properties include: 1) porosity (micro-, macro-, and total); 2) hydraulic conductivity; 3) water-holding capacity; 4) fiber content; 5) bulk density; 6) pH; 7) carbon, hydrogen, oxygen, nitrogen, chlorine, and sulfur; 8) major and trace element inorganic content and mineralogy (by INAA, XRF, and XRD); 9) botanical composition; 10) organic chemical compounds by chemical fractionation and combined pyrolysis GC/MS and pyrolysis GC/FT-IR/FID analysis; and 11) proportions and types of humic and fulvic acids. Selections of these peat samples have been used in the past by us for various sorption/desorption experiments, including experiments on gasoline-derived hydrocarbons (Cohen et al., 1991, 1995; 1996; Rizzuti et al., 1996; Stack et al., 1993, 1994), metals (Stack et al., 1994; Cohen et al., 1995; Cohen and Stack, 1995; Rizzuti et al., 1996), and nitrates (Cohen and Stack, 1995; Cohen et al., 1996;).

The advantage of using these highly characterized samples over peat samples tested by others is that, at minimal expense, the results of our odor tests can be correlated with the already known compositional properties of these peats to determine: 1) which parameters are most likely to be controlling our results and 2) more importantly, which parameters can be used by us or by others to predict whether a particular untested peat from some other part of the country would be a good candidate for this kind of use. Eventually, this information will also be used by us in future follow-up studies for testing and design of a treatment strategy.

For this study, five different peat types were tested. These were designated Loxahatchee Nymphaea peat, Loxahatchee Sawgrass peat, Okefenokee Taxodium peat, New York peat, and Shark River (Rhizophora) peat. These peats were selected because they represent a wide range of physical and chemical properties. Five peats types from our previous research (Rizzuti et al., 1998) were also used in the evaluation of the results from this study (Table 1).

Collection of LSM

LSM was collected at a commercial nursery-pig farm in North Carolina from the effluent being flushed into a holding lagoon from a hog barn. The LSM was frozen, then later thawed out and stored in a refrigerator at 4° C prior to use.

TABLE 1
Peat Samples Used for Odor Removal from LSM (* = from Rizzuti et al., 1998)

Sample Designation	ASTM Classification # D4427-92	Location	Dominant Botanical Components
Shark River (Rhizophora) peat	Fibric	Everglades National Park, FL	Rhizophora (red mangrove)
Loxahatchee Nymphaea peat	Fibric	Loxahatchee Wildlife Refuge, FL	Nymphaea (water lily) and Sagittaria (arrowhead)
Loxahatchee Sawgrass peat	Sapric	Loxahatchee Wildlife Refuge, FL	Grass-sedge, Sagittaria and Nymphaea
Okefenokee Taxodium peat	Sapric	Okefenokee Swamp, GA	Taxodium (cypress) and Persea (bay)
New York peat	Sapric	Fort Drum, NY	Spruce, woody dicot and fern
*Maine Sphagnum peat	Fibric	Maine	Sphagnum
*Okefenokee Nymphaea peat	Fibric	Okefenokee Swamp, GA	Nymphaea, Sagittaria, and grass-sedge
*Minnesota Hemic peat	Hemic	Minnesota	Spruce and woody Dicot
*North Carolina peat	Sapric	First Colony Farms, NC	Persea, woody dicot, grass and fern
*Snuggedy Swamp peat	Sapric	Snuggedy Swamp, SC	Myrica, Persea, & Lyonia

It had a pH of approximately 7.0 and its total solids measured 0.25 %. This undiluted LSM was used as the standard in all tests.

Laboratory Methods and Experimental Design

The variety of wet peat types (i.e. with inherent moisture contents as received from the bog) were slurried with LSM for 24-hours and compared with a standard consisting of LSM without peat addition. Only wet peats were tested since they were found to work best in our previous research. Eight percent slurries were prepared by combining 3.73 grams (dry weight- using wet weight equivalent) of peat with 53.3 grams of LSM in 150ml polyethylene vials. The vials were sealed, and shaken vigorously by hand for approximately one minute. These vials were then left undisturbed for 24-hours. After this time period, the samples were centrifuged for 15 minutes at 2000rpm and tested for odor type and intensity by an odor panel of 4 people who sniffed the sample for approximately 3-5 seconds immediately after unscrewing the vial top. The panel was provided with a list of possible odor descriptions with which to characterize these smells.

After testing for odor type and intensity, more precise measurements of changes in specific odor-causing compounds were accomplished using a GC/MS-SPME method modified from Zhang and Pawlizyn (1993). This involved acidifying the sample's liquids with phosphoric acid to a pH of approximately 2.0. A 26.7ml aliquot of the acidified liquid was then placed into a 40ml EPA head-space vial (amber glass, with open screw cap and Teflon-faced silicone septa), and heated in a 72°C water bath for approximately 45 minutes. Subsequently, a 85um polyacrylate SPME fiber needle was injected into the vial for 20 minutes to allow head-space gases to accumulate on the needle's fibers. The needle was then placed into a Hewlett Packard Gas Chromatograph (model 5890), the run was started, and the fiber needle was left in the injection port for 1 minute, then removed. The GC was fitted with a Restek DB5 column and connected to a Hewlett Packard Mass Spectrometer (model 5970). A split/splitless injector was used in the splitless mode. The oven program utilized was: 35°C for 1 min.; a ramp of 10°C/min. to 250°C, and a post run temperature of 250°C held for 5 minutes. Each analysis took 24.5 minutes to run. Results from the LSM standards were compared with those from the peat-treated LSM to determine the percent reductions of odor-causing compounds. Compounds were identified by comparing the peaks mass spectra to the National Institute of Standards and Technology (NIST) library. All samples were analyzed in triplicate and averaged. Average GC/MS-SPME results for all samples showed a relative standard deviation of less than 15%.

RESULTS

Odor Panel Results

Odor panel results revealed significant reductions in odor with all peat-treated samples (Table 2). However, some peats were found to work slightly better than others. Mixing LSM with either Loxahatchee Nymphaea peat or with Loxahatchee Sawgrass peat resulted in total elimination of odor after 24-hours (Table 2), while, mixing LSM with New York peat resulted in a light manure odor; and mixing LSM with Shark River (Rhizophora) peat resulted in a very light manure odor. Mixing LSM with Okefenokee Taxodium peat changed the manure

TABLE 2

Odor Panel Descriptions of Types and Intensities of Odors After Mixing Peats with LSM for 24-hours (* = from Rizzuti et al., 1998)

Sample	24-hour Treatment
LSM Standard (no peat addition)	strong manure odor
* Okefenokee Nymphaea	no odor
* Maine Sphagnum	no odor
* Snuggedy Swamp	no odor
* North Carolina	no odor
* Minnesota Hemic	no odor
Loxahatchee Nymphaea	no odor
Loxahatchee Sawgrass	no odor
Okefenokee Taxodium	very light burnt musty odor
Shark River (Rhizophora)	very light manure odor
New York	light manure odor

odor to a very light, burnt, musty odor (not an unpleasant odor). In comparing these results to our previous research, the three peats mentioned above that produced some odor after the 24-hour treatment were the only peats (out of a total of 10, 5 from our previous research) that did so. These three peats may not work as well as the other peats tested, or they may simply take longer to do as well.

GC/MS-SPME Results

In this study, two of the five peat types tested (Loxahatchee Nymphaea and Loxahatchee Sawgrass) had moderate to large reductions in all twenty-six of the odor-producing compounds identified (Table 3, Fig. 1). Of the three remaining peat types, Okefenokee Taxodium peat and Shark River peat showed reductions in

TABLE 3

GC/MS SPME Results Showing Reduction of Odorous Compounds that are Found in LSM (24-hour Treatment, Using Wet Peat, * = from previous research, nd = not determined, • = compounds considered more important in contributing to the LSM odor problem)

Compound Name	Percent (%) Reduction Lox. Nym.	Lox. Saw.	Oke. Tax.	New York	Shar. Riv.	*Ma. Sph.	*N. Car.
•Acetic Acid	45.51	89.06	8.91	12.77	-8.98	48.12	60.07
•Propionic Acid	80.60	34.61	100.00	-58.58	-20.72	100.00	100.00
•Butanoic Acid	60.04	53.71	9.12	-54.07	-27.47	68.69	45.20
•Pentanoic Acid	84.57	68.89	-109.83	48.19	23.93	100.00	100.00
•Pentanoic Acid, 2-methyl	68.16	81.04	52.59	48.58	13.03	Nd	nd
Pentanoic Acid, 4-methyl	92.86	77.74	41.61	70.18	37.91	Nd	nd
Benzaldehyde	87.34	81.21	2.85	70.06	93.92	100.00	92.31
•Hexanoic Acid	83.10	85.42	-108.31	81.36	32.88	70.93	91.49
•Phenol	71.88	81.87	75.28	29.15	18.33	94.04	50.56
Hexanol, 2-ethyl	72.45	97.12	40.63	80.29	35.81	96.75	95.70
Hexanoic Acid, 4-methyl	72.10	72.62	60.34	61.32	63.41	nd	nd
Phenol, 2-methyl	88.97	78.23	54.42	64.73	36.82	100.00	97.84
Heptanoic Acid	50.62	65.04	-149.95	39.28	5.03	nd	nd
Benzaldehyde, 2-methyl	64.63	60.54	37.01	67.57	2.95	nd	nd
Phenol, 4-ethyl	78.25	79.20	36.71	75.53	36.93	90.01	81.88
•Indole	86.22	93.99	86.01	89.88	86.27	95.02	76.33
Decanoic Acid	91.09	90.67	-33.41	98.28	90.88	93.00	98.45
•Butanoic Acid, 3-methyl	81.33	86.70	76.31	90.57	42.71	100.00	83.33
•1H-Indole, 3-methyl	93.52	95.40	91.72	91.89	84.87	93.41	99.30
Dodecanoic Acid	66.40	64.60	53.93	52.81	58.69	77.92	83.36
2,4-bis(1,1-dimethylethyl) Phenol	89.73	79.35	53.69	74.61	64.14	57.56	93.58
Propionic Acid,2-methyl,(1,1-dimeth	45.42	63.34	48.77	24.70	-6.00	70.24	52.30
Tetradecanal	40.04	33.47	31.48	31.53	40.17	75.02	90.79
Hexadecanal	34.93	17.76	29.73	21.84	34.58	70.01	87.84
Hexadecanoic Acid	74.52	61.29	-17.92	59.10	73.39	86.00	42.43
9-Octadecanal	42.91	24.17	54.18	14.51	-40.10	69.13	93.67
Average	71.05	69.89	24.07	49.46	33.59	83.61	81.73
Average of •	75.50	77.07	28.18	37.97	24.49	85.58	78.48

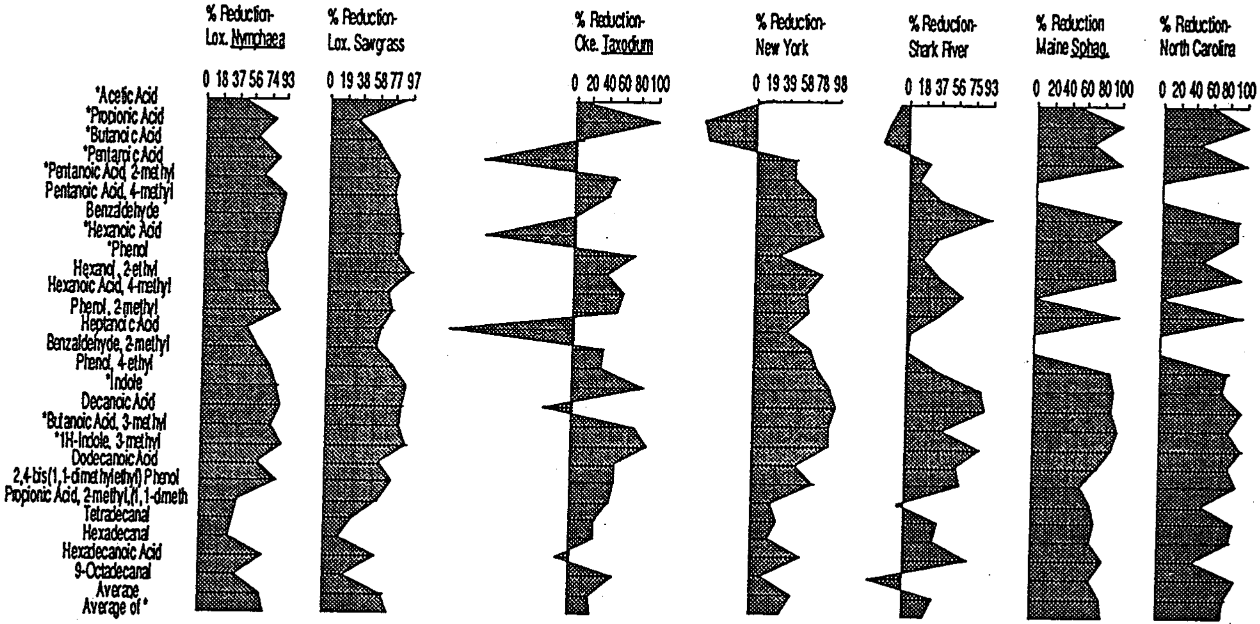


FIGURE 1

GC/MS results showing percent reductions of odorous LSM compounds (* = compounds considered more important in contributing to the LSM odor problem.

twenty-one of the twenty-six compounds, and; New York peat showed reductions in twenty-four of the twenty-six compounds. The two peat types tested in our previous research had moderate to large reductions in all of the compounds identified.

With regard to reductions in specific odor-producing compounds, Loxahatchee Nymphaea peat proved to be the best at reducing pentanoic acid,4-methyl; the Loxahatchee Sawgrass peat was much better at reducing acetic acid; and the North Carolina peat was much better at reducing three other compounds (tetradecanal, hexadecanal, and 9-octadecanal). Although all seven of the peat types worked well at reducing the LSM odor-causing compounds, overall, the Maine Sphagnum and the North Carolina peats produced the best reduction, with the Loxahatchee Nymphaea and Loxahatchee Sawgrass peats working almost as well. The New York peat did not do as well as these four peats, and the Shark River (Rhizophora) and Okefenokee Taxodium peats were the least effective.

In order to correlate the GC/MS-SPME results with the odor panel results, the GC/MS-SPME results were averaged in two different ways. One way was to average all compounds identified, known as the average LSM compound reduction (ALCR), and the other way was to average only those compounds that were considered important in contributing to the LSM odor problem, known as the average reduction of nine/ten compounds (ARN/TC) (10 identified in five peat types and 9 identified in the other two peats) (Williams, 1981a). Both of these average numbers were then plotted against the odor panel results.

Overall, the ALCR and ARN/TC results correlated fairly well with the odor panel results. In correlating ALCR with the odor panel results, the four peat types that produced no odor after the 24-hour treatment had the best ALCR results (Maine Sphagnum, North Carolina, Loxahatchee Nymphaea, and Loxahatchee Sawgrass), while the three peats that were reported to have some type of odor after the 24-hour treatment (Okefenokee Taxodium, New York, and Shark River) were confirmed to be less effective by the ALCR results (Fig. 2). Although the New York peat produced a light manure odor that was slightly stronger than the manure odor produced by the Shark River peat, it had slightly better ALCR results. And, although the Okefenokee Taxodium peat produced a very light, burnt musty odor, overall, it had somewhat similar ALCR results to the Shark River peat. The reason for these inconsistencies may be that certain compounds may produce more offensive odors and hence contribute more to the odor problem. This is why the odor panel results were also correlated with the ARN/TC results.

The ARN/TC values correlated slightly better with the odor panel results than did the ALCR values (Fig. 2). For the four peat types that were reported to have no odor after the 24-hour treatment (Maine Sphagnum, North Carolina, Loxahatchee Nymphaea and Loxahatchee Sawgrass), the ARN/TC-odor panel correlation was similar to the ALCR-odor panel correlation. However, for the three peats that were reported to have some type of odor after the 24-hour treatment (Okefenokee Taxodium, New York, and Shark River), the ARN/TC-odor panel correlation was slightly better than the ALCR-odor panel correlation.

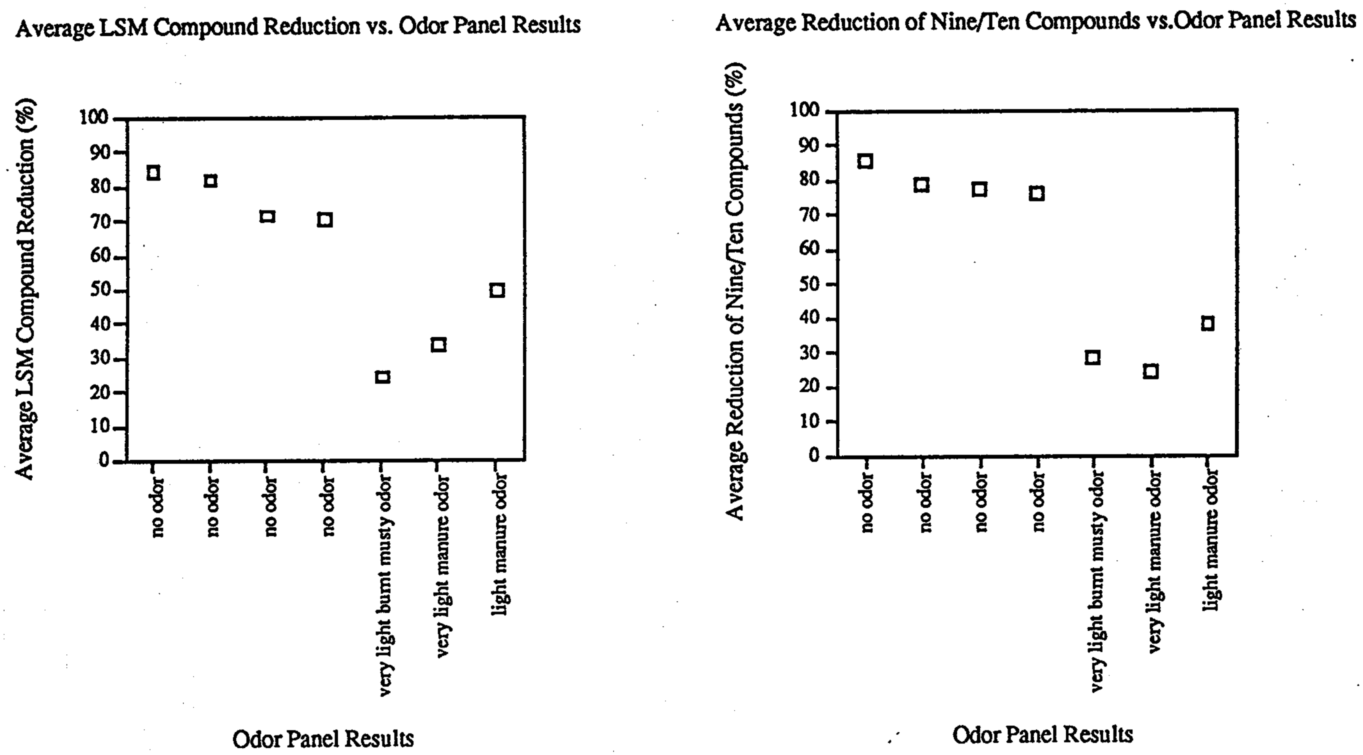


FIGURE 2
Average LSM compound reduction and average reduction of nine/ten compounds vs. odor panel results.

For these three peat types, only the New York peat had a correlation problem. Although this peat type had more offensive odor panel results, compared to the other two peat types, it had better ARN/TC results.

In order to determine which physical or chemical characteristics of these peats might be related to their odor removal capacity, some parameters of these samples that had previously been determined [Cohen et al., 1991a; Durig et al., in preparation; Rizzuti et al., in preparation; (Tables 4-7)] were plotted against both the ALCR and ARN/TC results. Out of the thirty-two parameters listed in Tables 4-7, sixteen did not correlate well with either set of results. These parameters included: fiber content, porosity, and pH (Table 4); N, Cl, S, and O contents (Table 5); Ti, Ca, and Na contents (Table 6); total aldehydes, total furans, total furanones, total pyranones, total other ketones, and total all lignins contents (Table 7). The remaining sixteen parameters (Tables 4-7) correlated very well with both the ALCR and ARN/TC results. In many cases these correlation's were made stronger by eliminating one of the peat types. Therefore, all of the correlation's done with the ALCR and ARN/TC results are shown both with and without one of the peat types tested (Figs. 3-19). Of the 34 correlation's made, Okefenokee Taxodium peat was eliminated in 24 of them. The North Carolina peat was eliminated in 6 of these correlation's, and the Loxahatchee Sawgrass and Loxahatchee Nymphaea peats were eliminated in 2 of these each.

Of the physical characteristics measured, water holding capacity, bulk density, and hydraulic conductivity, exhibited fairly strong correlation's with both the ALCR and the ARN/TC results (Figs. 3-5). The peats with higher bulk density

TABLE 4
Physical Properties of the Peat samples (from Cohen, et al. 1991$_a$; and *Rizzuti et al., in preparation)

Sample	Fiber (area %)	Porosity (area %)	Bulk Density (g/cm^3)	Water Holding Capacity (%)	PH (of water)	*Hydraulic Conductivity (cm/sec)
Lox. Nym.	40	37	0.069	1765	7.94	0.0034
Lox. Saw.	48	46	0.076	1500	6.65	0.002
Oke. Tax.	18	36	0.123	1025	3.14	0.000017
New York	23	38	0.125	891	7.85	0.00059
Shar. Riv.	55	30	0.164	757	6.51	0.00014
Ma. Sph.	81	48	0.083	1809	4.29	0.0052
N. Car.	17	20	0.199	649	3.70	< 0.00001

TABLE 5
Ultimate Analysis of the Peat Samples (wt. percent, from Cohen et al., 1991$_a$)

Sample	C	H	N	Cl	S	Ash	O
Lox. Nym.	54.50	5.90	3.98	0.09	0.69	6.44	28.40
Lox. Saw.	54.55	5.05	3.07	0.07	0.96	7.17	29.13
Oke. Tax.	51.30	5.18	2.38	0.05	0.29	12.76	28.04
New York	49.43	4.19	2.34	0.05	0.54	13.14	30.31
Shar. Riv.	36.43	3.59	1.65	0.11	2.72	31.01	24.49
Ma. Sph.	52.03	5.69	0.48	0.03	0.11	0.80	40.86
N. Car.	62.71	5.61	0.94	0.09	0.14	1.22	29.29

TABLE 6
Inorganic Chemical Composition of the Peat Samples (wt. percent, from Cohen et al., 1991$_a$)

Sample	Si	Ti	Al	Fe	Mg	Ca	Na	K	P
Lox. Nym.	0.77	0.01	0.21	0.39	0.13	1.80	0.05	0.02	0.02
Lox. Saw.	0.42	0.01	0.15	0.18	0.26	2.17	0.04	0.02	0.02
Oke. Tax.	6.04	0.02	0.37	0.13	0.02	0.02	0.02	0.04	0.05
New York	1.33	0.11	0.40	0.44	0.40	4.36	0.03	0.10	0.08
Shar. Riv.	4.87	0.03	1.90	0.74	1.32	1.17	3.28	0.37	0.08
Ma. Sph.	0.03	0.00	0.02	0.01	0.08	0.03	0.01	0.00	0.01
N. Car.	0.30	0.01	0.08	0.06	0.07	0.02	0.01	0.01	0.01

TABLE 7
Percent Abundance's of Organic Chemical Compounds Identified in the Peat Samples (wt. percent, nd = no data available, from Cohen et al., 1991a; and Durig et al., in preparation)

Sample	Humic Acids	Fulvic Acids	Total Aldehydes	Total Furans	Total Furanones
Lox. Nym.	7.1	0.20	8.012	5.255	7.791
Lox. Saw.	4.6	0.12	8.112	5.046	4.363
Oke. Tax.	14.5	0.27	11.021	6.259	3.376
New York	3.8	0.39	nd	nd	nd
Shar. Riv.	2.7	0.74	7.061	2.851	5.720
Ma. Sph.	5.5	0.06	12.891	2.926	15.068
N. Car.	nd	nd	nd	nd	nd

TABLE 7- continued.

Sample	Total Pyranones	Total Other Ketones	Total Guaiacyl Lignins	Total Other Lignins	Total All Lignins
Lox. Nym.	5.250	4.842	13.172	10.477	23.649
Lox. Saw.	1.551	2.949	12.580	16.767	29.347
Oke. Tax.	3.416	3.329	13.865	13.432	27.297
New York	nd	nd	nd	nd	nd
Shar. Riv.	5.701	1.578	14.225	13.067	27.292
Ma. Sph.	7.478	3.548	10.529	18.683	29.212
N. Car.	nd	nd	nd	nd	nd

(Fig. 4) tended to have poorer ALCR and ARN/TC results, while the peats with higher water holding capacity (Fig. 3), and hydraulic conductivity (Fig. 5) tended to have better ALCR and ARN/TC results.

Of the inorganic chemical characteristics measured, ash content, P content, Fe content, Mg content, K content, Si content, and Al content exhibited fairly strong correlation's with both the ALCR and the ARN/TC results (Figs. 6-12).

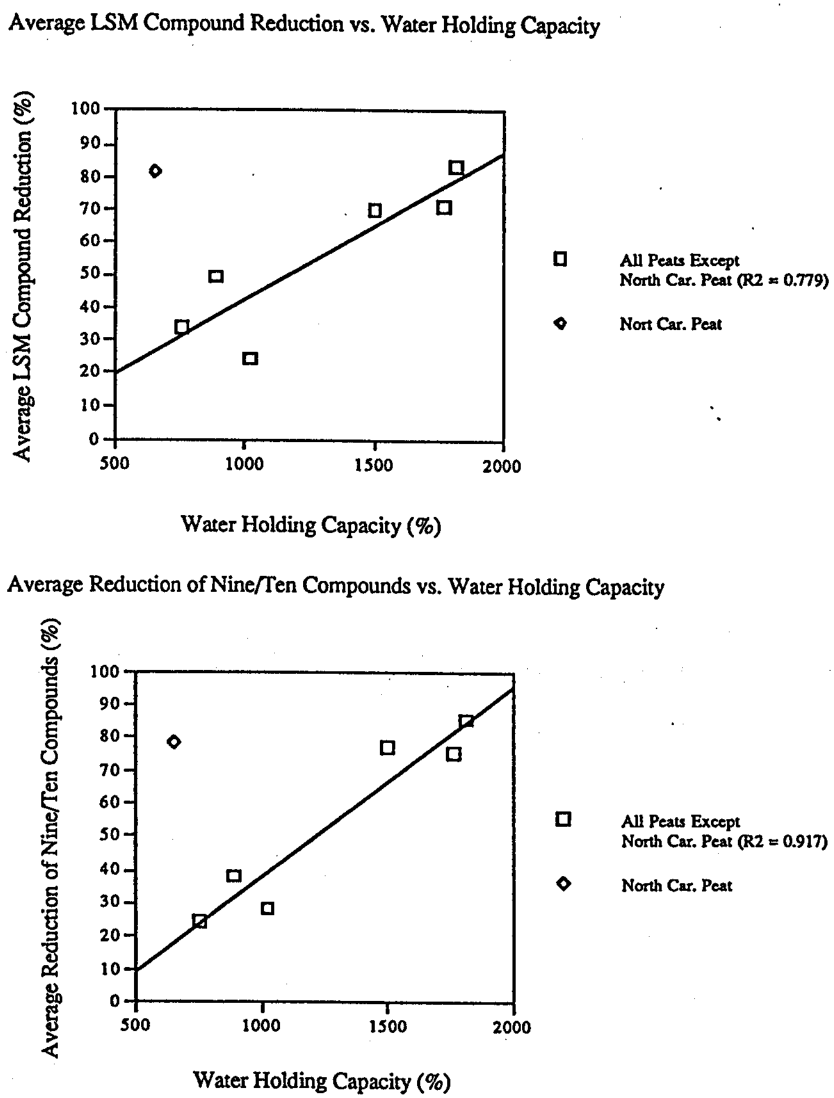
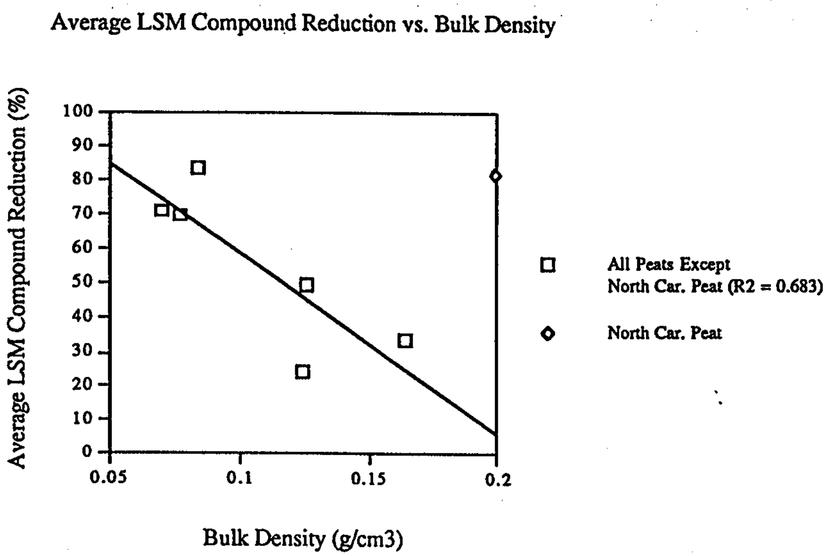


FIGURE 3
Average LSM compound reduction and average reduction of nine/ten compounds vs. water holding capacity.



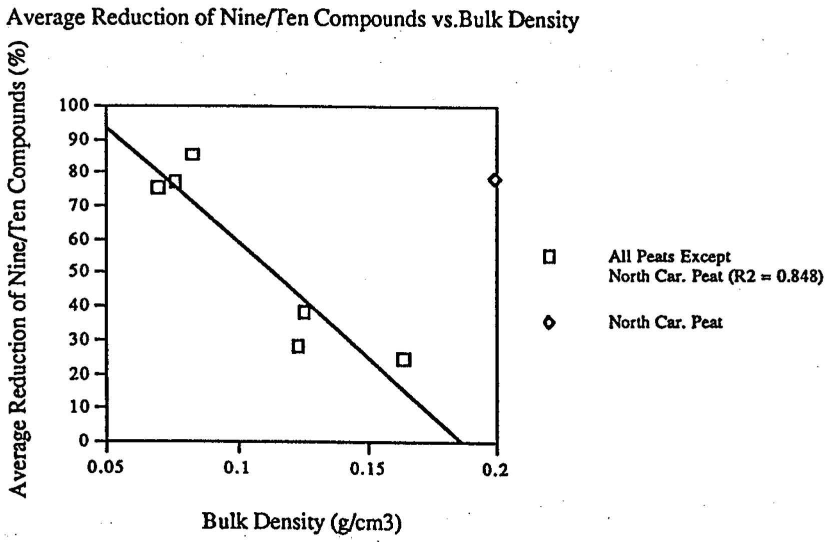
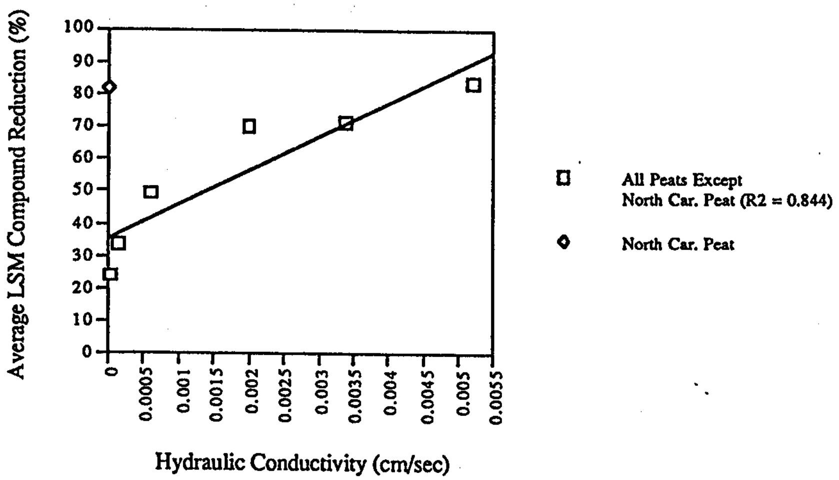


FIGURE 4
Average LSM compound reduction and average reduction of nine/ten compounds vs. bulk density.

Average LSM Compound Reduction vs. Hydraulic Conductivity



Average Reduction of Nine/Ten Compounds vs. Hydraulic Conductivity

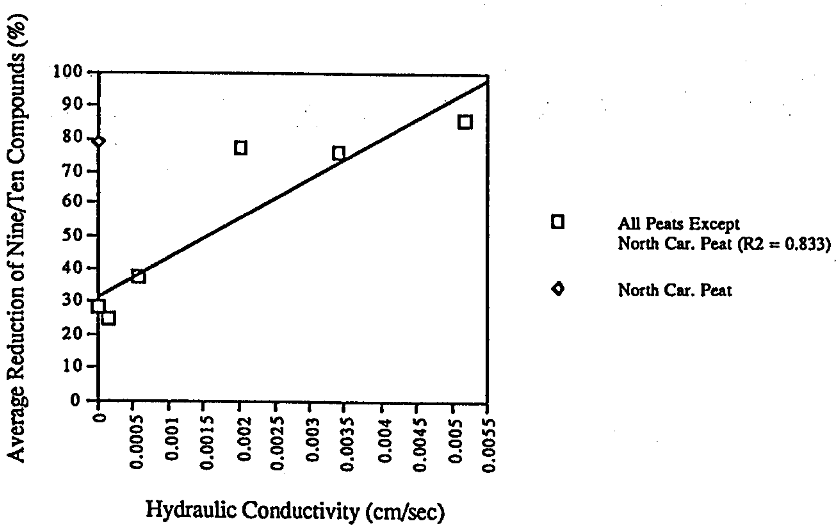
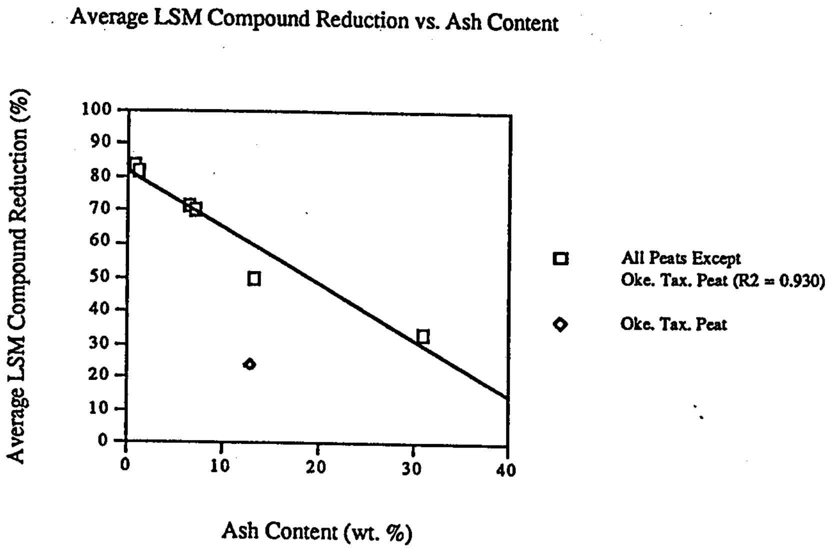


FIGURE 5

Average LSM compound reduction and average reduction of nine/ten compounds vs. hydraulic conductivity.



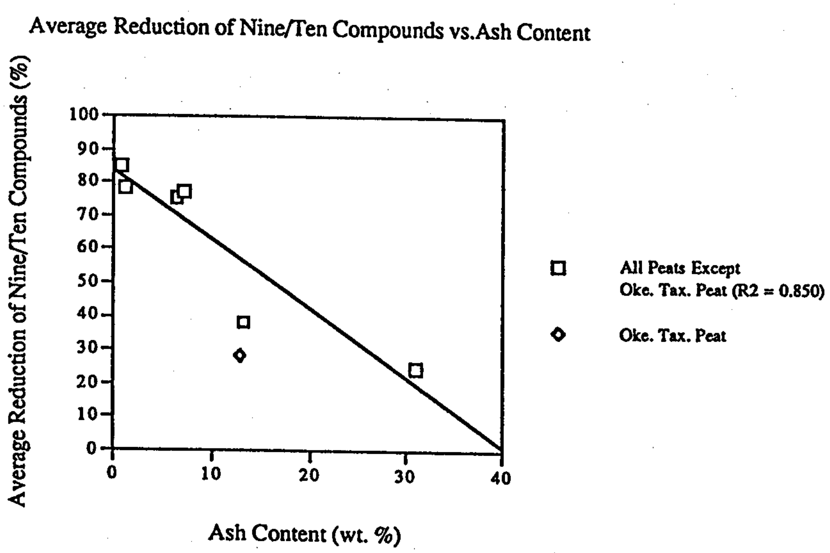


FIGURE 6
Average LSM compound reduction and average reduction of nine/ten compounds vs. ash content.

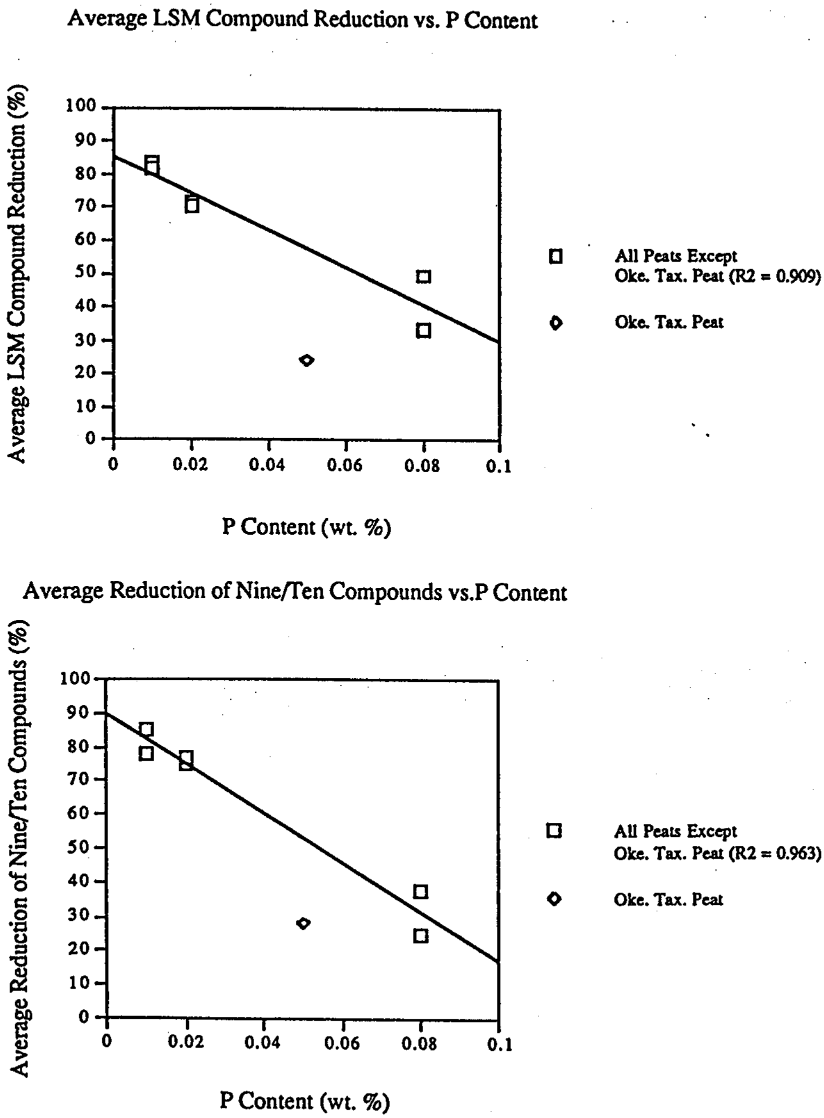
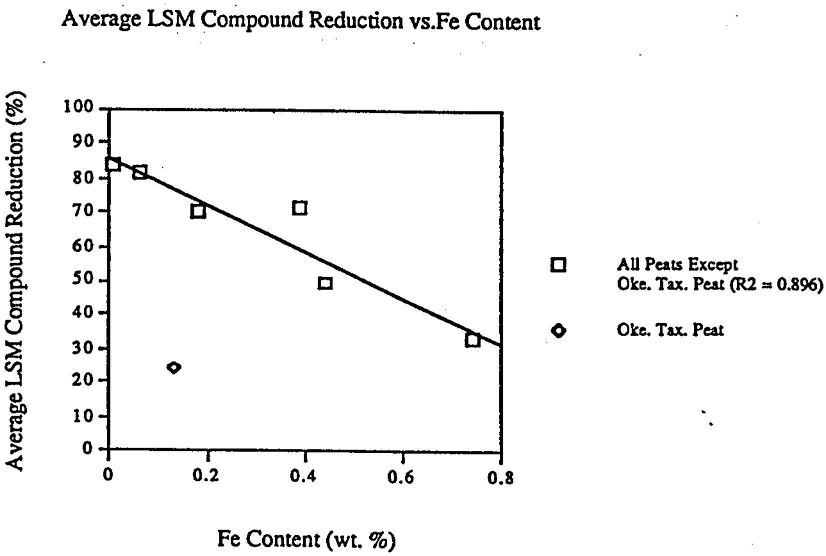


FIGURE 7
Average LSM compound reduction and average reduction of nine/ten compounds vs. P content.



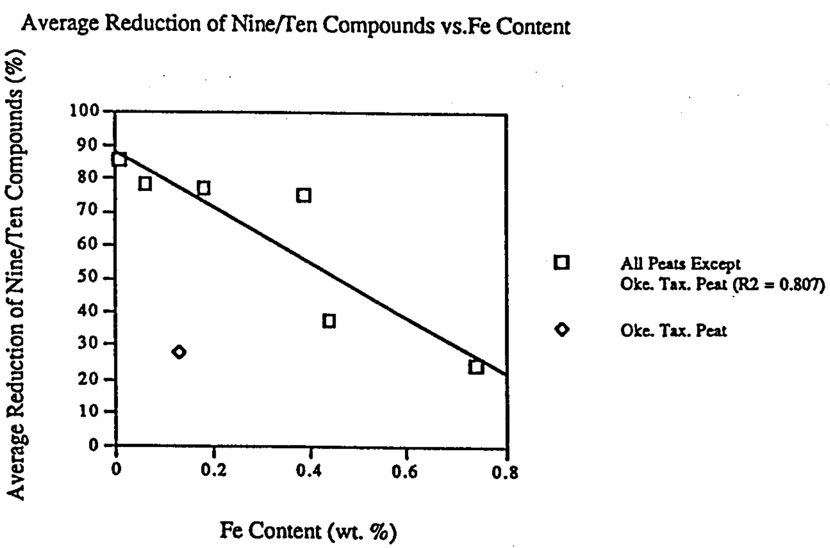
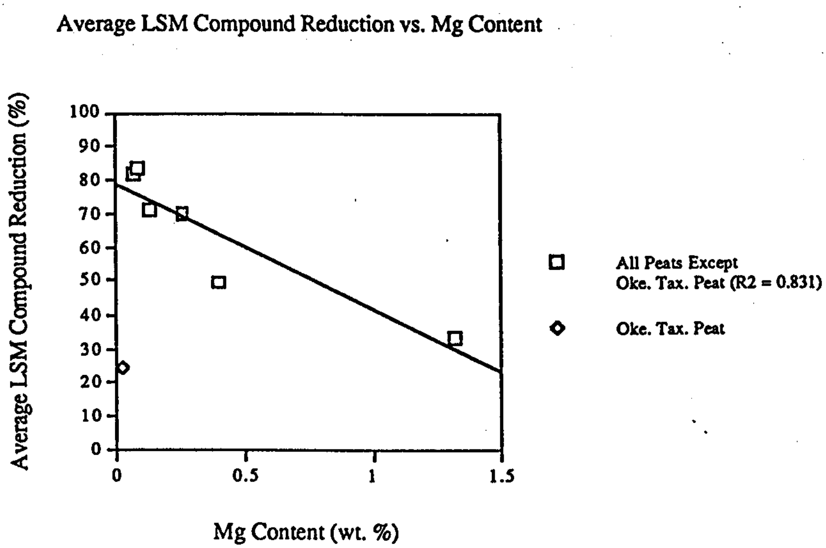


FIGURE 8
Average LSM compound reduction and average reduction of nine/ten compounds vs. Fe content.



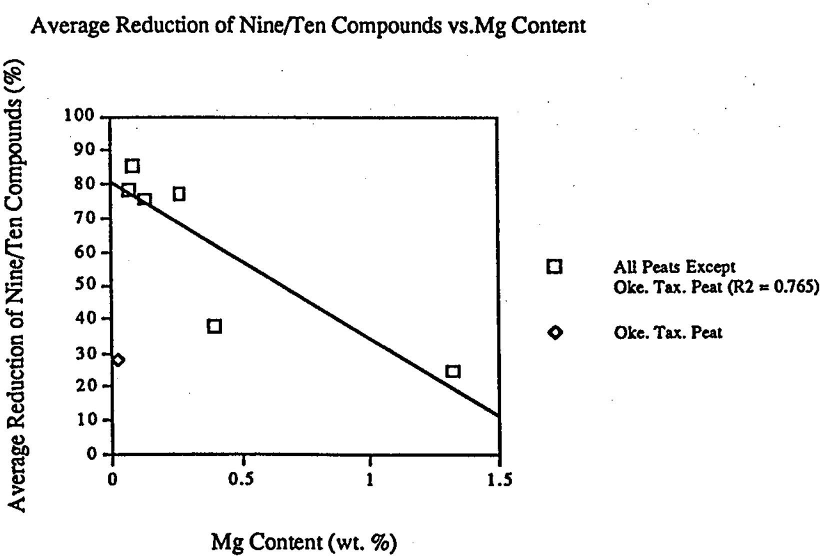


FIGURE 9
Average LSM compound reduction and average reduction of nine/ten compounds vs. Mg content.

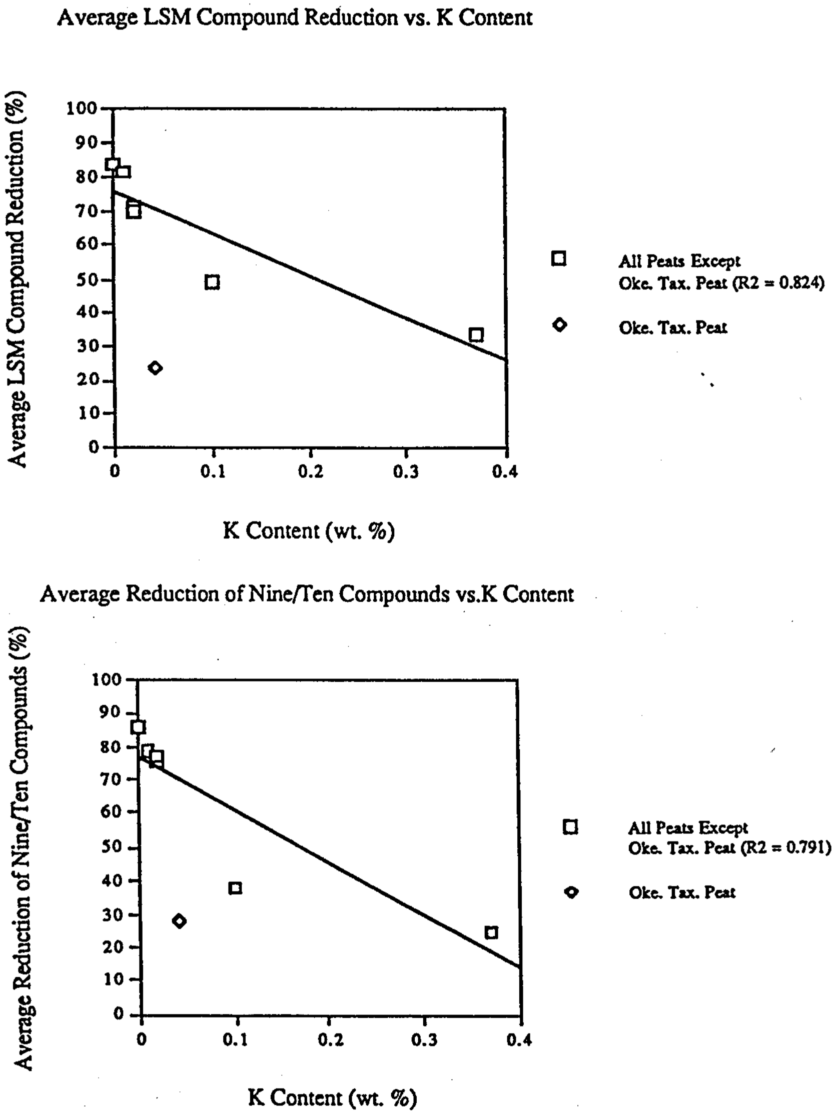


FIGURE 10
Average LSM compound reduction and average reduction of nine/ten compounds vs. K content.

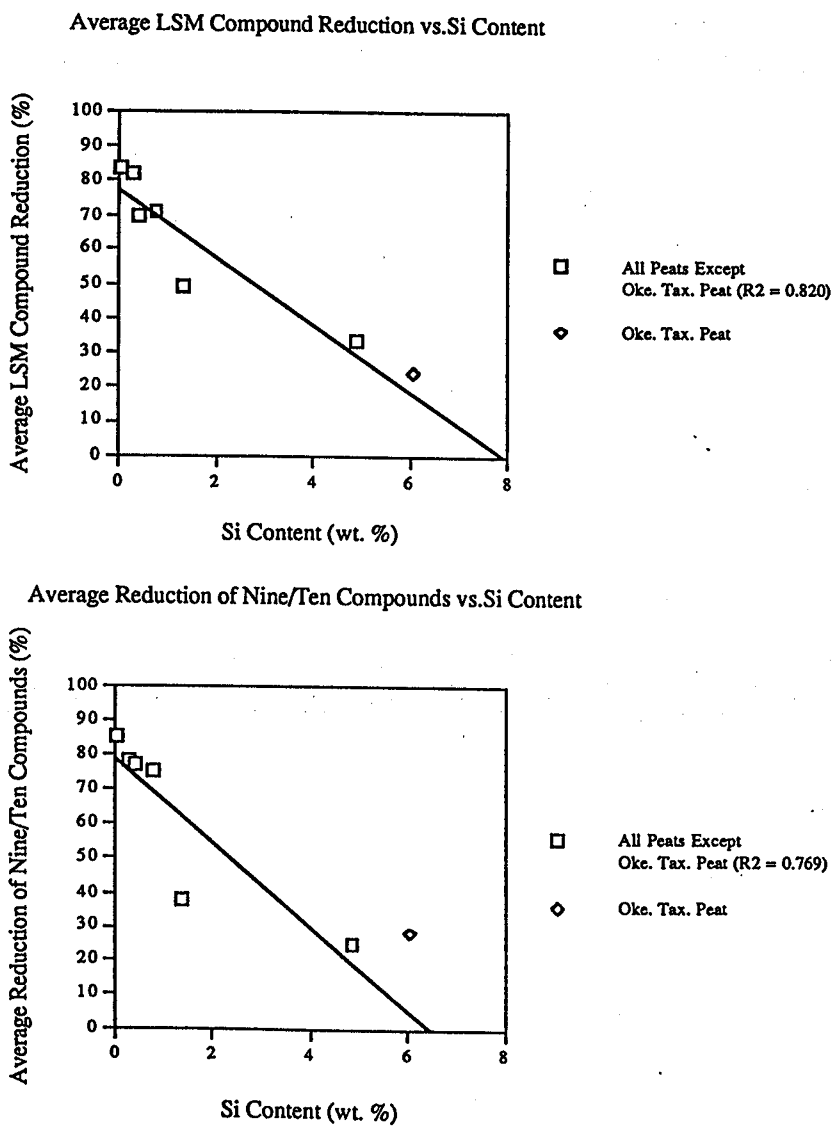


FIGURE 11
Average LSM compound reduction and average reduction of nine/ten compounds vs. Si content.

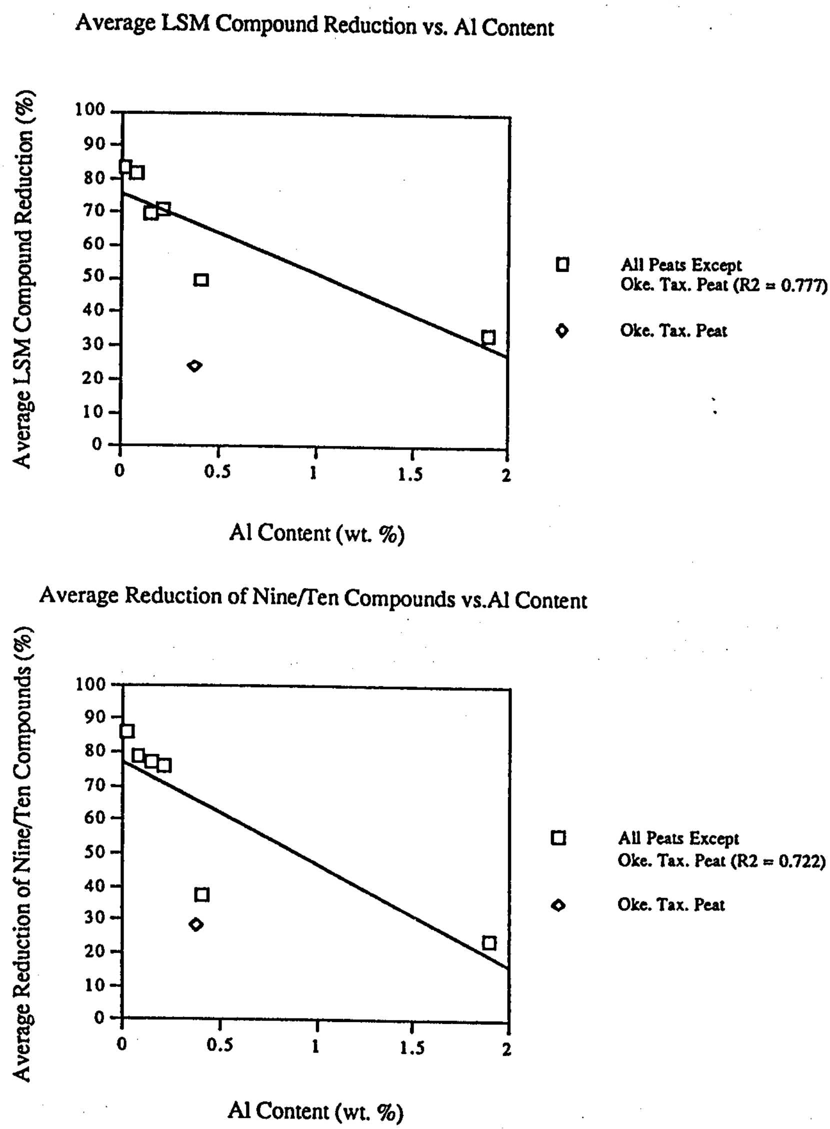


FIGURE 12
Average LSM compound reduction and average reduction of nine/ten compounds vs. Al content.

The peat types with higher concentrations of ash and, consequently, of these inorganic elements tended to have poorer ALCR and ARN/TC results.

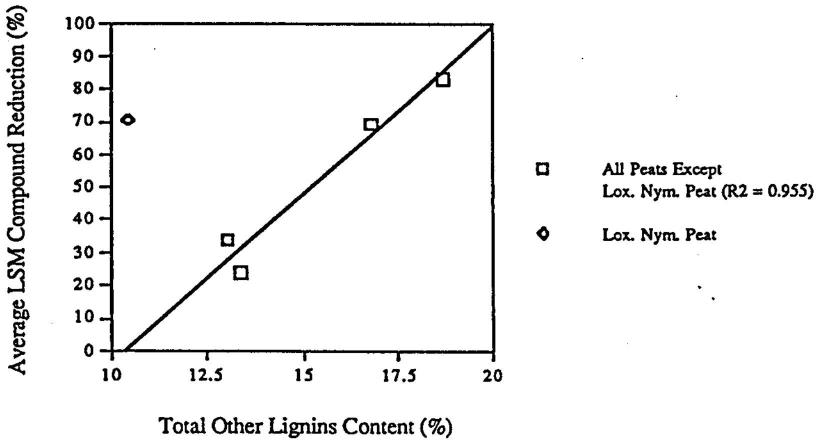
Of the organic chemical characteristics measured, "total other lignins" content, fulvic acids content, H content, C content, total guaiacyl lignins content, total cellulose content, and humic acids content exhibited fairly strong correlation's with both the ALCR and the ARN/TC results (Figs. 13-19). The peats with higher fulvic acids content (Fig. 14) and total guaiacyl lignins content (Fig. 17) tended to have poorer ALCR and ARN/TC results, while the peats with higher "total other lignins" content (Fig. 13), H content (Fig. 15), C content (Fig. 16), and total cellulose content (Fig. 18) tended to have better ALCR and ARN/TC results. With humic acids content (Fig. 19), it is not quite clear whether peats with higher humic acids content have better ALCR and ARN/TC results or whether peats with humic acids content around 5% have the best ALCR and ARN/TC results.

In examining the correlation's made, the peats with the best ALCR and ARN/TC results tend to have lower bulk densities, ash contents, fulvic acids contents, guaiacyl lignins contents, but higher water holding capacities, hydraulic conductivities, "total other lignins" contents, H contents, C contents, and total cellulose contents.

CONCLUSIONS

Although all peats tested in this study were found to be effective at removing odor-causing compounds found in LSM, some peats tended to work slightly better than others. This was confirmed by both the odor panel and

Average LSM Compound Reduction vs. Total Other Lignins Content



Average Reduction of Nine/Ten Compounds vs.Total Other Lignins Content

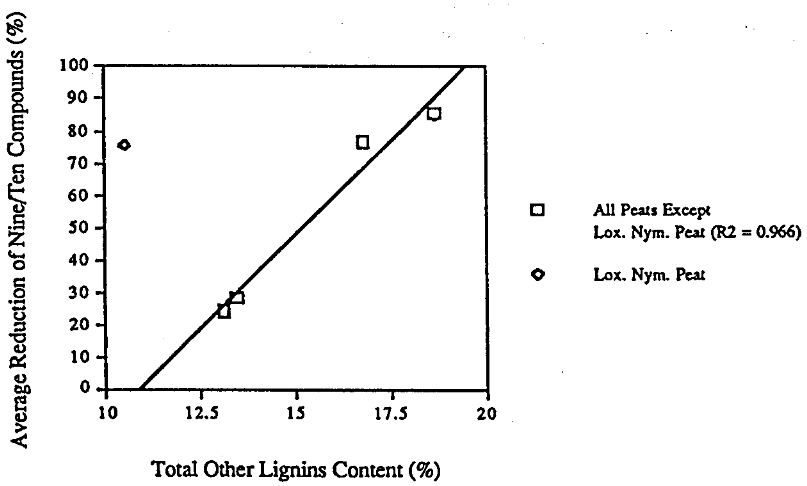


FIGURE 13
Average LSM compound reduction and average reduction of nine/ten compounds vs. total other lignins content.

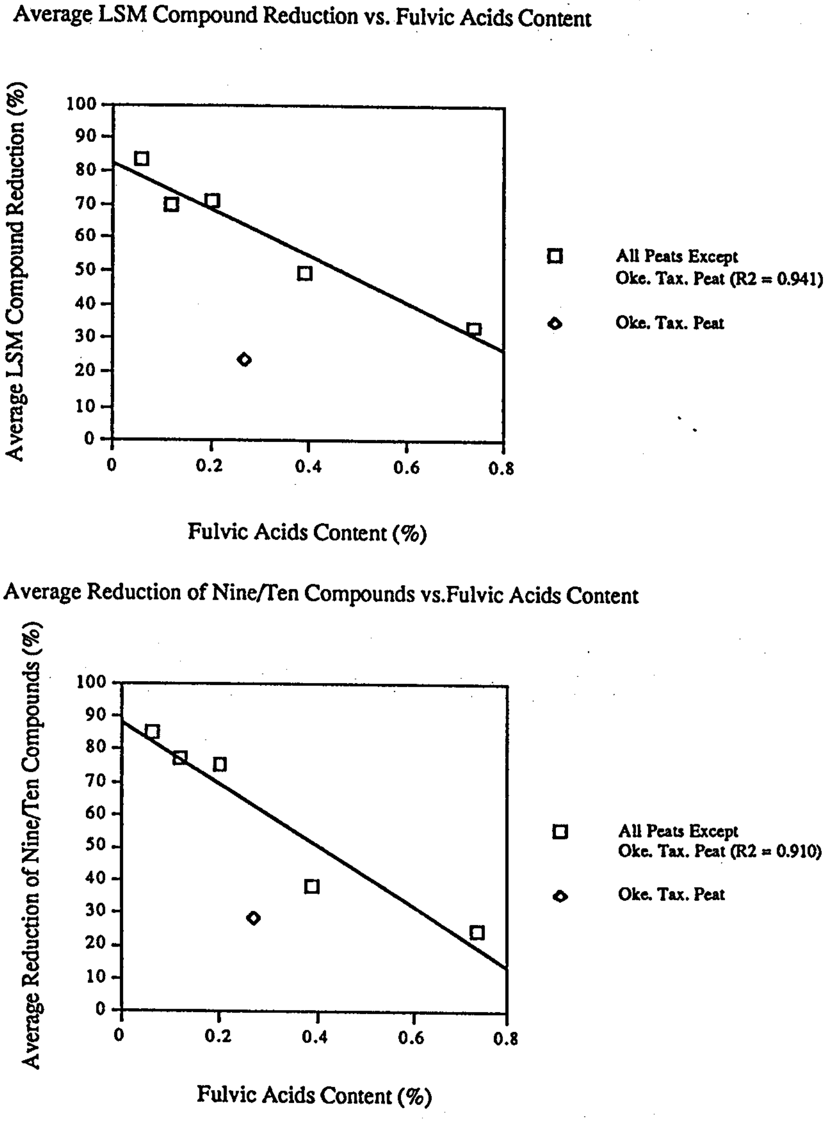


FIGURE 14
Average LSM compound reduction and average reduction of nine/ten compounds vs. fulvic acids content.

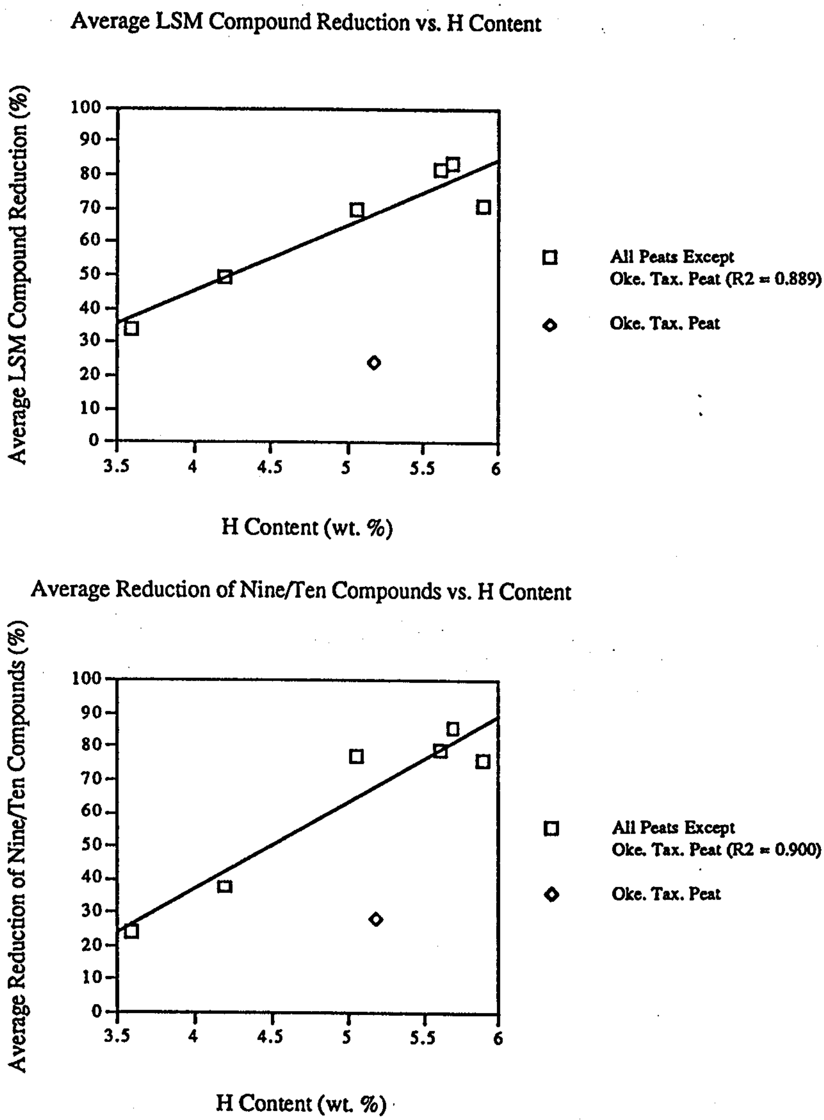


FIGURE 15
Average LSM compound reduction and average reduction of nine/ten compounds vs. H content.

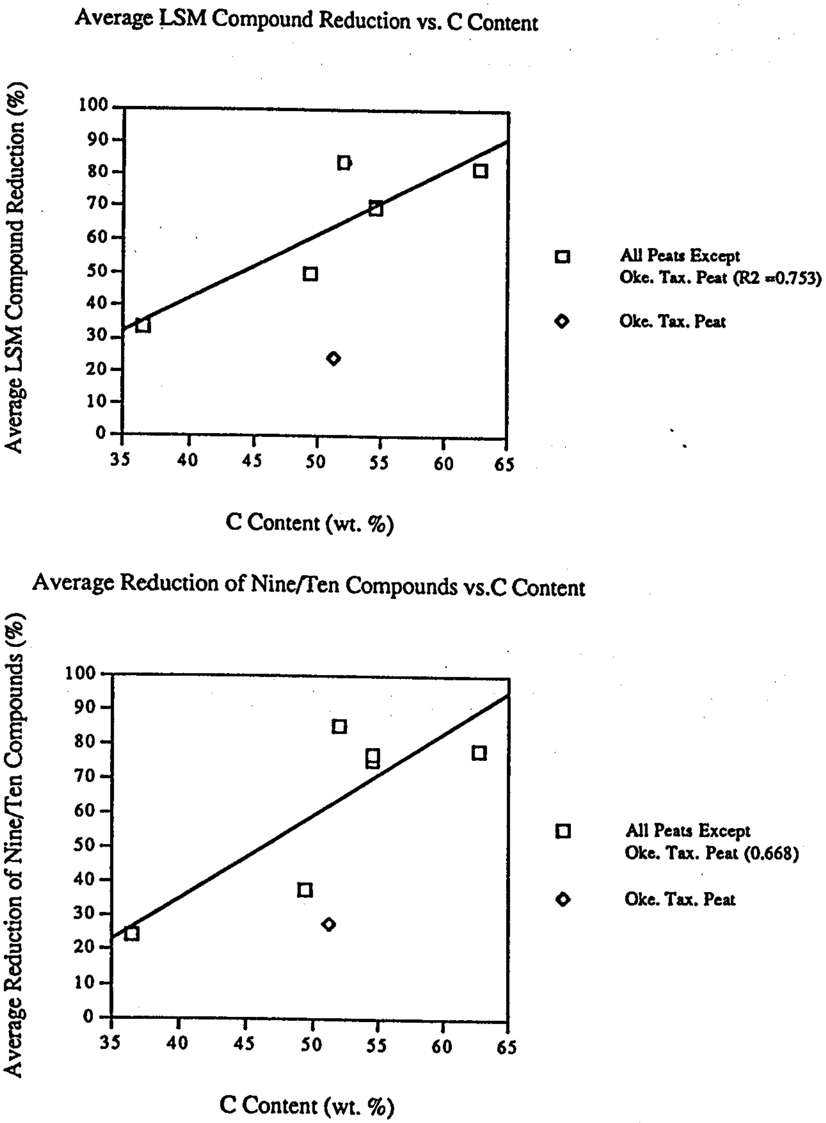
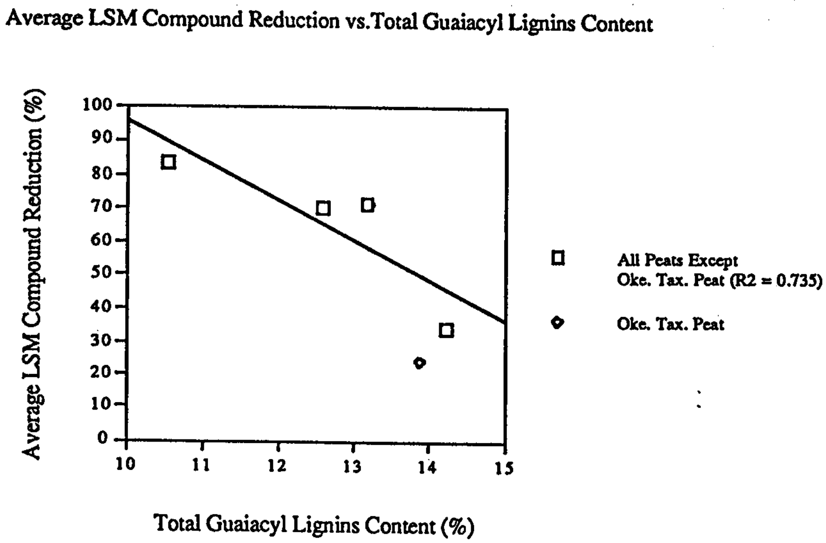


FIGURE 16
Average LSM compound reduction and average reduction of nine/ten compounds vs. C content.



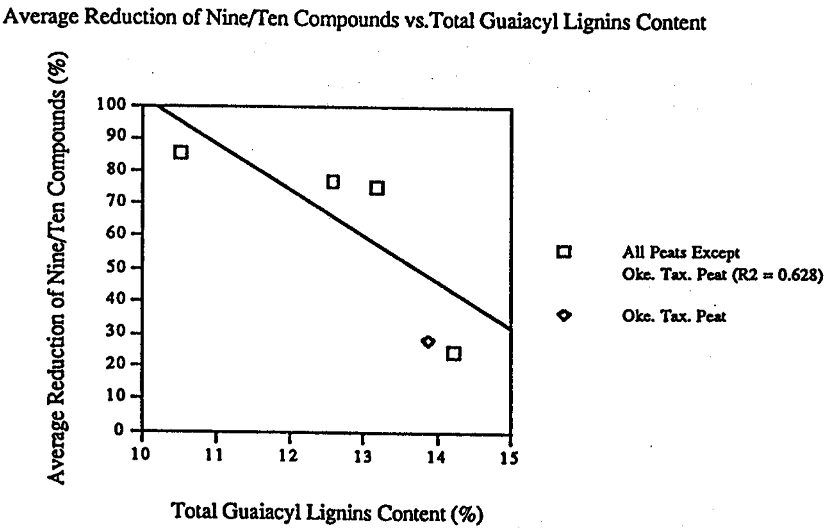


FIGURE 17
Average LSM compound reduction and average reduction of nine/ten compounds vs. total guaiacyl lignins content.

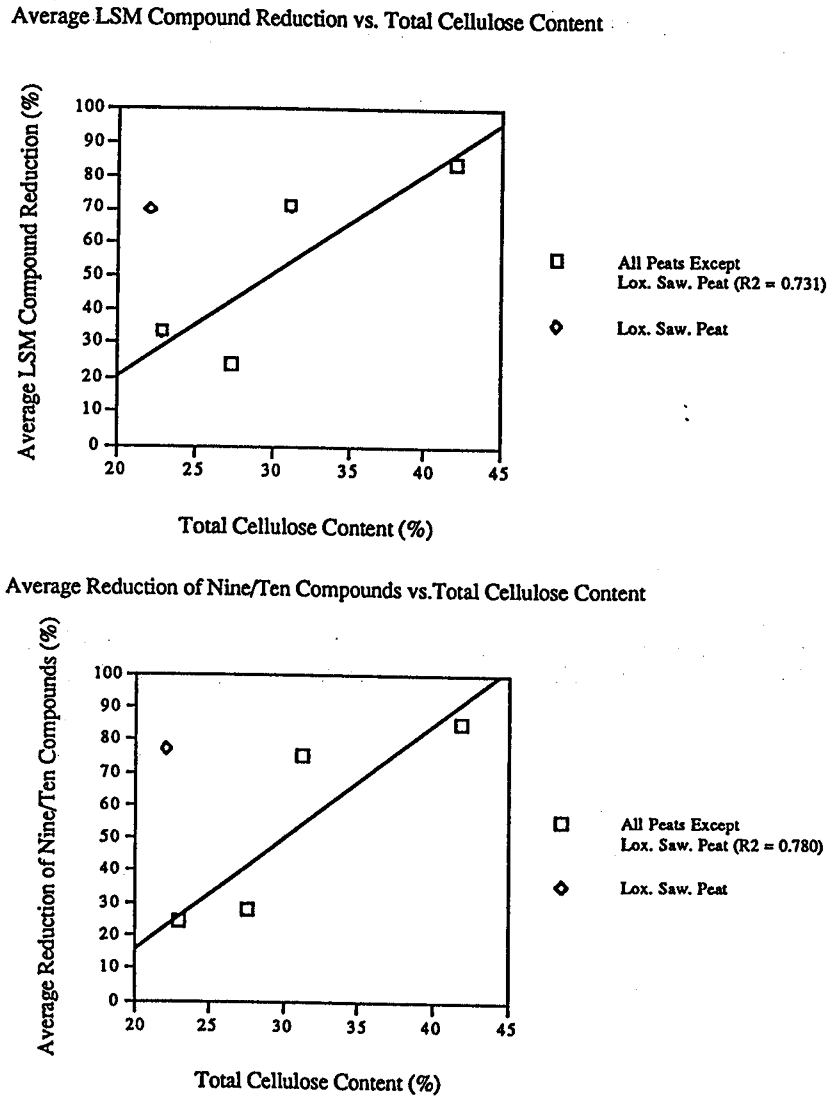
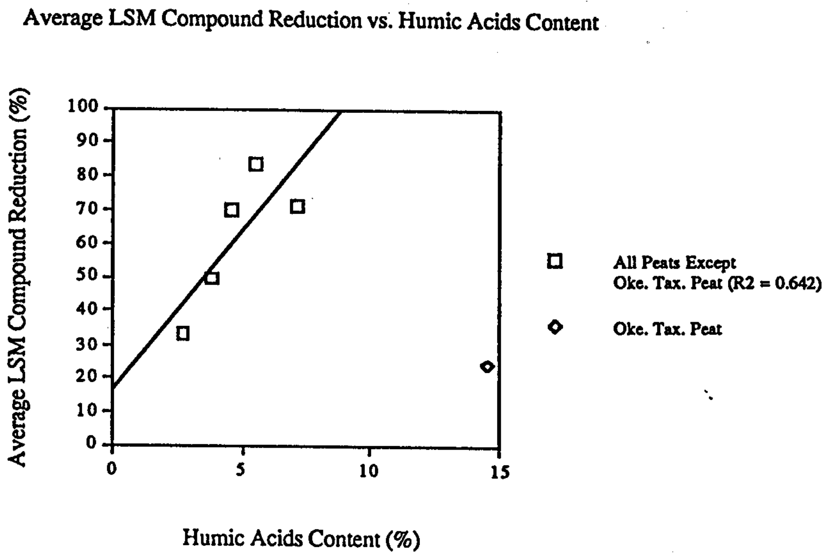


FIGURE 18
Average LSM compound reduction and average reduction of nine/ten compounds vs. total cellulose content.



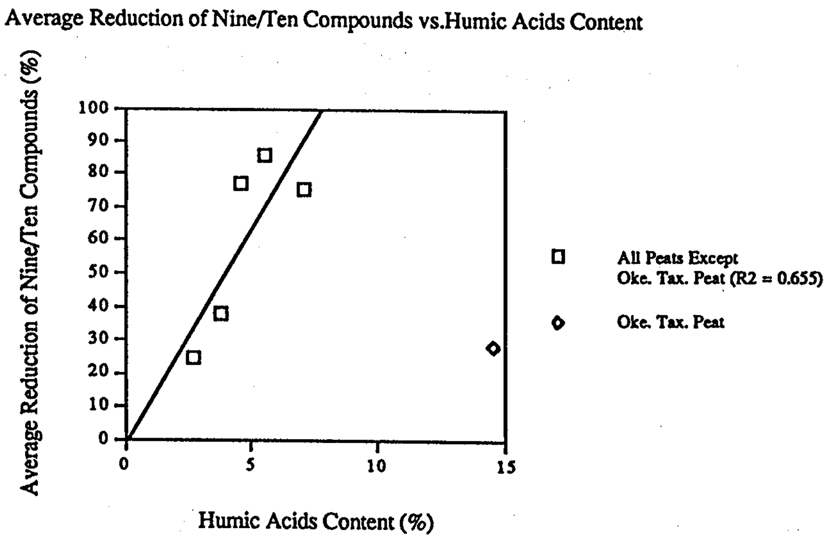


FIGURE 19
Average LSM compound reduction and average reduction of nine/ten compounds vs. humic acids content.

GC/MS-SPME results. Overall, the peats that were more effective at removing odor-causing compounds tended to have lower bulk densities, ash contents, fulvic acids contents, and guaiacyl lignins contents, and higher water holding capacities, hydraulic conductivities, "total other lignins" contents, H contents, C contents, and total cellulose contents.

GC/MS-SPME analysis was found to be a reasonably inexpensive and efficient way of doing this type of research. It allowed us to identify a large number of the odor-causing compounds found in LSM, and more importantly, allowed us to detect specific differences in these compounds between peat types. This kind of information should prove to be very important for selection of peat-based materials for future design of odor-remediating treatment strategies.

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