EFFECT OF FLY ASH AND GYPSUM ON DISPERSION, HYDRAULIC CONDUCTIVITY, AND CONTAMINANT LEACHING IN SOIL COLUMNS

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INTRODUCTION

Fly ash (FA) is the major coal combustion by-product produced in electric power generation; nearly 3.5 million tons of this waste product are produced in Georgia annually. To date, no power plants in Georgia have installed stack scrubbers for the removal of sulfur dioxide gas during coal combustion; however, beginning in 1995, the electrical utilities will have to reduce sulfur emissions under the Clean Air Act (Reisch, 1992). This will lead to the production of flue-gas desulfurization gypsum (FGDG) as an additional by-product.

Land application has been proposed as a disposal option for fly ash and flue-gas gypsum; however, there is some concern that heavy metals found in the ash may pollute surface water or leach into groundwater. High levels of soluble boron found in the fly ash have been shown to cause toxicity problems for plants under greenhouse conditions (Ciravolo and Adriano, 1979). In spite of the potential hazard associated with fly ash usage, alkaline ash has been shown to be an effective liming agent for increasing soil pH (Adriano et al., 1980). Additionally, gypsum has been shown to ameliorate chemical and physical limitations associated with the highly weathered soils of the southeast (Shainberg et al., 1989). Ultisols in Georgia display improved plant-water relations and a decrease in root penetration resistance following gypsum application. Gypsum also decreases exchangeable acidity and increases available calcium. The solubility of flue-gas gypsum is similar to or greater than that of phosphogypsum and thus may be a more effective soil amendment than phosphogypsum or mined gypsum.

In an effort to assess potential environmental implications, column and batch experiments were conducted to determine the influence of FA and FGDG amendments on boron (B) and arsenic (As) movement, hydraulic conductivity (HC), and dispersion properties of an Appling Ap loamy sand.

METHODS

Batch Studies

A batch study was conducted to determine the impact of the FA treatments on water-dispersible clay from the Appling soil. The Appling series is a member of the clayey, kaolinitic, thermic family of Typic Hapludults and the topsoil consists of less than 6 % clay. Treatments were created by mixing the air-dried soil with the proper level of ash (0, 1%, 5%), or ash + gypsum mixture, to a combined weight of 100 grams. Water-dispersible clay (WDC) was measured by the pipette method (Miller and Miller, 1987). An ANOVA test was performed on the dispersibility results to determine treatment differences at the 0.05 significance level.

Column Studies

The column studies were performed in 10 cm plexiglass tubes with an interior diameter of 5 cm. The soil was packed to a depth of 7 cm at a uniform density of about 1.7 g/cm^3. Above and below the soil, sand layers were placed to help disperse flow throughout the column. The incorporated and surface applied treatments consisted of mixing 1% ash (10 mt/ha) with the topsoil prior to packing or adding the ash to the column after the topsoil was in place. The two-layer columns consisted of 3.5 cm of Ap over 3.5 cm of Bt with the ash incorporated only in the Ap layer. The columns were oriented vertically and slowly saturated from the outlet with deionized water (< 0.25 mL/min). After saturation, the columns were turned horizontally and flow was initiated at a constant rate of 1 cm/hr. with deionized water for at least 6 pore volumes. The electrical conductivity (EC), pH, and turbidity of the effluent were monitored continuously, and fractions were collected for B and As determination. The pressure head was measured at the inlet of the column as an indicator of hydraulic conductivity and column plugging.

RESULTS

Selected physical and chemical properties of the soil used in this study are given in Table 1. The texture of the surface horizon for the sample was a loamy sand. The dominant clay mineralogy for the Appling series consists of kaolinite > goethite > HIV ≈ gibbsite.

Table 1. Selected Physical and Chemical Characteristics for the Ap and Bt Horizons of the Appling Soil (Typic Hapludults).

Horizon	Sand	Silt	Clay	Organic C	H_2O pH	$CaCl_2$ pH
			%			
Ap	79.2	15.0	5.8	0.43	5.4	4.7
Bt	61.4	18.2	20.4	0.25	4.8	-

Table 2. Selected Physical and Chemical Characteristics for the Coal Waste Products.

Coal Waste	Sand	Silt	Clay	As	B
		%		(μg/g)	
Alk. Ash	23.9	72.7	3.4	44	615
Acidic Ash	38.0	61.5	0.5	18	94
FGDG	99.5	0.1	0.0	0.24	93

Selected properties of the two ashes and the flue-gas gypsum used in this study are given in Table 2. The alkaline fly ash had substantially higher B concentration than the acidic ash or flue-gas gypsum. Both fly ash samples displayed a tendency to set up like cement when wetted. Due to the pozzolanic nature of the ashes, incorporation of this material may be required to reduce surface crusting and runoff. The alkaline ash had an acid neutralizing capacity of 1.9 expressed as an equivalent % of calcium carbonate.

Water Dispersibility

The Appling topsoil was naturally dispersive and about 84.4 % of the clay fraction dispersed when shaken in deionized water. The ashes, both acidic and alkaline, were ineffective in significantly reducing clay dispersion of the soil, with the exception of the 5% rate of acidic ash, which decreased the water dispersible clay by about 20% relative to the control. When FGDG was included with the ash, the Ap was well flocculated at all ash levels due to the large amount of soluble salt released by the FGDG. The Bt soil was well flocculated in its natural state. However, the 5% alkaline ash treatment slightly increased the amount of dispersible clay (1.5%) by raising the pH and exchangeable Na, with insufficient salt release to cause particle attraction.

Column Results

All of the ash and gypsum treatments were effective at raising the EC of the effluent solutions. In general, the electrical conductivity was higher for the incorporated treatments compared to their surface applied equivalents. The FGDG treatments displayed much greater maximum EC values and the EC remained elevated throughout the experiment. Only trace amounts of As (< 50 μg/L) were detected in the leachate from the fly ash treatments, indicating As movement over the leaching period was insignificant. The application method influenced the effluent pH for the alkaline ash treatments (Figure 1). If incorporated, the alkaline ash was effective at raising the effluent pH (6.5), but essentially no change in pH (5.5-6.0) was observed in the effluent from the surface-applied or acidic ash treatments. Effluent from the two-layer columns failed to show an increase in pH with either surface-applied or incorporated fly ash, when compared to the control.

Boron

Most of the B added in the incorporated alkaline treatment was eluted in the first 3 pore volumes. The maximum B concentration for the surface applied treatment was below that of the incorporated treatment, but remained elevated for several pore volumes longer than that of the incorporated treatments (Figure 2). Incorporation, by mixing the ash throughout the column, increased B solubility by increasing the duration of exposure of the ash to the percolating solution. The addition of gypsum increased both the maximum B concentration and the movement of B through the column, while reducing the effluent concentration differences between application methods. Sulfate released by the gypsum may have enhanced B movement by competing for adsorption sites, resulting in more rapid removal of B from the soil. Boron movement from the acidic ash was considerably less than that of the alkaline treatments, due to lower total and soluble B found in this ash (Table 2). Columns containing a Bt layer were not effective in attenuating B movement through the column.

Turbidity

The effluent turbidity (NTU) for the incorporated alkaline ash was much less than that of the control, while the effluent turbidity of the surface-applied alkaline ash was comparable to that of the control for

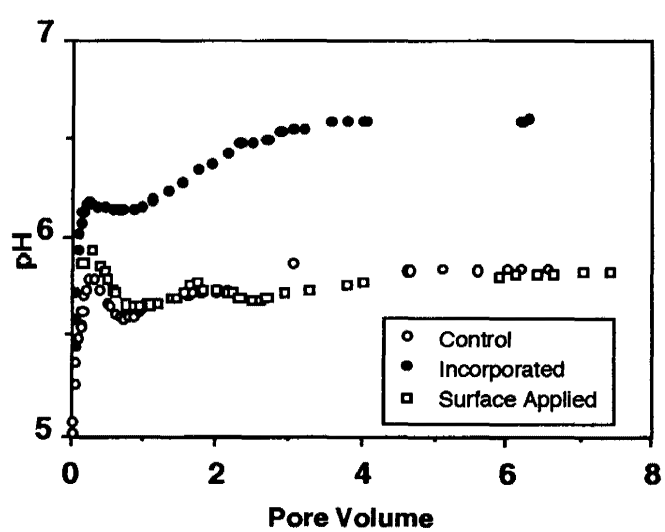

Figure 1. Effluent pH for alkaline fly-ash treatments.

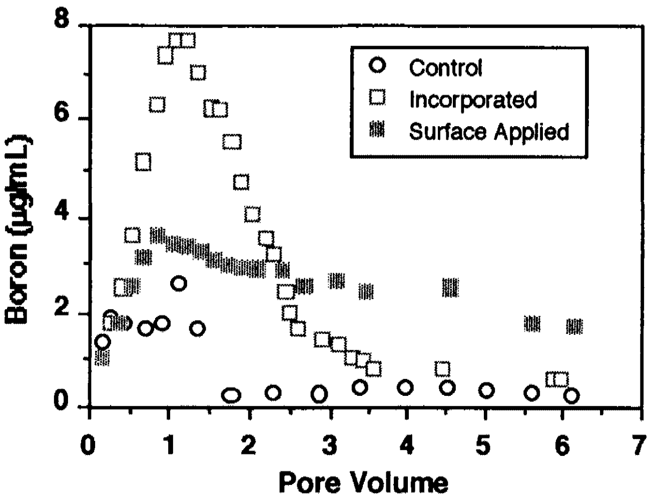

Figure 2. Effluent Boron concentration from alkaline fly-ash treatments (1%) for the Appling Ap soil.

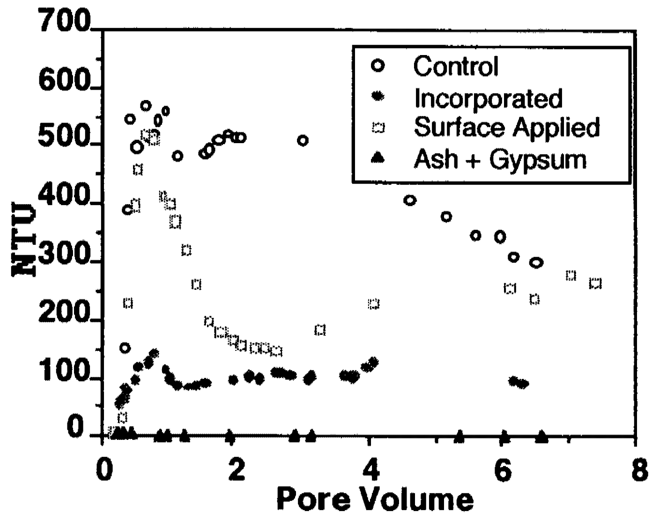

Figure 3. Effluent turbidity (NTU) for 1% alkaline ash treatments for Ap columns.

the first pore volume before decreasing to a level similar to that of the incorporated treatment (Figure 3). When FGDG was incorporated with the ash, the effluent turbidity was the lowest of all of the alkaline ash treatments, and leachate solutions were essentially clear. Turbidity of leachates from the acidic ash columns was quite variable, but the incorporated ash tended to produce a higher effluent turbidity than the surface-applied ash or the control columns (not shown). When a Bt layer was included in the column, the effluent turbidity was negligible due to flocculation and filtering in the Bt layer.

Hydraulic Conductivity

The pressure head developed during the leaching of the columns is displayed in Figure 4. The control showed a gradual increase in hydraulic head over time, indicating some clogging of the column due to clay movement and blockage of pores. The acidic or alkaline ash, when combined with FGDG, displayed the least head buildup during leaching, and HC often increased slightly over the duration of the experiment. The incorporated alkaline ash had the greatest increase in head over time while displaying a lower effluent turbidity. The lower effluent turbidity and decrease in HC for the alkaline ash columns would tend to indicate that there is a dispersion threshold at which more of the dispersed clay is captured in the column, thus reducing the HC for that column. In controlling dispersion, the increase in pH and exchangeable Na associated with the alkaline ash treatment may outweigh the effect of a slight increase in ionic strength. At this elevated dispersion level, the pores can become clogged and the effluent appears clearer than under less dispersive conditions. The acidic ash treatment displayed one of the highest effluent turbidities and one of the highest HC. The acidic ash treatment may decrease dispersion to some degree by increasing ionic

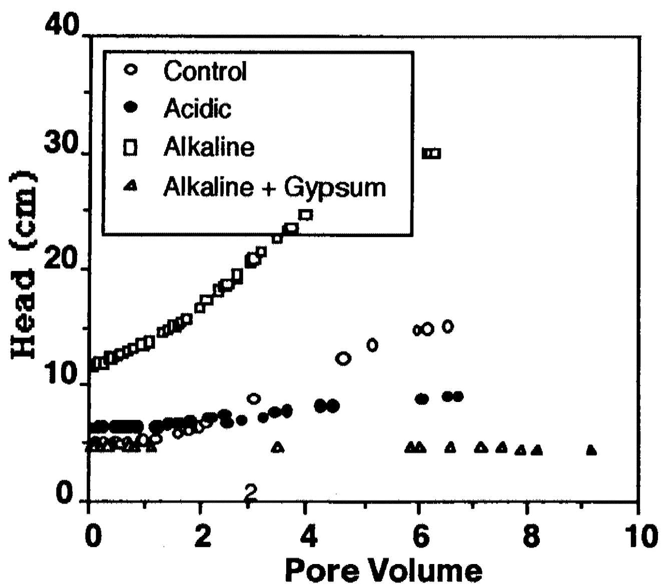

Figure 4. Head build-up at inlet of Ap columns for the 1% incorporated fly-ash treatments.

strength, but this lower dispersion level decreases filtering and allows more of the dispersed clay to exit the column.

SUMMARY AND CONCLUSIONS

Low levels (1%) of acidic and alkaline ash were ineffective at reducing water-dispersible clay from a topsoil, but the addition of FGDG induced complete flocculation. If incorporated, the alkaline ash and alkaline ash + gypsum treatments were effective at increasing the effluent pH from an Ap column. Results of the incorporated ash treatments indicate that sparingly-soluble alkaline ash may act as a dispersing agent by raising the pH and exchangeable Na, while failing to release sufficient salts to encourage flocculation. The addition of FGDG to the fly ash decreased effluent turbidity and increased the leaching of B from the column. The presence of a Bt layer was effective at decreasing effluent turbidity, but failed to retard the movement of B from the Ap horizon.

The results of this study indicate that for alkaline fly ashes, land application may result in decreased hydraulic conductivity of the surface horizon, which can increase the potential for surface runoff and soil erosion. However, addition of FGDG to the ash, as proposed in some experimental scrubber systems, may inhibit the dispersion and pore clogging associated with the incorporation of alkaline ash. Acidic ashes pose less of a problem in this regard; similarly, surface application of the alkaline ash appears to be less dispersive, although the cementing nature of the ash may enhance surface crusting and runoff. Leaching of As was not observed in any treatment, due to the high adsorption by even this very sandy soil. Boron was readily leached form the surface soils; this appears to be advantageous, since B is highly toxic to plants but quite non-toxic to animals.

Our results indicate that management of fly-ash amended soils needs to take into account the impact of ash on soil hydraulic properties in order to avoid excessive runoff and surface-water contamination. Using As as a contaminant indicator, no groundwater effects would be predicted under aerobic conditions; however, further studies are underway.

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