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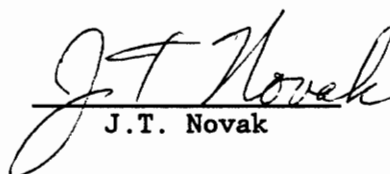
Groundwater Effects of
Land Applied Alum Residuals

by

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by
James J. Kuper
(Abstract)

Soil columns of predominantly Peawick and Slagle soils had various amounts of alum residuals, lime and plant nutrients incorporated into the topsoil. A weekly dose of rainwater was applied to each column over a six month period. Leachate and soil constituents were analyzed to evaluate migration of specific constituents from the alum residuals through the soil profile and into the groundwater.

Soil analysis indicated little, if any, migration of metals from the alum residuals occurred. Metal constituents found within the leachate appear to have originated from the soil rather than the alum residuals.

Of the measured anions, nitrate - nitrogen was the only component which had increasing concentrations within the leachate. Much, if not all, of the nitrate can be attributed to the plant nutrients incorporated into the topsoil and disturbance of the topsoil.

Nitrate and zinc were the only components that consistently degraded the leachate quality beyond Virginia Water Control Boards' Groundwater Standards, but were within observed ranges of non-sludge amended soil columns. Groundwater contamination is not likely as a result of land application of alum residuals up to a loading of four percent.

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I. INTRODUCTION

Need for Study

The disposal of water treatment plant residuals (sludge) is one of the most challenging management problems currently facing water utilities. Concerns over new drinking water standards are important; however, the attainment of drinking water quality and the allocation of resources necessary to meet those standards can be understood by water customers and municipal officials alike. Not so for sludge disposal. The problem of disposal cost, permitting of acceptable disposal sites, and environmental problems associated with sludge disposal are often unappreciated and poorly understood. Equally important are the political or jurisdictional considerations in developing a disposal method. The impact of residuals on receiving water quality are often minimal, especially during periods where stream flow provides substantial dilution.

The City of Newport News, VA., water utility faces the problem of alum residuals disposal. Its previous practice of total discharge to a stream has met opposition from the community; therefore, alternate disposal options were needed. To minimize public interference and disruption in treatment practice, and to provide for safe disposal of residuals even with probable changes in water treatment requirements and technology, CH2M-Hill reviewed various residual disposal options for the Newport News Waterworks and elected to further study the land applica-

tion option. The appeal of this option was based on cost, environmental protection, minimization of public objection, and the maintenance of the entire disposal process within the utility.

In order to assure that this approach was environmentally sound and can stand up to public scrutiny, a series of pilot and laboratory bench-scale tests were undertaken. These tests were designed to evaluate the acceptability and determine applicable loading rates for the land application of alum sludge residuals to forest land within the Harwood's Mill Reservoir watershed of the Newport News Waterworks. Two areas of concern were important to the land application process, namely the impact on groundwater, and the impact on plant growth. The study area considered in this document deals with the impact on groundwater; especially the leaching of metal ions such as aluminum and copper.

The leaching studies were conducted to determine if the application of residuals would contribute an unacceptable level of metals and/or nutrients to the groundwater. Metals could come directly from the applied residuals (for example, aluminum or copper) or as a result of release or exchange of metals already in the soil. In addition, at the end of the leaching studies, soil analysis was performed to analyze metal movement through the soil profile.

Objectives of the Study

The research evaluation criteria was to avoid violation of the Virginia Water Control Boards' (VWCB) Anti-degradation Policy for Groundwater. This policy stated that the natural quality of groundwater

shall be maintained for all constituents in groundwater, including those for which no numerical limits have been established (CH2M - Hill, 1990). The discharge of any element into the groundwater which would not be found under natural conditions was the evaluation criteria for the column experiment. The monitoring of concentrations would dictate the success or failure of the purposed land application of alum residuals. The objectives are summarized as follows:

- 1). Evaluate migration of specific constituents in the column leachate over time in response to residual loading rates, liming practices, and Powdered Activated Carbon (PAC) and fertilizer additions under laboratory conditions.
- 2). Evaluate migration and retention of specific constituents in the soils over time in response to residual loading rates, liming practices, and PAC and fertilizer additions under laboratory conditions.

II. LITERATURE REVIEW

The purpose of this research was to determine the effects on groundwater resulting from land application of alum residuals to soil. The effects of sewage sludge land application, or treatment, has been well studied; however, the land application of water treatment sludge has not been studied in detail. This literature review will focus on the problems expected with water treatment sludge land application, but will use as a barometer of expectations information gained from the land application of sewage sludge.

Water Treatment Plant Sludge Characteristics

The treatment of water for human consumption in most surface water treatment plants involves the use of a coagulant, such as ferric chloride or aluminum sulfate. Aluminum sulfate, commonly known as alum, reacts with hydroxyl ions to form complexes which form a gelatinous floc that settles slowly, carrying colloids with it as it settles (Tchnobanoglous and Schroeder, 1987 ; Montgomery Engineers 1985). The flocs created by alum, and the colloids removed from the water, are collected, along with backwash from filtering operations, for disposal. These are collectively called water treatment sludges (WTS) or residuals.

The characteristics of the residuals depends on the source water and filter backwash characteristics, the amount and type of coagulant,

the pH, and the sludge handling methods of the treatment plant (Knocke et al., 1987). Although no typical values exist, Table 1 presents water treatment sludge values from Elliott et al. (1989) in comparison with sewage sludges and values reported for soils.

Elliott et al. (1989) reported that water treatment sludge was more like a fine-textured soil than that of a sewage sludge. Water treatment sludge has lower concentrations of organic carbon and nitrogen, few pathogens, and aluminum concentrations similar to what is found in some soils. Alum sludge can contribute 50 to 100 percent higher aluminum than in agronomic soils, yet because of its buffering and reaction capacity, land application can decrease soluble concentrations of trace metals, ligands and phosphorus (Elliott et al. , 1989).

Land Application of Alum Sludge

The consideration of land application of alum sludge results from federal legislation - specifically the Clean Water Act (CWA), the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). These regulations, along with state and public sentiment, have forced water utilities to consider land application of sludges to negate the negative effects of direct discharge to waterways or disposal by other means (DeWolfe, 1989; Sludge Committee Report, 1987).

The practice of land application of municipal sewage sludge has long been an acceptable practice, especially on agricultural lands where the sludge can benefit plant growth by providing plant nutrients (i.e.

Table 1

"Typical" Element Values For Water Treatment Sludge, Soils,
and Sewage Sludge - mg/L unless noted.
(Elliott et al., 1989.)

<u>Element</u>	<u>Water Treatment Sludge</u>	<u>Soils</u>	<u>Sewage Sludge</u>
% Solids	2	7.5	10
Loss on Ignition-%	33	5	70
TOC-%	3	3	40
TKN	0.5	0.5	4
C/N Ratio	7	10	10
Total P - %	0.01	0.1	0.1
Aluminum - %	2 - 20	4	0.5
Iron - %	1 - 15	7	1.5
pH	6 - 7	6 - 9	6.9 - 7.5
CaCO ₃ Equiv.-%	10 - 25	-	6.5 - 7.5
Coliforms #/100 ml.	<20	1000	10 ⁶
Cadmium	<2	0.4	15
Copper	200	12	800
Nickel	100	25	80
Lead	220	15	500
Zinc	550	40	1700

nitrogen, phosphorus and potassium) (Loehr et al., 1979). Water treatment sludge land application has seen limited practice, but the techniques used have followed the procedures established for land application of sewage sludges. Land application, or treatment - as it is sometimes referred to - involves the controlled spreading of sludge onto, on the soil surface with or without subsequent incorporation or injection of sludge into the surface layer of soil, to degrade and immobilize sludge constituents (Elliott et al., 1989).

Alum Residuals Effects on Soil Properties

Because of the reactive nature of alum in the water treatment process, aluminum hydroxides are formed. These hydroxides can have profound effects on physical soil properties.

Rengasamy et al. (1980) reported that land application of alum residuals added to the soils moisture holding capacity and increased aggregation. Because of the increase in moisture holding capacity, Bugbee and Frink (1985) reported that alum improved the physical properties of the soil they tested, and acted as a liming material in their plant growth study. In their field research, forest floor soil pH was increased .5 to 1 units in the top 10 cm of soil when liquid alum residuals were applied at a 1.5 percent solids concentration.

Dempsey et al. (1989), Bugbee and Frink (1985), and Grabarek and Krug (1987) reported that alum sludge binds phosphorus, making it unavailable, or slowly available, to plants and unable to readily leach from the soil. This binding makes phosphorus a limiting nutrient for

plant growth, and a major concern when considering land application of alum residuals.

Alum Residuals Effects on Groundwater

Little has been reported on the effects of alum residual effects on groundwater. This may be due to the relatively few studies on alum residuals. For example, Grabarek and Krug (1987) showed no problems with respect to organic or metal leachate production or aluminum toxicity to plants. Further inspection of aluminum mobility through the soil profile and sewage sludge leachate research will provide information that can be used to evaluate the impact of alum residuals on leachate characteristics.

In order to understand transport of elements through the soil profile one must understand that soil profiles are generally divided into distinct levels called horizons. The top horizon is called the O horizon and is characterized by organic debris and decaying plant residues.

The A horizon lies below the O horizon and is the area of greatest interest. It is the zone of aerobic biological activity as well as the region where humus accumulates, nitrification and adsorption of elements occur, and the region from which salts and clays leach. The A horizon varies in depth, but ranges between 2 to 50 cm and provides anchoring for plant roots.

The B horizon underlies the A horizon and is the zone of deposition and accumulation of the leached salts and clays. It has a lower

permeability than the horizons above, may be locally anaerobic, and the site for denitrification. The C horizon extends from the B horizon to the top of the parent bedrock and is made up of weathered parent rock with low organic matter. The C horizon is traditionally thought of as the region where groundwater flows (Novotny and Chesters, 1981).

Research has been performed on leachate quality resulting from application of sewage sludge to soils. Effects on the soil, as measured by plant and chemical composition, has also been performed with sewage sludge (Hue et al., 1988). Most recently, alum residuals influence on plant growth has been researched, as well (Lucas, 1991; Heil and Barbarick, 1989; Bugbee and Frink, 1985). Studies on groundwater effects with alum sludge, especially when considered with acid rain, are non-existent.

Because alum residuals have such a high aluminum concentration, aluminum toxicity and transport are major concerns with land application. Aluminum has an average concentration of 70,000 mg/kg in the lithosphere, with soil contents that range from 10,000 to 200,000 mg/kg (Bohn et al., 1985). Because of the tremendous amounts of aluminum within the soil profile, leaching of aluminum by acid rain can be a significant problem even without alum sludge as a soil amendment.

The chemical behavior of acids and bases within soil solutions is linked intrinsically with the solution chemistry of aluminum. The aluminum ion is trivalent and hydrolyzes to monomeric and polymeric hydroxyaluminum complexes, thereby liberating hydrogen ions. Review of equilibrium solubility curves show that aluminum is amphoteric; that is,

it has high solubility in acidic and basic solutions, and low solubility at near neutral pH's (Bohn et al., 1985; Benefield et al., 1982).

Aluminum hydroxide consumes hydrogen ions when dissolving in acid solutions acting like a base, and consumes hydroxide ions in basic solutions.

Tam and Williams (1986) described the association of metals for anions to occur in the order of $M^{3+} \geq M^{2+} \geq M^{+}$ (where M is a metal ion). They point out that as pH is lowered from 7 to 4, M^{3+} ions may be released from where they are originally bound, namely hydroxy complexes and phenolates. The M^{2+} ions are released from carboxylates at a much slower rate resulting in a net influx of M^{3+} ions. These M^{3+} ions can then bind acid anions resulting in increased competition from M^{3+} ions against M^{2+} ions (i.e. Mg^{2+} and Ca^{2+}) for binding sites on ligands (Tam and Williams, 1986). The researchers also point out that reactions cannot be reversed easily by just returning the pH to 7 after it has been below 4. This occurs because of different dissolving rates of solids and reprecipitation rates of aluminum.

Turner et al., (1985) theorized that aluminum mobility through the B and C horizons was dependent upon the flux of soil moisture and the concentration of inorganic acids. Aluminum movement occurred to the depth at which hydrogen ions were exhausted by exchange site sorption and dissolution of gibbsite, below which aluminum concentration in solution decreased because of aluminum sorption on exchange sites.

Cronan and Schofield (1979) found that with the presence of organic ligands, the solubility of aluminum could be greatly enhanced by

the formation of soluble organic aluminum complexes, thus helping transport aluminum to and through the B horizon. The researchers found that fir tree zone soils had lower pH with depth than expected because of the effects of H_2SO_4 dominating the soil solution. This allowed aluminum to remain in solution through the soil profile.

David and Driscoll (1984) reported that aluminum speciation in leachates from the O through the B horizons in a spodosol soil were dominated by organic matter and fluoride complexes within the soil profile. There were decreasing levels of free aluminum found in each successive horizon once organic, fluoride, hydroxide and sulfate compounds were accounted for.

Cozzarelli et al. (1987) studied the extent to which fast flow (macropore) versus slow flow (micropore) hydrological pathways affect the mobilization and speciation of aluminum. The researchers reported that macropore flow limited soil water contact, which resulted in acidic soil waters with low total dissolved solid concentrations and high aluminum and organic contents. However, there were low concentrations of aluminum in the deeper soil zones due to the immobilization of organic acids below the B horizon and the loss of inorganic monomeric aluminum from solution as various precipitates formed. Therefore, micropore flow was not as important in transporting aluminum through the soil profile as macropore flow, but exerted the same solubility on aluminum speciation when pH of the soil solution was considered.

In summary, the dominating factors of aluminum mobilization through a groundwater system are soil solution pH and moisture, and the

availability of aluminum accepting anions (Turner et al., 1985; Cronan and Schofield, 1979). At pH values below 5.0, aluminum would readily solubilize and would create a net influx of Al^{3+} and $\text{Al}(\text{OH})^{2+}$ in the water solution (Turner et al., 1985). Once in solution, the aluminum ions strongly associate with hydroxides, sulfates, fluorides, and inorganic acids and transport with these through the soil profile, especially when macropore flow dominates (David and Driscoll, 1984; Cozzarelli et al., 1987). Aluminum output in deep seepage is highly dependant on the lower soil horizon geochemistry and soil moisture.

If the soil water pH is low enough, aluminum will strongly bind to anions and will transport as a conservative material through the groundwater system until the soil solution changes. Therefore, if the O and A horizons have high organic matter, aluminum would tend to bind to ligands within these horizons and would transport primarily by macropore flow or remain in the upper horizons (Cronan and Schofield, 1979; Cozzarelli et al., 1987). If little organics are present, aluminum would follow the rain water seepage into the ground and follow its resulting solubility and hydroxylation in accordance with the surrounding soil pH.

Sewage Sludge Land Application Studies

As stated earlier, the content of elements within water treatment sludge is a function of the raw water source and the water treatment chemicals. Heavy metals, especially cadmium (Cd), copper (Cu), chromium (Cr), nickel (Ni), lead (Pb) and zinc (Zn) are toxic and commonly

monitored when land application is considered. Elliott and Dempsey (1989) point out that studies of metals in soil-food chain systems from land application of sewage sludges are numerous, but are lacking for water treatment sludge. The evaluation of "total" metals in water treatment sludge may be helpful to some degree, but may fail to show the fraction of plant available or readily mobile metal forms.

In sewage sludge experiments measuring element mobility from heavily dosed land treatments, Campbell and Beckett (1988) found nitrate (NO_3^-), sulfate (SO_4^{2-}), magnesium (Mg), calcium (Ca), strontium (Sr), boron (B) and possibly barium (Ba) were still moving through a ferruginous fine loamy soil (Sutton series) seven years after application. Nitrate and sulfate were the major anions in the soil solution leaching through the soil and reaching the groundwater table. Copper and zinc concentrations were higher than in untreated plots, but decreased sharply below the topsoil, signifying little or no mobility. Manganese (Mn) was not affected at depths below the topsoil; however, iron (Fe) and aluminum showed an increase in the soil solution in the top soil profiles to 20 centimeters. There appeared to be little mobility of aluminum and iron through the loamy soil and thus a small probability of reaching the groundwater.

Robertson et al. (1982), also working with heavy applications of sewage sludge (up to 335 metric tons/ha), reported little movement of copper and limited movement of zinc, iron and aluminum through 90 cm of a Ultisols soil. Calcium, magnesium, and some potassium (K) did move below the 90 cm depth.

Emmerich et al. (1982) studying leachate through sewage sludge amended soil columns, reported that soils (Holland sandy loam, Ramona sandy loam, and Helendale loamy sand) were able to retain cadmium, copper, nickel and zinc in the sludge-soil layers. The researchers did note a situation conducive to metal movement, however. They theorized that a pH reduction in the sludge soil layer would increase metal solubilization leading to metals leaching from the columns.

Similar findings have been reported by Sidle and Kardos (1977) for cadmium and zinc. The sewage sludge application research was on a forest floor and showed a relative mobility in the soil of $Cd > Zn > Cu$. These results were only for the highest dosage of sludge (26.96 metric tons/ha) and only represented 6.6, 3.2, and 0.3 percent of the total addition of cadmium, zinc and copper, respectively. Elliott et al. (1990) concurred with this assessment, stating that although cadmium had the lowest concentrations in their water treatment sludge study, it displayed the most potential for soil profile mobility.

Dudka and Chlopecka (1990) reported an increase in exchangeable zinc and nickel with a massive (210 Mg/ha) sewage sludge application; however, only negligible changes were observed for cadmium and chromium. Zinc and nickel was taken up in plants and was present in soil leachate. These data agreed with the distribution pattern found in the pseudo-podzolic soil profile.

In effect, element mobility through the soil profile or with leachate appears to be minimal with sewage sludge land application experiments. Riekerk and Zasoski (1979) summarized in their research by

stating "Heavy metals and phosphorus introduced with sludge applications showed very little mobility... Only the extremely high ... sludge application rate resulted in limited movement of [phosphorus and zinc] into the subsoil". Although there are conflicting results from various studies presented, the overall results showed limited mobility of metals, while anions, like nitrate and sulfate continued to reach the groundwater.

Acid Rain Effects on Soil Leachate

Acid rain (rainwater below a pH of 5.0) can affect leachate movement through a soil-water continuum. Depending upon the buffering capacities and geochemistry of the soil, moisture flux, and the elemental composition of the rainwater, several unique and complex scenarios can occur during the transport of elements through the soil water continuum.

In a relevant study, Huete and McColl (1984) reported that acid deposition accelerated the transport of nutrient cations from terrestrial to aquatic systems and increased soil mineral weathering, aluminum solubilization and soil acidification. They observed that anion adsorption capacity of a soil varied with the pH, the associated anions, and will differ among horizons. On the whole, larger sulfate concentrations were adsorbed by the soil than nitrate concentrations, although not uniformly, as the soil pH decreased.

Acid rain leachate studies conducted by Fernandez and Kosian (1986) showed that a deposition rate twice that of ambient (as done in

this study), acidified resulting leachates approximately 0.5 pH units over a 26 week period. In addition, releases of cations, iron, and aluminum were noted.

Summary

This literature review has touched on the few studies done on land application of alum residuals, as well as relevant studies on sewage sludge land application and acid rain effects. The alum residual studies have provided background information on alum residuals properties.

The review of sewage sludge land application was used as a benchmark of what one can expect with regard to alum residuals land application. This review suggests little movement of metals into groundwater systems, with the exception of cadmium, calcium, and magnesium, when considering anything besides heavy dose loadings (greater than 150 tons/ha). Cadmium mobility has been addressed several times in the literature as the metal most likely to be mobile, but the reported concentrations moving through the soil water continuum have been very low. An important aspect of any elements mobility within the soil is the acid rain interactions and the buffering capacity of the soil after alum residuals application.

III. METHODS AND MATERIALS

The purpose of this research was to investigate the potential for groundwater contamination due to land application of alum residuals at the Harwood Mills Reservoir site in Newport News, Virginia. Applying simulated acid rain to soil columns from the area with varying amounts of alum residuals, plant nutrients, and lime was the method of simulating residuals leaching. The collection and analysis of the resulting leachate and soil cores were the measures of weathering conditions.

Column Construction

On November 9, 1989, soil columns were collected at the Newport News watershed property, which has been proposed as a site for the land application of waste alum residuals. The soil columns were collected at the site as undisturbed soil cores predominantly from the B horizon. Prior to collection of the soil columns, the top eight inches of soil (the O and A horizons) were removed to form a shallow trench with side dimensions approximately 2 feet by 125 feet. Six inch diameter four foot sections of PVC pipe were pushed into the soil at the base of the trench to collect approximately a 2.5 foot depth core of soil. The sections of PVC were pushed into the soil by a backhoe into the soil in the manner of a thin-walled sample tube. The PVC sections were supported with a framed structure to keep the pipe vertical and minimize

disturbance of the soil core. The soil columns were then dug out of the ground, sealed, and transported back to Virginia Tech. The upper eight inches of soil excavated from the trench was wrapped in plastic bags, put into airtight coolers, and transported with the columns.

After the columns were transported back to Virginia Tech, the construction of each column was completed. The columns were finished for collection of leachate by placing a porous ceramic cup, packed by a mixture of silica flour and fine sand to ensure a good hydraulic connection from the soil to the ceramic cup (see Figure 1).

On December 5, 1989 construction of the columns was completed and a simple infiltration test was performed on each column. Distilled water was added to the tops of the columns and vertical infiltration rates were measured over several weeks to check variations in flow rates, possible short circuiting in columns, and bring the soils to field capacity. Two columns exhibited short circuiting and were eliminated; however, the remaining 24 columns were deemed acceptable.

During January 1990 a vacuum system was constructed and connected to the columns to facilitate leachate collection. The system consisted of a series of tubes from the leachate collection bottles to a vacuum pump on a timer switch. This system could draw 20 to 25 p.s.i. pressure for 20 minutes every four hours. Because of the number of bottles and space limitations, only one bottle of the two for each column were connected to this system. The remaining bottles were depressurized by a hand vacuum pump to approximately 25 p.s.i. and then clamped off to maintain that pressure in the collection bottle. These bottles were

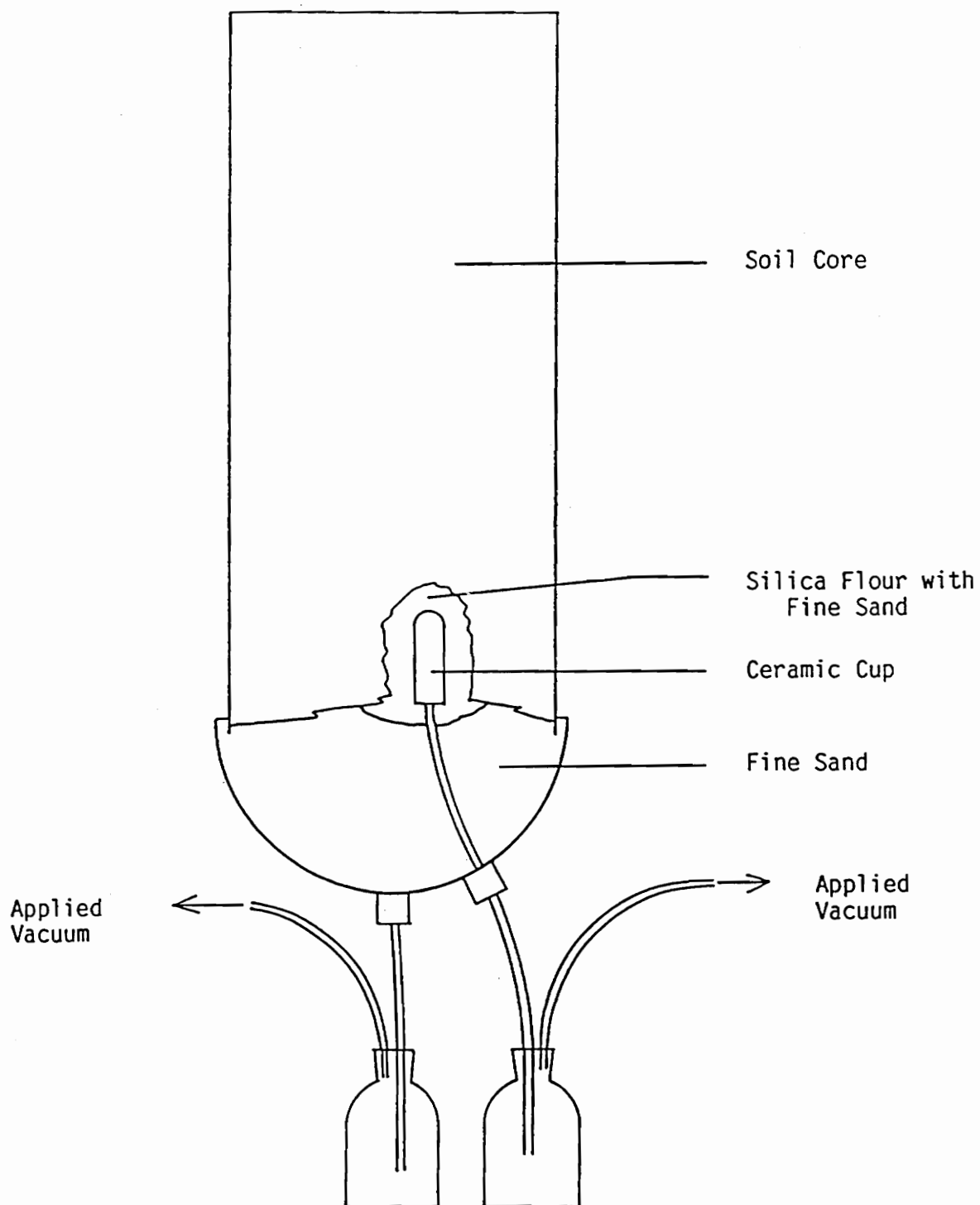


Figure 1 - Column construction diagram

maintained daily during the research period. The purpose of the vacuum system was to accelerate moisture flux through the column.

The alum residuals to be used for the study were gravity drained and air dried to approximately seven percent solids. The distilled water leachate was collected and prepared for analysis. Also during January, decisions on the columns loadings were finalized. Column tests were decided to be done in duplicate.

The loading of columns started early in February 1990. The moisture contents were determined for both the sludge and the topsoil (92.5 and 22.4 percent, respectively). This was accomplished by oven drying several samples at 105° centigrade (C) for 24 hours and comparing pre-oven weights with post-oven dried weights (Standard Methods, 1989). A 3.1 kg mass of topsoil [oven dry weight (ODW)] was added along with varying quantities of sludge and other constituents (see Table 2), mixed by hand for two minutes, and added to the top of the column. The topsoil mixture was tamped four times with a 2.7 kg weight to compact the soil slightly. Loadings of residuals were zero, one, three and four percent by dry weight to the 3.1 kg (ODW) of topsoil. Of those loadings, one set of columns had no additional constituents added to serve as controls, one set received only nutrients, and one set had only lime and nutrients added. Lime and nutrient additions are shown in Table 3.

Lime was added to raise the topsoil pH to 6.5, as determined by the Adams and Evans procedure for lime requirements (Methods of Soil Analysis - Part 2, 1982). The lime added varied with the residual loading and is reported in Table 3. The nutrient additions were

Table 2
Residuals Loading Plan

Residuals Loading Rates	0%	1%	3%	4%
With lime, and nutrients	X	X	X	
Without lime, with nutrients	X	X	X	X
Control, no additives	X		X	
Total Number of columns	6	4	6	2

X = Duplicate columns

Table 3

Nutrient and Lime Additions

Nutrient Requirements (ODW)

- 200 mg/kg Nitrogen
- 71 mg/kg Calcium
- 120 mg/kg Potassium
- 93 mg/kg Sulfur
- 50 mg/kg Phosphorus
- 71 mg/kg Magnesium

Supplied By

- 204 mg/kg $\text{Ca}(\text{H}_2\text{PO}_4)_2 \bullet \text{H}_2\text{O}$
- 355 mg/kg MgSO_4
- 312 mg/kg KNO_3
- 331 mg/kg $\text{Ca}(\text{NO}_3)_2 \bullet 1.25 \text{H}_2\text{O}$
- 306 mg/kg NH_4NO_3

Dolomitic Lime Requirements (ODW)

- 2100 mg/kg (0% residuals loading)
- 2010 mg/kg (1% residuals loading)
- 1500 mg/kg (3% residuals loading)
- no lime was added to 4% residuals loading.

determined by soil analysis for specific elements (P, K, Ca, Mg, and N) and doubling those fertilizer requirements as explained by Donohue and Hawkins (1979).

A simulated rain solution was prepared and water application began on February 27. The rainwater was designed to contain ion concentrations typically found in rainwater for the area [as reported by the Virginia Acid Precipitation Network (VAPN) Rain Water Analyses; Third Quarter 1989; by the Dept. of Biology and the Pollution Laboratory, Dept. of Plant Pathology and Physiology; Virginia Polytechnic Institute and State University, Blacksburg, Virginia]. To meet these ion requirements, the rainwater solution was prepared with additional potassium and sodium to balance the cation/anion ratio. The cation/ anion equivalents are shown in Table 4. The pH of 4.7 was met by mechanical stirring, which imparted atmospheric carbon dioxide into the mixture until the desired pH was achieved. Leachate water was collected continuously at the bottom of the column and was removed for analysis one week after application of the artificial rainwater. Immediately after the collection of leachate samples, the next artificial rain application was applied by sprinkling the rainwater onto the top of the column with a hand-held plant sprinkler.

The artificial rainwater was applied at an approximate rate of 267 mL per week (every Tuesday morning) for 28 weeks. This translated to a six month total of 28 inches, about double the six month average rainfall for the Newport News watershed area. This application rate was used to accelerate data collection.

Table 4

Artificial Rainfall Characteristics

<u>Cations</u>	<u>Concentration</u>	
	<u>mg/L</u>	<u>meq/L</u>
NH ₄ ⁺⁺	.14	.008
Ca ⁺⁺	1.56	.049
Mg ⁺⁺	.78	.020
Na ⁺	.28	.007
K ⁺	.15	.006
 <u>Anions</u>		
Cl ⁻	1.60	.045
NO ₃ ⁻	.81	.013
SO ₄ ²⁻	3.07	.032
 pH = 4.7		

Because of a staggered column loading, column start up was completed on April 2 and simulated rainfall was applied to all columns until September 25, 1990. In addition, two columns containing two percent sludge, 2.2 percent Powdered Activated Carbon (PAC), nutrients and lime were put into operation on April 2. An inner sleeve tube was placed within all tubes on April 11. The sleeve fit inside the main column and was pushed into the residual/soil mixture approximately two inches to ensure ample contact between soil and simulated rainwater and to prevent short circuiting of the rainwater down the sides of the columns.

Leachate Analysis

Samples were collected each Tuesday morning and were analyzed for pH within the first hour of collection following the procedures described in Standard Methods (1989), Part 1060. Approximately 30 mL of the collected sample were filtered through a 0.45 micron syringe filter and put into acid-washed sample containers. The samples were then acidified five percent by volume with concentrated nitric acid following Standard Methods (1989) Parts 3010 and 3110. This was in preparation for analysis on the atomic absorption spectrophotometer for aluminum, calcium, copper, iron, magnesium, manganese, and zinc.

The samples were tested on a Perkin - Elmer Atomic Absorption Spectrophotometer - Model 703, except when testing for aluminum. Aluminum was measured using a Perkin - Elmer Zeeman 5100PC Atomic Absorption Spectrophotometer.

The detection limits for the spectrophotometers were as follows:

Aluminum	1 ug/L
Calcium	0.092 mg/L
Copper	0.032 mg/L
Iron	0.039 mg/L
Magnesium	0.052 mg/L
Manganese	0.052 mg/L
Zinc	0.018 mg/L

Leachate alkalinity was measured using the titration method from Standard Methods (1989) Part 2320. Solution pH was measured using a Fisher Accumet pH Meter Model 610A.

Anion concentrations were measured from unacidified samples using the Dionex Ion Chromatography Model 2010i, following Standard Methods (1989) procedures listed in Part 4110. Detection limits of anions was approximately 0.01 mg/L, but accuracy fell off sharply below one mg/L. Therefore, anion concentration values below one mg/L are reported to show detection, but are not accurate. These data are reported in Appendix B.

To measure if increasing percentages of residuals increased metals in the leachate, analysis by linear regression was performed on the leachate data. Because of the high variability of data from the columns, average weekly leachate concentrations were used in performing regression analysis for each combination of nutrient and lime additions

(i.e. lime and nutrients, no lime with nutrients, and no lime or nutrients). Since each combination of loading and additions had duplicate columns, there were two data points for each residual loading. The mean concentration of metal for each column were the dependent variables, while the residual loadings were the independent variables. These data are reported in Appendix E.

Soil Analysis

The columns were retired after the 29th week and were split open with a rip saw. The depth of the cut resulted in minimal disturbance of the soil. The cores were sampled at the 0 to 4 inch, 8 to 12 inch, 16 to 20 inch, and 24 to 28 inch depths as measured from the top of the soil core. Each depth interval was mixed to ensure a homogeneous sample so testing gave an accurate picture of that depth range.

One gram of air dried soil sample was prepared for perchloric acid digestion in accordance with Methods of Soil Analysis - Part 2, 1982. This prepared the samples for Inductively Coupled Plasma - Optical Emission Spectrometry (ICP) analysis, which was accomplished by the Crop, Soil and Environmental Science Soil Testing Laboratory at Symth Hall on the Virginia Tech campus. These samples were reported as solution concentrations and were converted to soil concentrations - as they are reported in Appendix C.

The pH of the soil was measured using the prescribed procedure from Methods of Soil Analysis - Part 2, 1982. A Fisher Accumet pH Meter Model 610A was used for the pH measurements of the soil solution.

Analysis was performed on the soil data by determining means and standard deviation of means for all control columns (zero percent loadings). These ranges were then used as a comparison for measured values with control means and one standard deviation above and below mean. This range translates to a 68 percent statistical probability of confidence for control ranges.

IV. RESULTS AND DISCUSSION

The distilled water which was applied to the columns for several weeks prior to residual loading was used to determine the flow characteristics of the columns. At the end of this period, the leachate was analyzed to determine the initial metal and alkalinity values. Comparison of metals values using distilled water and synthetic rainfall suggest little difference between them. Distilled water leachate data are presented in Appendix A. In addition, residuals analysis are also presented in Appendix A.

Flow Rates

The columns were designed to draw approximately 300 mL of water through the ceramic cup drains, aided by a vacuum system which drew up to 25 p.s.i. pressure for 20 minutes every four hours. All columns initially exhibited good flow characteristics. With a weekly application of approximately 267 mL of artificial rain per column, the leachate collected per week in most columns was quantitatively measured at between 200 and 275 mL, with an average observation of 250 mL collected.

Some columns eventually exhibited pooling of rainwater on top of the columns after several weeks and generally had poor flow characteristics after they had initially pooled. These columns are noted in Appendix B by an asterisk by the column and week it first appeared to

pool. At first, pressure leaks in the vacuum system were suspected to have caused the pooling. Repair work was attempted to prevent pressure leaks in the vacuum system; however, this did not solve the pooling.

All pooled columns, when split open, contained a layer of extremely fine and tightly packed soil, indicating that this problem was a function of the soil characteristics. The soils in all columns were predominantly Peawick - a high silt and clay soil - and Slagle - a fine sandy loam over a sandy clay loam (CH2M - Hill, 1990).

Two of the columns which exhibited pooling had three percent loadings with lime and nutrients; one pooling on the fifth week and the other on the twelfth week of rain application. The other columns exhibiting pooling were one of the zero percent loading with nutrients and one of the two percent loading with PAC, lime and nutrients. Both columns pooled during the twelfth week of rain application.

Rengasamy et al. (1980) reported that alum sludge application increased soil moisture holding capacity and aggregation; however, this does not appear to be the case with the pooling columns. More residuals would mean there would be a lesser chance of pooling. When these columns were split open the soil structures were tightly packed and very little aggregation was noted.

Qualitative observations of flow rates were made on the columns throughout most of the 28 week period. Measured weekly flow rates were only kept after week 17, and are listed in Appendix B. The measured mean flow for leachate volumes were as low as 49.3 mL for a pooling column and as high as 232 mL. This is inconclusive because of the

variability within these measurements from week to week, and the early flow rates which qualitatively averaged near 250 mL for most columns. Further research needs to be done on flow rates with respect to column loadings and additions.

Metal Analysis

Metals analyzed in the leachate were aluminum, calcium, copper, iron, magnesium, manganese, and zinc (see Appendix B for weekly values). Chromium, cadmium and boron were analyzed in the soils along with those monitored in the leachate. The later three were added because of the high concentrations of these metals found in some of the field studies by CH2M-Hill. The soil profile data are presented in Appendix C.

Expected metal mass calculations within the following text were determined by multiplying the percent of residual loadings (1, 3, and 4 percent) with the mass of topsoil added (3.1 kg) this amount was then multiplied by the concentration of the element measured in the initial residual analysis (found in Appendix A). This amount was then divided by the total soil and residuals incorporated into the soil (3.13, 3.19, and 3.22 kg for the 1, 3, and 4 percent loadings, respectively). This result is what is referred to as the expected metal mass. Simply, it is an indication of elements added into the topsoil with the addition of the alum residuals.

Aluminum

The major observation for aluminum in the leachate samples was the

extreme variability in the leachate concentrations within any single column from week to week and between duplicate columns. Figures 2 and 3 show variability for the aluminum leachate concentration versus leachate pH for the control columns (Figure 2) and one percent loaded columns (Figure 3). Table 5 shows the variability of the data by presenting the median, arithmetic mean (normal distribution) and geometric mean (log normal distribution) of the leachate aluminum concentrations over the entire study period.

A comparison of leachate pH with aluminum in the leachate shows that high concentrations of aluminum were always associated with low pH values, regardless of residuals, lime and/or nutrient loadings. As seen in Figure 4, a plot of aluminum concentrations against leachate pH from all columns, showed a steady increase of aluminum concentrations at pH levels below 5.5.

There was concern that the high variability of leachate aluminum could signify mobility of aluminum through the column. The regression analysis has shown that there was not a linear fit for aluminum concentrations with respect to residual loading amounts. As shown in Table 6, the R squared values are near .25 (1.0 optimum). This means that 75 percent of the variability of aluminum can not be explained by the residual loadings.

In addition, a calculation of aluminum mass in the residuals applied to the top of the columns indicates that movement of aluminum did not occur. An expected mass of aluminum for one percent loadings show additional aluminum of 1525 mg/kg mixed into the topsoil. The

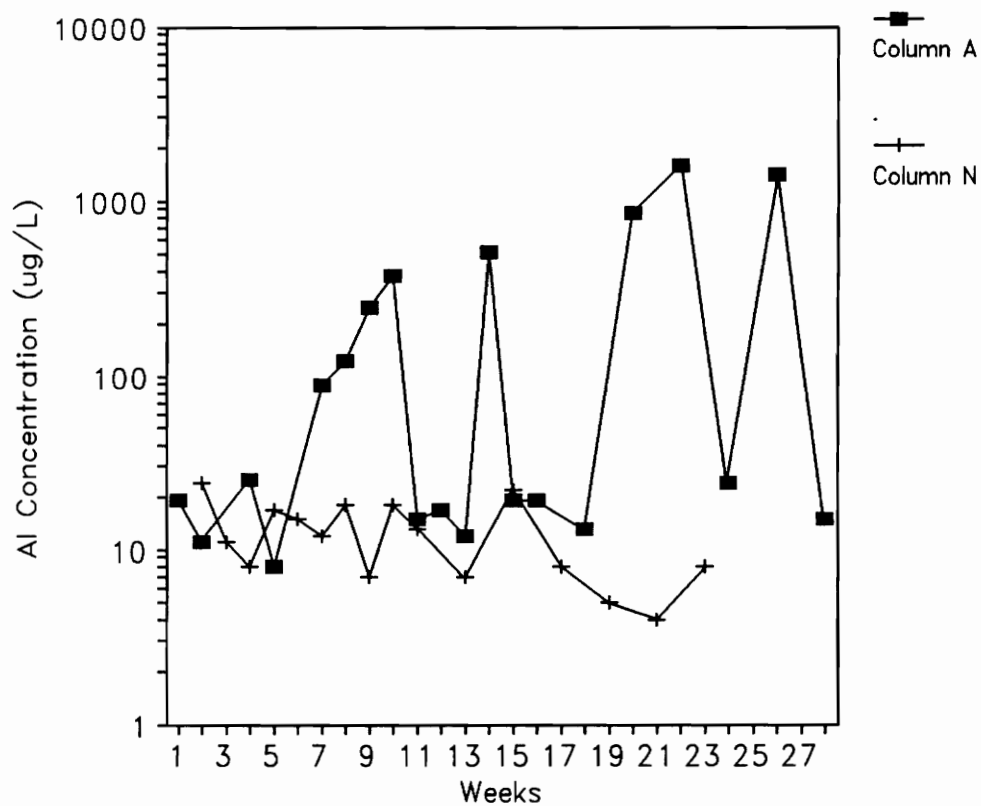


Figure 2 - Leachate aluminum concentrations over time - Control columns no additions.

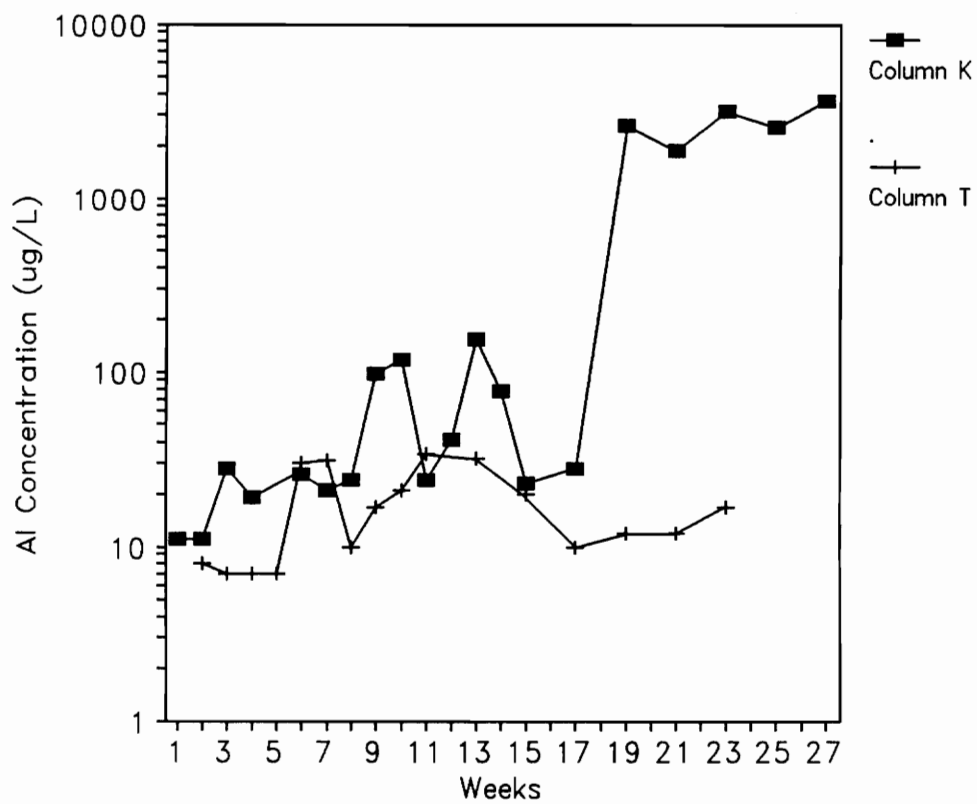


Figure 3 - Leachate aluminum concentrations over time - 1% residual loading with lime additions.

Table 5

Leachate Aluminum Concentrations - ug/LControl Columns:

	A	N	F	G
Median:	24	11	15	18
Arithmetic Mean:	270	12	20	21
Geometric Mean:	58	11	16	17
Range:	8-1590	4-22	7-44	7-56

Columns without lime and varying sludge loadings:

	C	0% P*	D	1% Q	B	3% O	ZZ	4% X
Median:	14	12	557	25	17	37	32	315
Arithmetic Mean:	20	18	472	370	54	476	215	836
Geometric Mean:	17	14	199	67	27	82	52	321
Range:	7-58	7-76	5-1070	9-1520	6-357	9-2860	6-1565	25-5020

Columns with Lime and varying sludge loadings:

	0% H	R	1% K	T	J*	3% U*
Median:	652	18	41	12	15	15
Arithmetic Mean:	922	20	729	17	32	38
Geometric Mean:	268	18	100	15	19	19
Range:	5-2980	9-48	11-3630	7-32	3-252	6-284

* - Denotes a pooling column

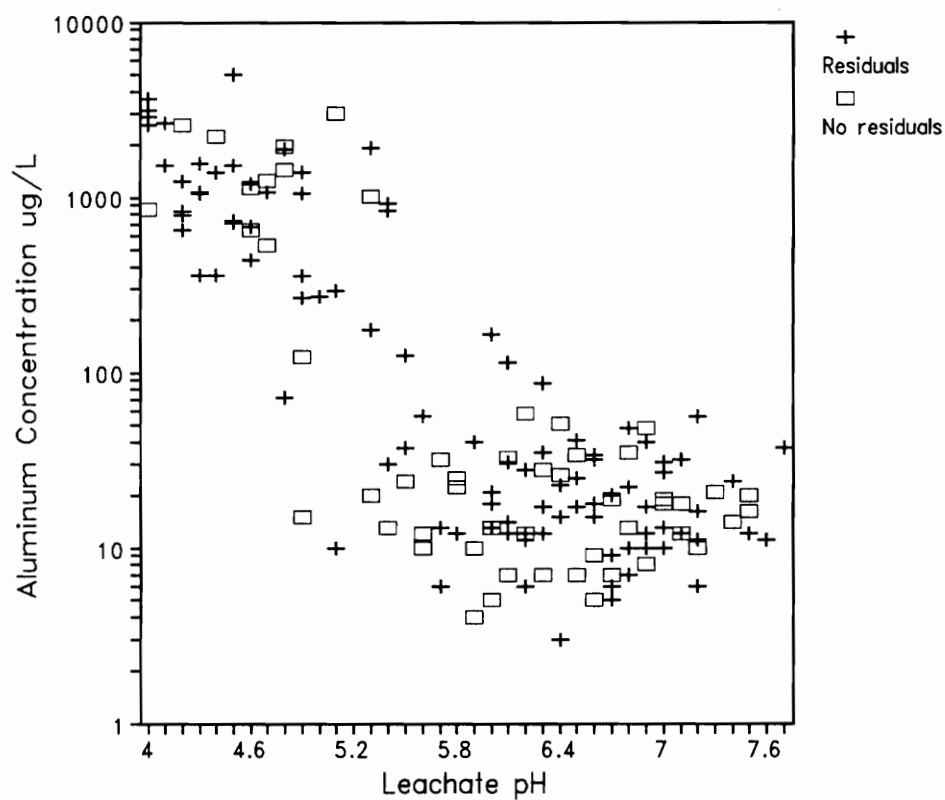


Figure 4 - Leachate aluminum concentrations versus leachate pH for all columns.

Table 6

Regression Analysis on Weekly Averages of Leachate Aluminum

	0%	Loading Rates		
		1%	3%	4%
Columns without lime	20	473	54	837
	18	370	476	215

Regression Output

Constant	1.10
Std. Err. of Y Est.	1.58
R Squared	0.25
No. of Observations	8.00
Degrees of Freedom	6.00

	0%	Loading Rates		
		1%	3%	4%
Columns with lime	922	729	32	
	20	17	37	

Regression Output

Constant	1.80
Std. Err. of Y Est.	1.33
R Squared	0.24
No. of Observations	6.00
Degrees of Freedom	4.00

three percent loadings would result in approximately 4500 mg/kg additional aluminum, while the four percent loading would add about 6000 mg/kg.

The mean and standard deviation of aluminum in the control column soils provides a range which can be used for comparison to the sludge loaded columns (see Appendix D). As shown in Figures 5 and 6, the mass balance loading range depicts the expected range (one standard deviation above and one below mean) of aluminum concentration within the soil after the addition of sludge. The soil in the top four inches appears to contain an aluminum concentration that suggests little or no mobility of the aluminum from the top soil. The lower soil profile shows some data that is substantially greater than the control range.

In Figure 5, the data for the three percent loading columns show a wide spread of soil aluminum concentrations in the lower profile, with respect to the control standard deviation range. On a mass balance basis, the aluminum added to the top soil could not have raised the concentration in the profile to that level. In addition, when looking at the values from Table 5, the leachate aluminum concentrations were similar for the columns depicted in the figure. This suggests no transport of aluminum through the column by leaching, but rather a wider range of concentrations of aluminum in the soils than that which was found in the controls.

The aluminum transport mechanisms described by Robertson et al. (1982), Campbell and Beckett (1988), and Turner et al. (1985) appear to

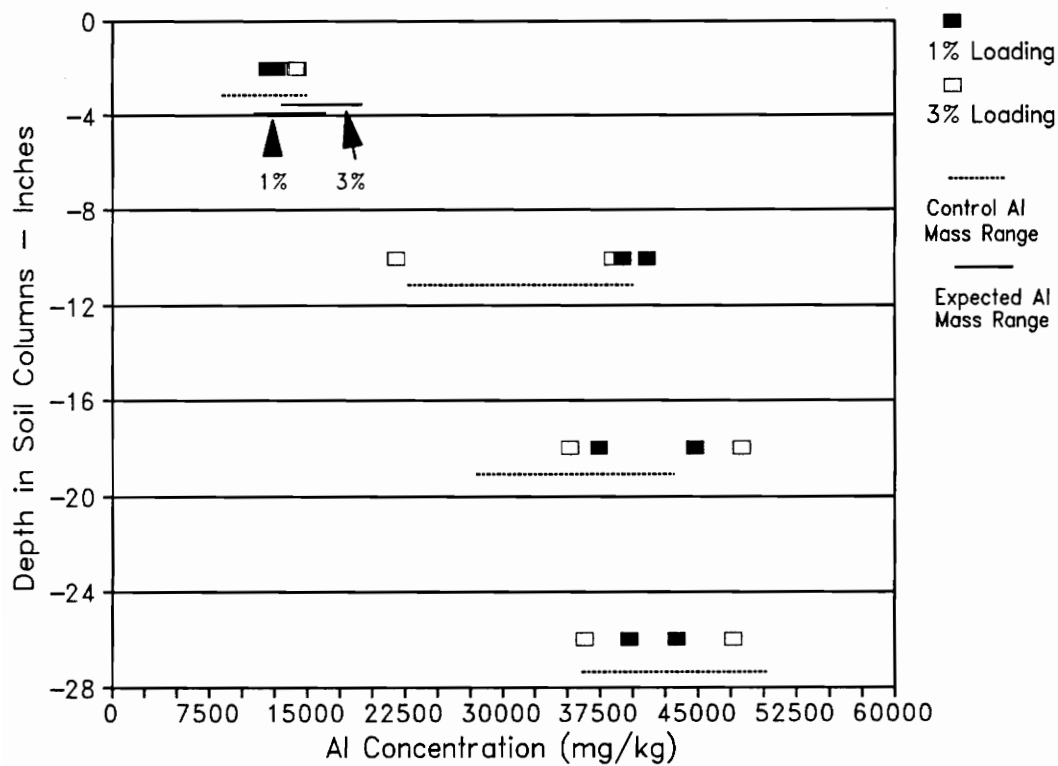


Figure 5 - Aluminum concentrations at various soil depths - Columns with lime. Shows expected aluminum mass range from residual additions (solid lines) and measured control aluminum mass range (dashed lines).

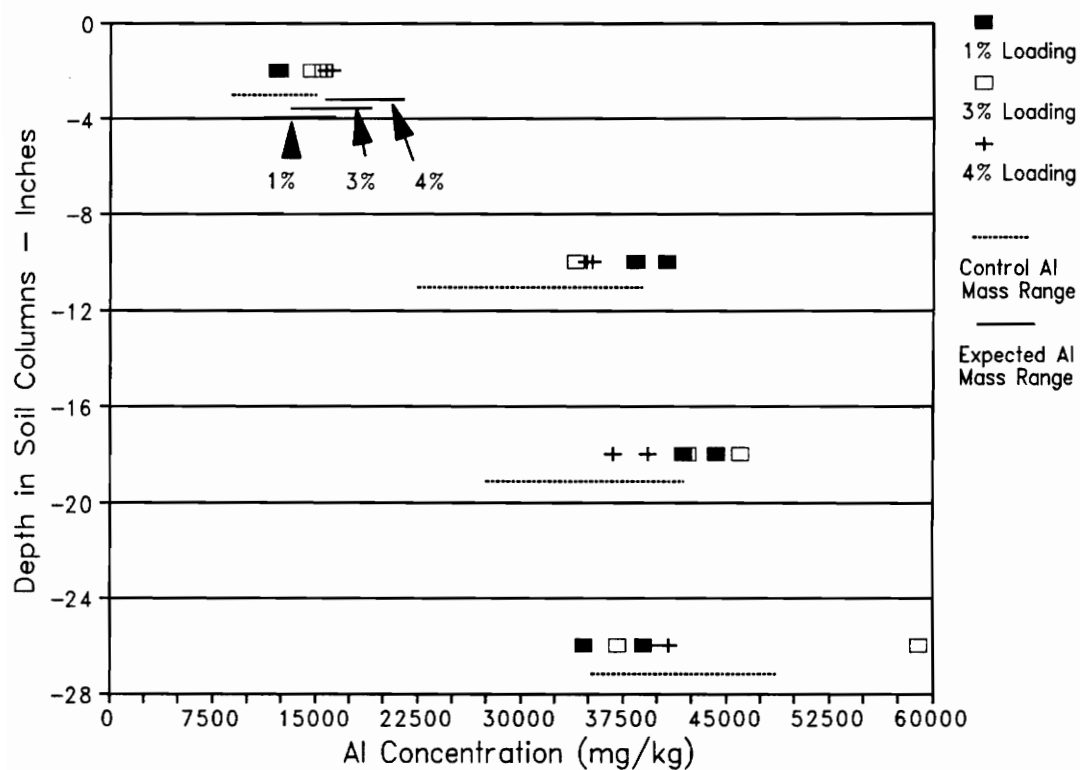


Figure 6 - Aluminum concentrations at various soil depths - Columns without lime. Shows expected aluminum mass range from residual additions (solid lines) and measured control aluminum mass range (dashed lines).

relate here. That is, there appears to be limited mobility of aluminum through the soil profile regardless of the alum residual loadings.

Iron

The leachate iron concentrations generally increased with decreasing pH in a manner similar to aluminum, as shown by Figure 7. It can be seen that, as with aluminum, iron concentrations generally increase at pH levels below 5.5, regardless of residual loadings, but not as defined as the aluminum trend. A pH below 5.5 does not guarantee a high concentration for aluminum or iron, however. Iron leachate concentrations were low and most times were just at or below detection levels (.03 mg/L).

The soil profile data (Appendix C) show that iron concentrations were low in the topsoil mixture to a point near the 16 to 20 inch depth, down through the columns. A calculation of expected iron in the residuals added to the column show an addition of 160, 460, and 615 mg/kg for the one, three, and four percent loadings, respectively. Comparing these figures to one standard deviation above and below mean, as seen in Figures 8 and 9, the range of iron concentrations for control columns and the mass balance loading range of iron (the amount of iron expected within the topsoil) appears, like aluminum, not to have migrated down the column. The variations below the topsoil layer, especially the 16 to 20 inch depth, show a wider variation than the control columns, much like aluminum displayed. The data agree with reports by Campbell and Beckett (1988), Robertson et al. (1982), and

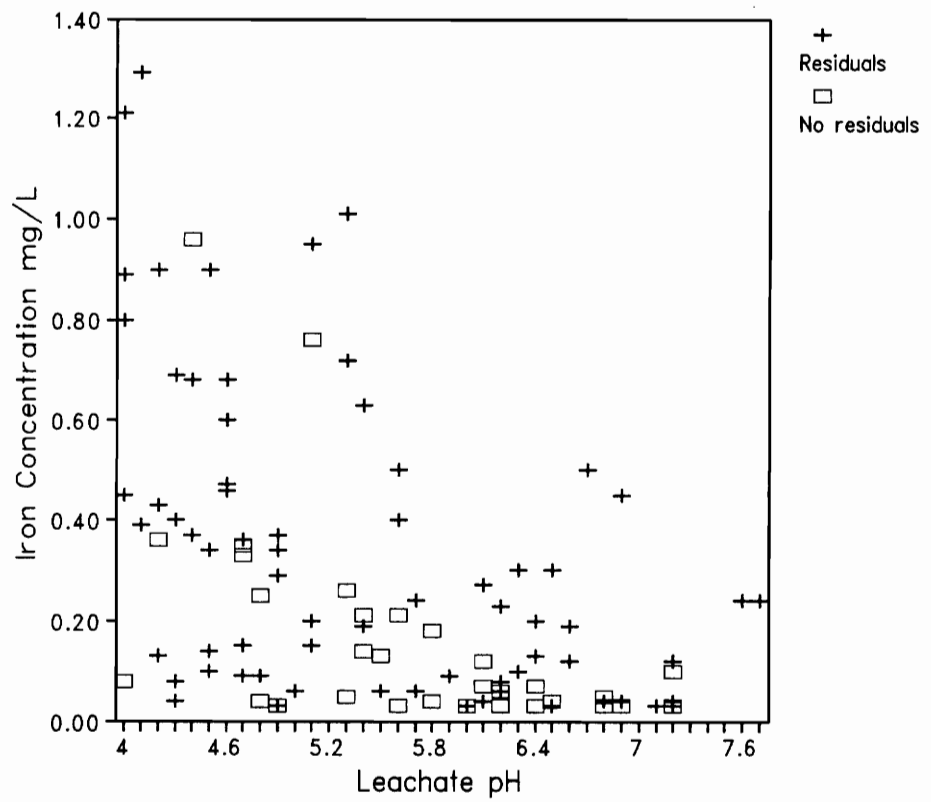


Figure 7 - Leachate iron concentrations versus leachate pH for all columns.

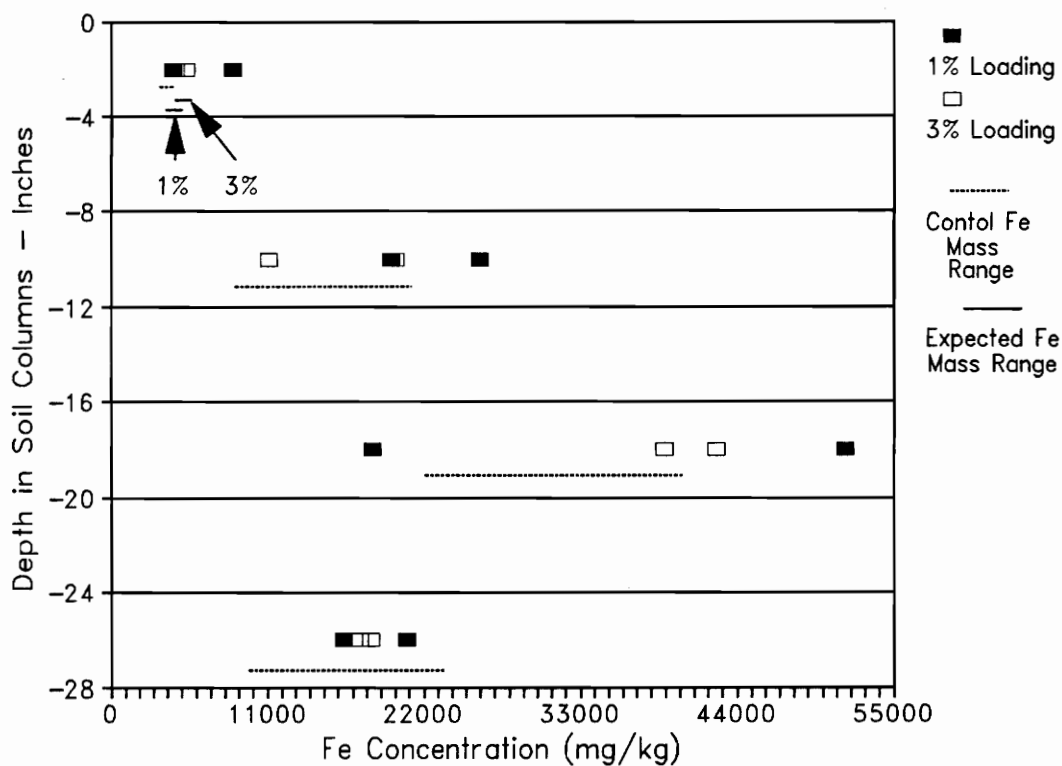


Figure 8 - Iron concentrations at various soil depths - Columns with lime. Shows expected iron mass range from residual additions (solid lines) and measured control aluminum mass range (dashed lines).

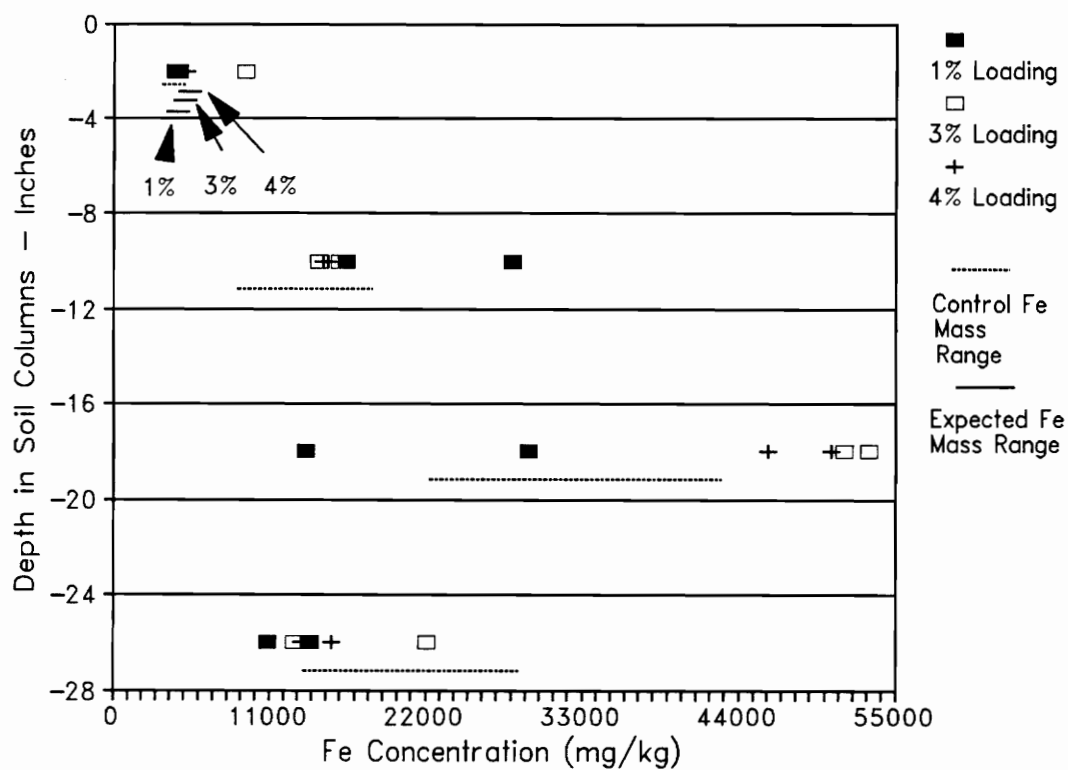


Figure 9 - Iron concentrations at various soil depths - Columns without lime. Shows expected iron mass range from residual additions (solid lines) and measured control aluminum mass range (dashed lines).

Turner et al. (1985), who concluded that iron has little, if any, mobility through the soil column.

Zinc

This element was unusual in that it appeared in the leachate at concentrations over one mg/L in some columns which exhibited a near neutral pH, while never getting above 0.3 mg/L in others with more acidic conditions.

Data in Table 7 shows the range, mean concentrations for the first and last 14 week period, and the overall mean for representative columns. With the exceptions of column H (zero percent loading with lime and nutrients), and column T (one percent loading with lime and nutrients), all other columns show a weekly mean concentration near 0.6 mg/L. For columns which exhibited mean weekly concentrations above 0.6 mg/L, the first 14 week period shows a higher mean concentration over time than the last 14 week period. The exception to this was Column H.

It appears that a washout of available zinc occurred in most columns within the first 14 weeks. This washout appears to be a function of the soil rather than the residuals, because the averages for discharge were remarkably similar for all columns regardless of loadings. The exceptions - Columns H and T - had zero and one percent loadings, respectively.

Figures 10 and 11 show zinc leachate concentrations over time. Figure 10 shows a wide variation between the loadings, but careful inspection shows that the control and zero percent loadings had the

Table 7

Leachate Zinc Concentrations - mg/L

<u>Column</u>	<u>Range</u>	<u>Mean Weeks 1-14</u>	<u>Mean Weeks 15-28</u>	<u>Mean Overall</u>
A - Control	.06 - 1.37	.57	.69	.63
N - Control	.12 - 1.73	.45	.18	.31
M - 3% no additions	.06 - 1.87	.95	.23	.64
Z - 3% no additions	.03 - .56	.19	.11	.15
C - 0% No lime	.21 - 1.16	.74	.46	.56
P - 0% No lime	.26 - 2.94	1.36	.59	.95
D - 1% No lime	.28 - 1.00	.56	.42	.50
Q - 1% No lime	.25 - 1.04	.39	.64	.54
X - 4% No lime	.24 - .82	.41	.57	.51
ZZ - 4% No lime	.29 - .85	.53	.62	.56
H - 0% Lime & Nutrient	.87 - 1.15	.87	1.15	1.00
R - 0% Lime & Nutrient	.03 - .52	.11	.05	.08
K - 1% Lime & Nutrient	.04 - .89	.19	.57	.38
T - 1% Lime & Nutrient	.40 - 4.10	1.61	1.47	1.55

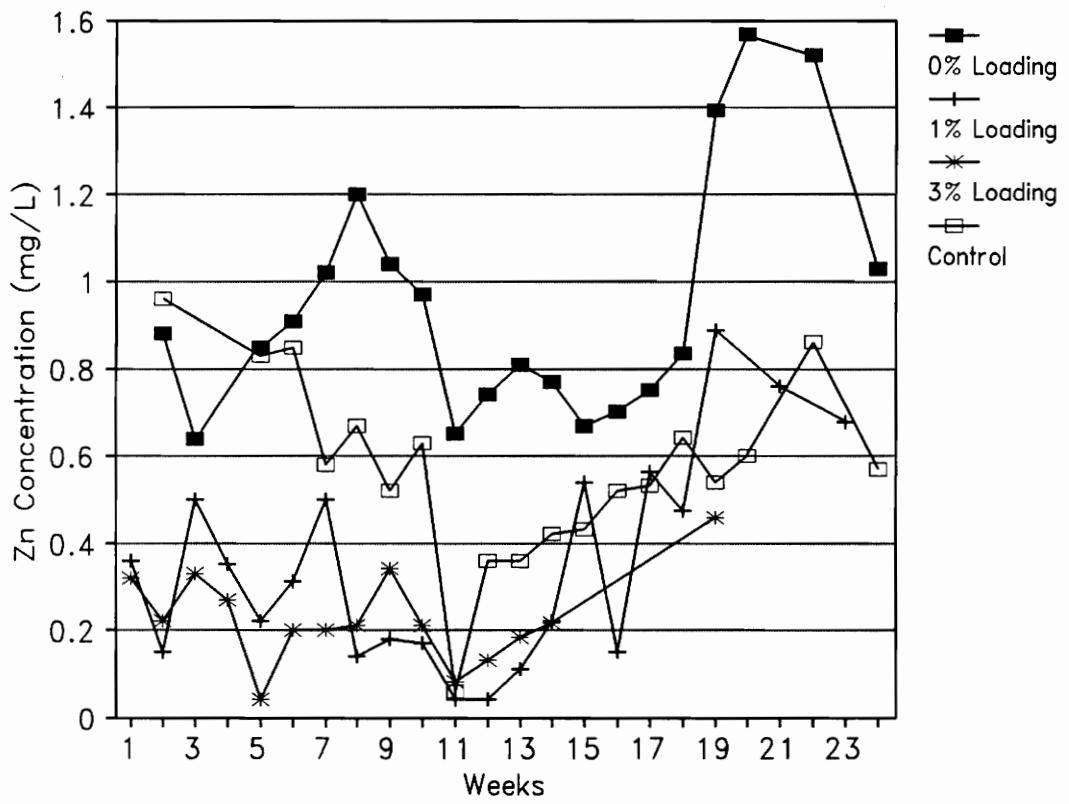


Figure 10 - Leachate zinc concentrations over time - Columns with lime additions.

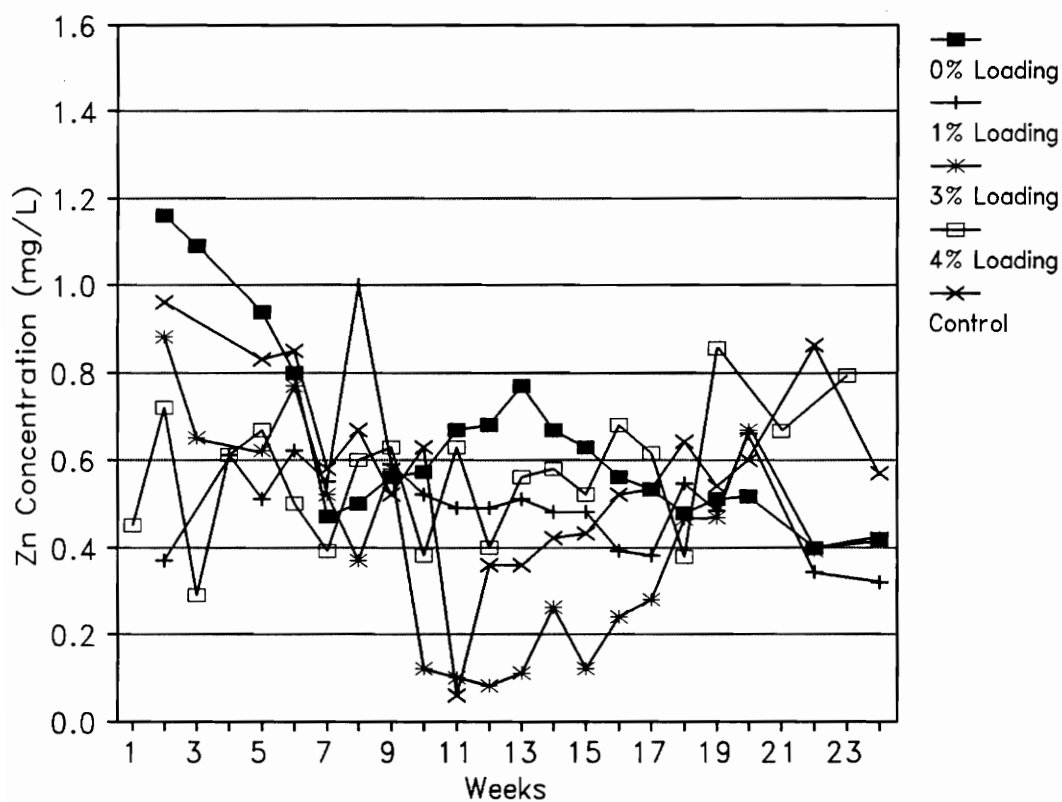


Figure 11 - Leachate zinc concentrations over time - Columns without lime additions.

highest leachate zinc concentrations over time. Figure 11 displays a definite band of concentrations within the 0.4 and 0.8 mg/L range for all loadings. In general, leachate zinc concentrations were low.

Although the concentrations were above the VWCB Groundwater Standard of 0.05 mg/L (CH2M - Hill, 1990), regression analysis shows that less than 15 percent of the iron was explained by the difference in residual loadings. See Appendix E.

Copper

Initially, copper was thought of as a metal which might be a limiting factor for land application of alum residuals at the Newport News site. Copper sulfate is used in the reservoir to control algal growth (CH2M - Hill, 1990). The leachate results showed copper levels which were well below the detection limits of the atomic absorption spectrometer (.032 mg/L) for every column regardless of loading; therefore no leachate copper data are reported.

The soil profile data show that added copper was retained within the top soil. Copper measured in the underlying soil was similar to those in the control columns. A mass balance of copper in the sludge shows that essentially all copper added to the top soil remained there at the end of the study period. The sludge additions would, according to mass balance calculations, add 8, 25, and 32 mg/kg of copper for the one, three and four percent loadings, respectively. Figures 12 and 13 bear this out by showing the concentrations of copper for all residuals loadings. As the residuals loading increased, the copper concentrations

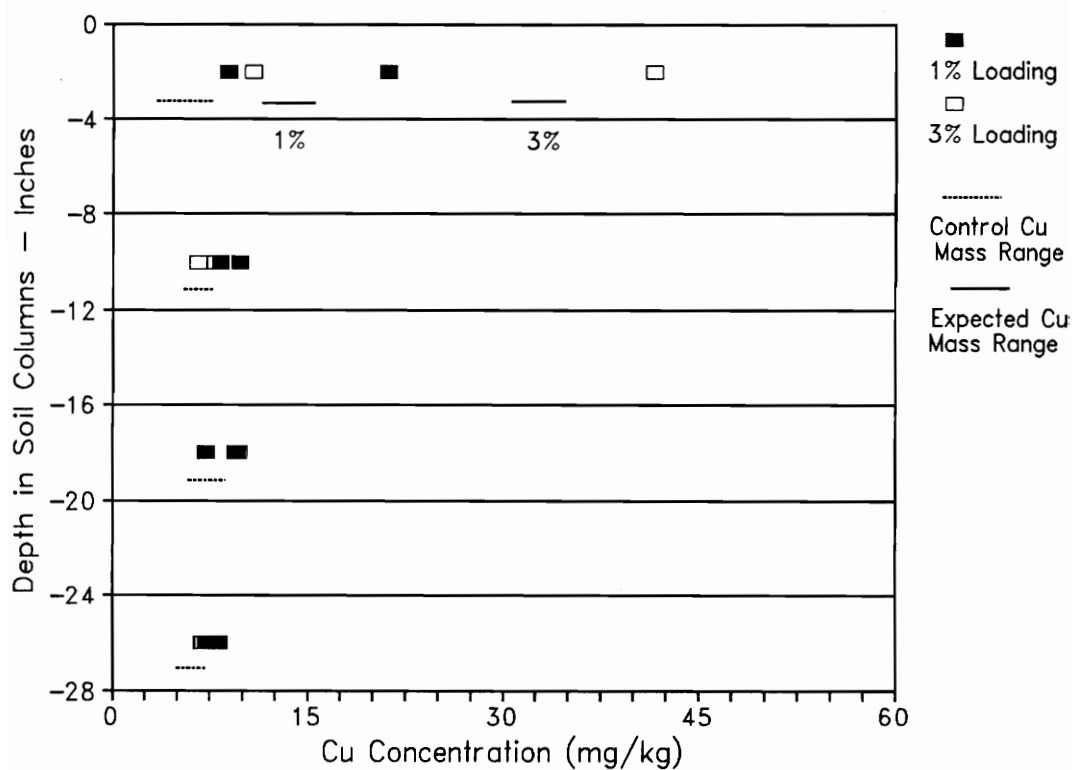


Figure 12 - Copper concentrations at various soil depths - Columns with lime additions. Shows expected copper mass range from residual additions (solid lines) and measured control copper mass range (dashed lines).

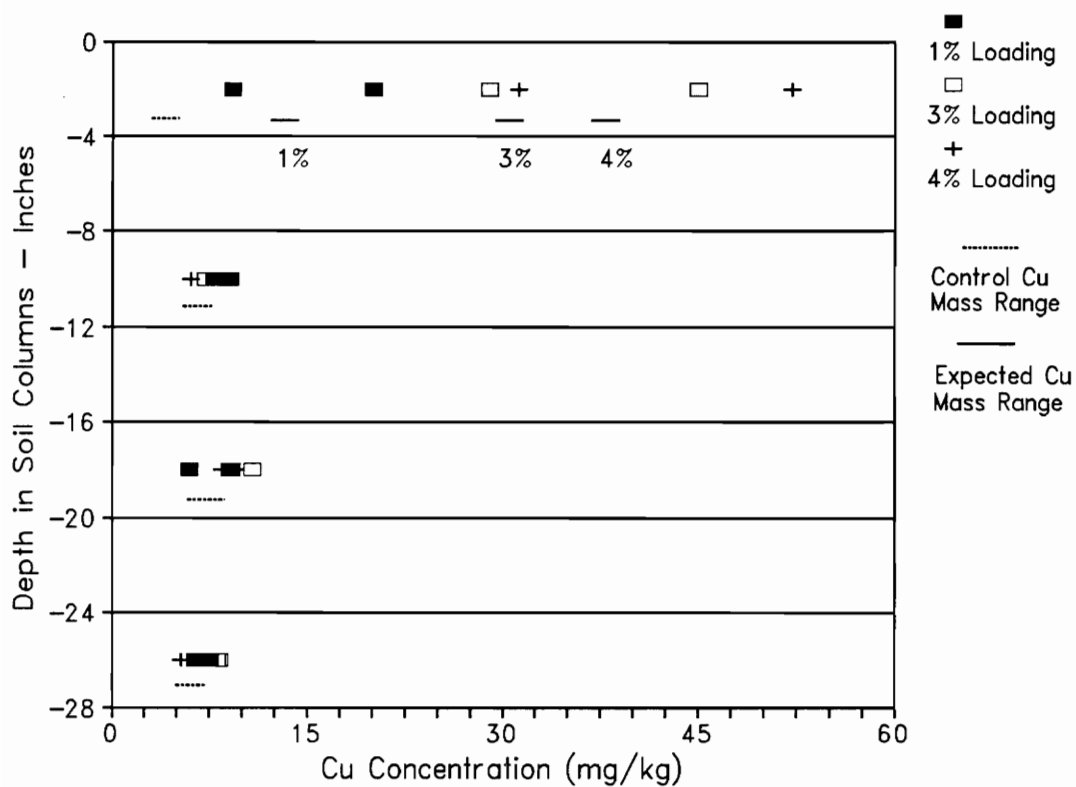


Figure 13 - Copper concentrations at various soil depths - Columns without lime additions. Shows expected copper mass range from residual additions (solid lines) and measured control copper mass range (dashed lines).

within the topsoil increased as well, but did not increase at lower levels compared to the controls.

Calcium and Magnesium

These elements showed concentrations in the leachate that were comparable to the nutrients and lime added to the top soil. A mass balance of the columns showed that the addition of calcium and magnesium had an increase in the concentrations which were found in the leachate. Table 8 shows the concentrations of calcium and magnesium which were added to the various residual loadings, and the mean concentrations per week for the various loadings and additions.

In general, columns with lime additions had higher weekly concentrations of calcium and magnesium than columns without lime. Therefore, the addition of these elements added to the concentrations found for the various columns.

Figures 14 and 15 show the release of both calcium and magnesium for various loadings. These elements would not degrade the groundwater, but these figures suggest movement into the groundwater system. Calcium and magnesium movement through the soil profile has been reported by Campbell and Beckett (1988) and Robertson et al. (1982).

Manganese

The leachate concentrations for manganese were low throughout all the columns (generally < 0.2 mg/L, see Appendix B). The minimum solubility pH of manganese hydroxides (pH 12) (Benefield et al., 1982)

Table 8

Mean Leachate Calcium and Magnesium Concentrations per Week - mg/L

	Controls	Loadings			
		0%	1%	3%	4%
Calcium	26				
w/ Nutrients		33	49	19	29
w/ Lime & Nutrients		55	51	29*	-
Magnesium	5				
w/ Nutrients		7	17	6	9
w/ Lime & Nutrients		15	10	8*	-

* = pooling columns

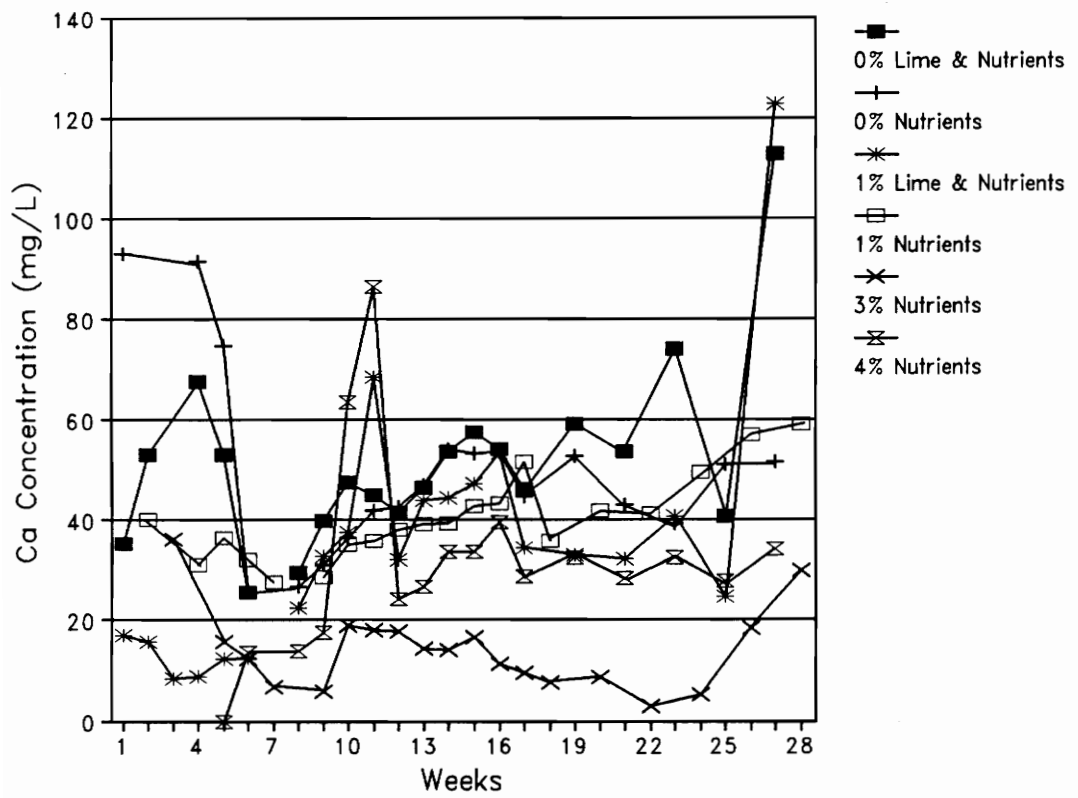


Figure 14 - Leachate calcium concentrations over time - Various loadings with and without lime.

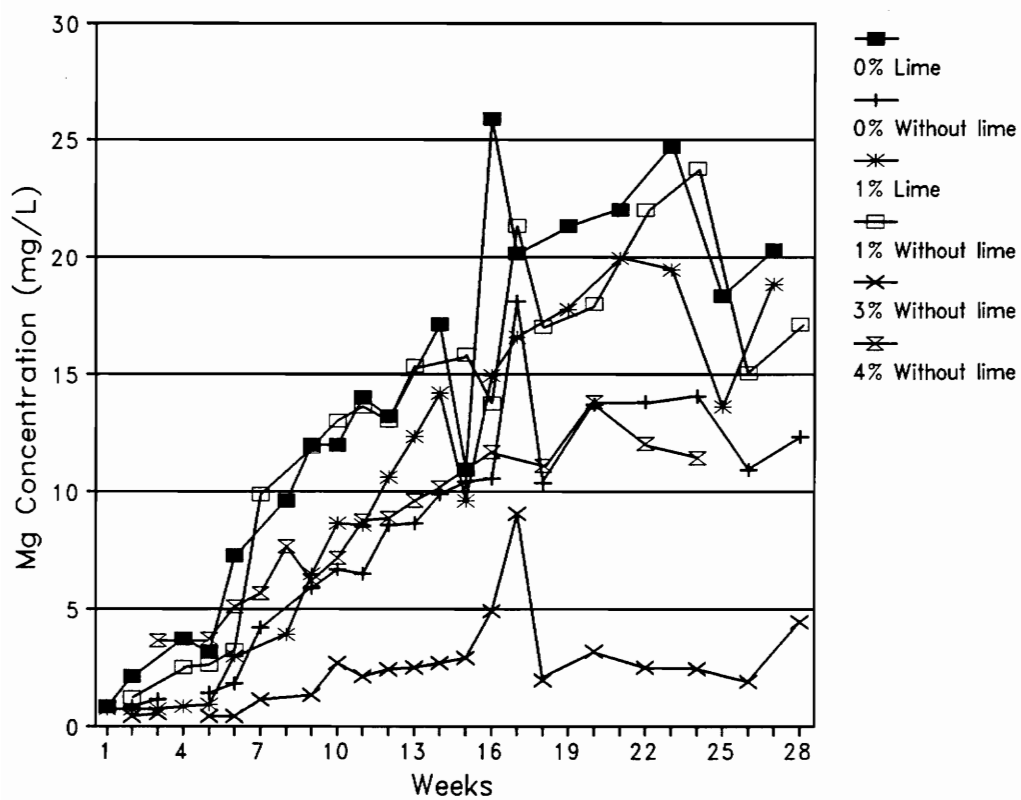


Figure 15 - Leachate magnesium concentrations over time - Various loadings with and without lime.

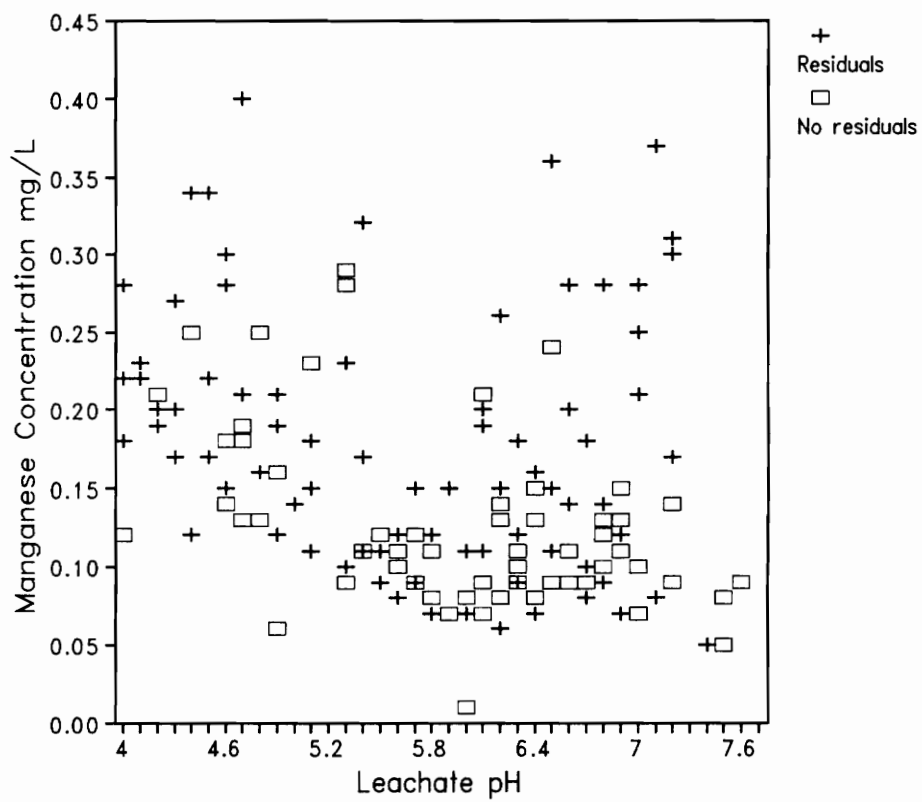


Figure 16 - Leachate manganese concentrations versus leachate pH for all columns.

is well above the leachate pH found in this research, and, like zinc, one would think that the leachate washed all soluble manganese out immediately. This was not the case. In fact, as shown in Figure 16, manganese concentrations were relatively similar over the study period. There is a similar pattern as found in the aluminum and iron data; however the trend is not as strong.

Table 9 shows the regression analysis output. The R Squared value for columns with and without lime showed that there was a low correlation (12 and 14 percent) between average weekly concentration and residual loadings.

The soil profile data along with low leachate concentrations suggest that manganese was retained within the topsoil and correlates directly with percent residuals loading. The loading mass figures show that a one percent loading added about 66 mg/kg, a three percent loading added 194 mg/kg, and a four percent loading added 256 mg/kg. Figures 17 and 18 show that little, if any, migration of manganese through the soil column occurred during the study period.

Boron

This element became a concern later in the project because of the observed negative impacts on plant growth found in the greenhouse study (Lucas, 1991). Specifically, when unwashed or unused powdered activated carbon (PAC) was added to the topsoil mixture, boron was observed as limiting growth in the plants under study. Therefore, boron was analyzed in the soil profiles at the end of the project. The concentra-

Table 9

Regression Analysis on Weekly Averages of Leachate Manganese

		Loading Rates		
	0%	1%	3%	4%
Columns without lime	.12	.17	.11	.15
	.12	.22	.11	.09

Regression Output

Constant	0.15
Std. Err. of Y Est.	0.04
R Squared	0.12
No. of Observations	8.00
Degrees of Freedom	6.00

		Loading Rates		
	0%	1%	3%	4%
Columns with lime	.18	.16	.12	
	.08	.24	.07	

Regression Output

Constant	0.17
Std. Err. of Y Est.	0.07
R Squared	0.14
No. of Observations	6.00
Degrees of Freedom	4.00

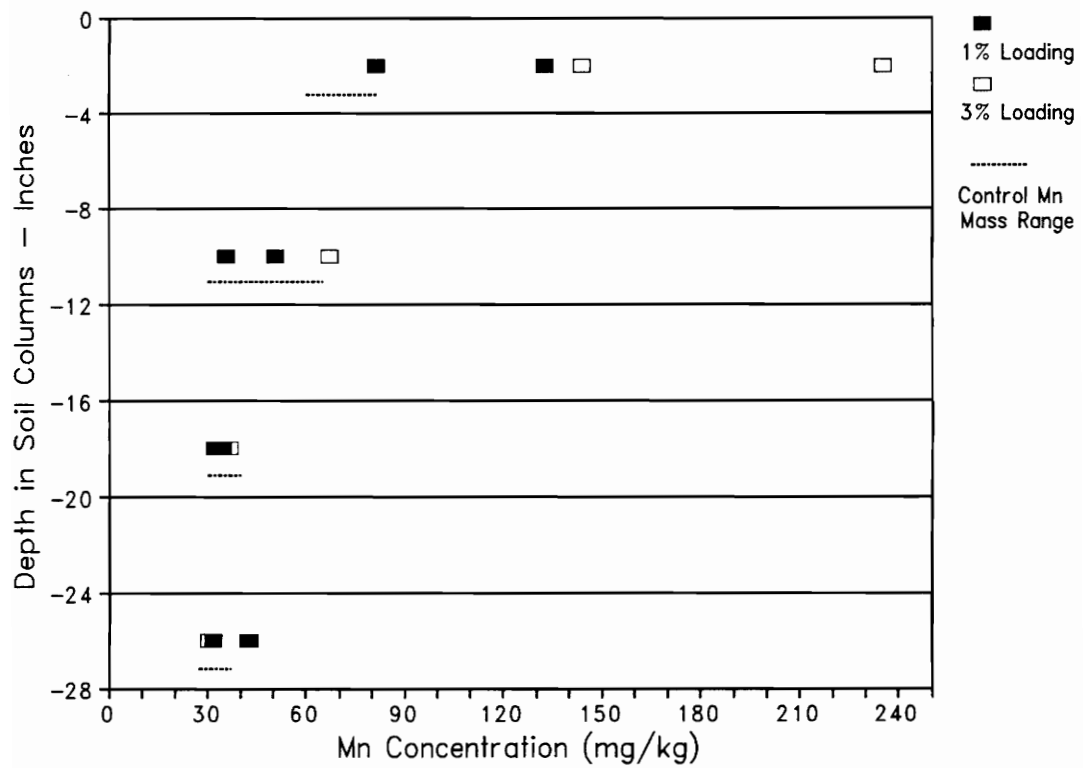


Figure 17 - Manganese concentrations at various soil depths - Columns with lime. Shows measured control manganese mass range (dashed lines).

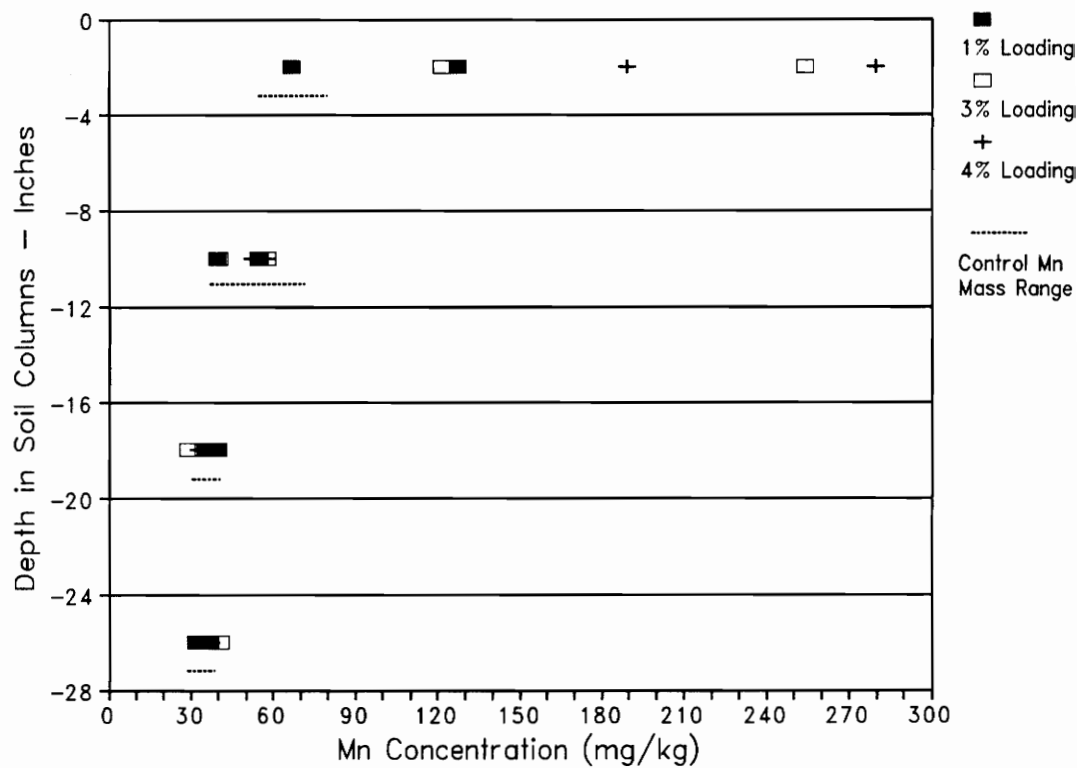


Figure 18 - Manganese concentrations at various soil depths - Columns without lime. Shows measured control manganese mass range (dashed lines).

tions were low through the soil profile for all the columns including the columns with PAC additions. The phenomenon that caused high concentrations in the plant study was probably because the boron would be readily flushed from columns where there was no plant growth.

Campbell and Beckett (1988) have reported movement of boron through the soil profile in their research. Movement of boron can not be confirmed in this study, however, since boron was not measured in the leachate. This issue is discussed in more detail by Lucas (1991).

Cadmium

This element, like boron, was only studied in the soil profile. The concentrations were in parts per billion with the highest reading at 170 ug/kg and the lowest at 15 ug/kg in the non-PAC columns. Little variation was seen in any of the columns regardless of residuals loading. As shown in Table 10, the mean concentrations were higher in the lower reaches of the three percent loadings. All other readings were within 20 percent of the reported values for zero percent loadings.

Sidle and Kardos (1977) and Elliott et al. (1990) have shown cadmium to be mobile in the soil profile, but usually in concentrations between 1 and 5 ug/kg. The research effort presented here is inconclusive in terms of cadmium movement because the residuals analysis failed to detect any cadmium. Therefore, a direct correlation is impossible.

Chromium

Chromium, like cadmium and boron, was studied only in the soil

Table 10

Mean Soil Profile Cadmium Concentrations - ug/kg

<u>Depth in inches</u>	0%	Loadings		
		1%	3%	4%
0 - 4	105	138	107	61
8 - 12	43	30	47	55
16 - 20	77	33	83	40
24 - 28	44	44	73	33

profiles. The concentrations were consistent throughout the entire column regardless of sludge loading and showed a range of 15 to 35 mg/kg. The residuals analysis showed 147 mg/kg; however, the reported soil profile values are below the mass one should expect. This could mean there was movement of chromium out of the column; however, since the leachate was not analyzed for chromium this can not be confirmed. Further studies are needed on this element.

Anion Analysis

The following anions were analyzed in the rainwater leachate: chloride (Cl^-), nitrite ($\text{NO}_2\text{-N}$), nitrate ($\text{NO}_3\text{-N}$), phosphate (PO_4^{2-}), and sulfate (SO_4^{2-}). See Appendix B for weekly values.

Chloride

This anion is traditionally used as a tracer through groundwater systems such as this experiment. Chloride was in the rainwater at 0.045 meq/liter. This translates to 1.59 mg/L, or 11.9 mg over 28 weeks.

For column M, a good flowing column, the amount of chloride leached was at a mean of 7.86 mg/L or 49.32 mg over a 27 week period. Column B, a low flowing column, produced a mean of 7.85 mg/L, which translates to 24.1 mg over 28 weeks. Therefore, regardless of the flows or column loadings, the leachate washed out additional chloride present in the soil. This element would not be a concern in the groundwater table.

Nitrite-Nitrogen

This anion showed very low concentrations (< 1 mg/L) in three columns and was not detectable in other columns over the duration of the study. The only columns which had measurable concentrations of nitrite were one of the control columns (A), the fastest flowing (qualitative observation) column (T), and column U (three percent loading with lime and nutrient additions), which pooled after the 12th week and had no more nitrite-nitrogen measured in the leachate. This element appears to be insignificant (in terms of concentration and column repeatability) with respect to this study.

Nitrate-Nitrogen

The leachate concentration of nitrate-nitrogen increased in every column regardless of loading, nutrients or lime additions. The addition of nutrients to the columns added to the overall nitrate concentration, which was then released because no plant life was present to utilize the available nitrate. The concentration of nitrate increased more rapidly in the columns with nutrients than the concentration of the columns without nutrients. It should be pointed out that those columns without nutrient addition had increases in nitrate but not in the quantities found in the columns with nutrient addition.

Nitrate release in all columns occurs for two reasons. First, nitrogen can be released from the soil when it is disturbed and since no plant life took up any of the nitrates, they were free to migrate (Evanylo, 1990). Secondly, nitrate moves through the soil profile

during times of high moisture flux (Novotny and Chesters, 1989). Since rainwater was added every week, one would expect continuous releases.

Figures 19 and 20 show the increase in nitrate-nitrogen over time for the control, nutrient, and lime and nutrient containing columns. Figure 19 shows one column which is declining in concentration. This is predictable because the three percent loadings with lime and nutrients pooled. Table 3 reported that nutrient additions accounted for 200 mg/kg of nitrogen, the largest component in the system. It would take several months to remove all the nitrogen in columns with nutrient additions.

Phosphate-Phosphorous

The precipitation of phosphorous by aluminum is known to occur as a result of alum residual application (Bugbee and Frink, 1985; Dempsey et al. 1989; Brabarek and Krug, 1987). All columns showed concentrations near or below the detection limit. Column A, a control column, had the highest measurements of phosphate, but was not consistent from week to week. None of the columns leached phosphate equal to the amount which was added to the soil by the nutrient addition (see Table 3). Since phosphate associates with aluminum and/or soil particles (Novotny and Chesters, 1981), little would be expected in filtered leachate.

Sulfate

Sulfate decreased over time at all sludge loadings. The amount of sulfate in the system appeared to be directly related to the residual

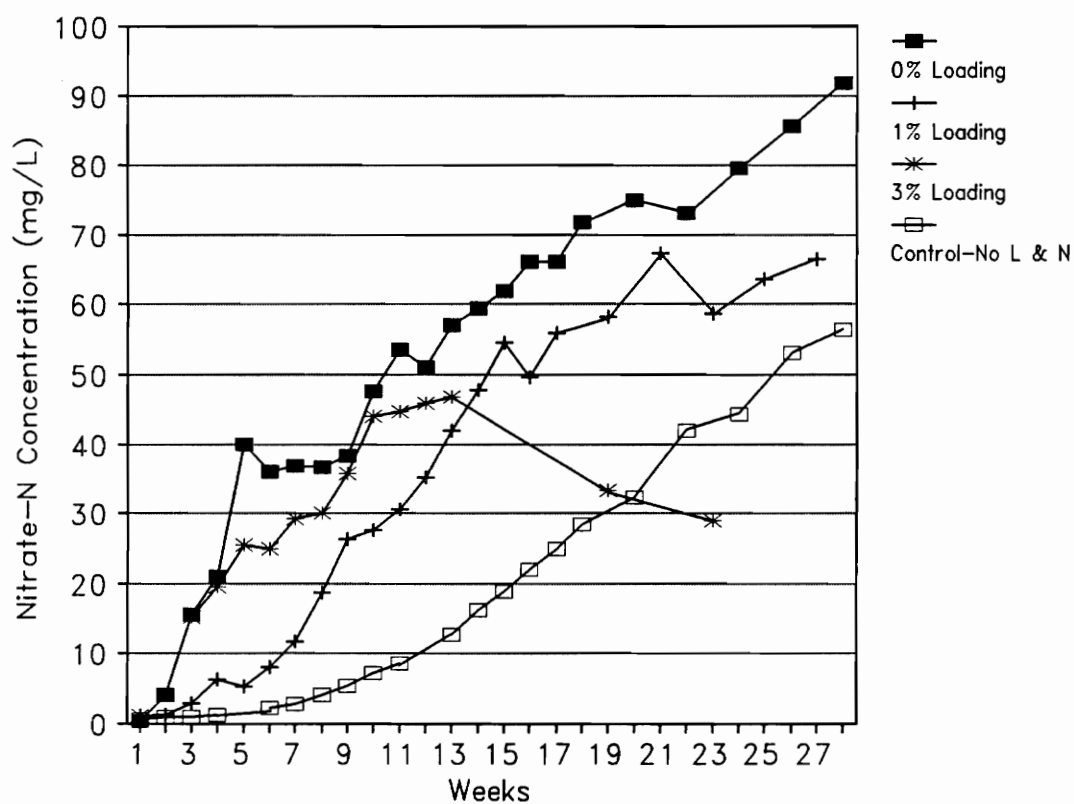


Figure 19 - Leachate nitrate concentrations over time - Columns with lime additions.

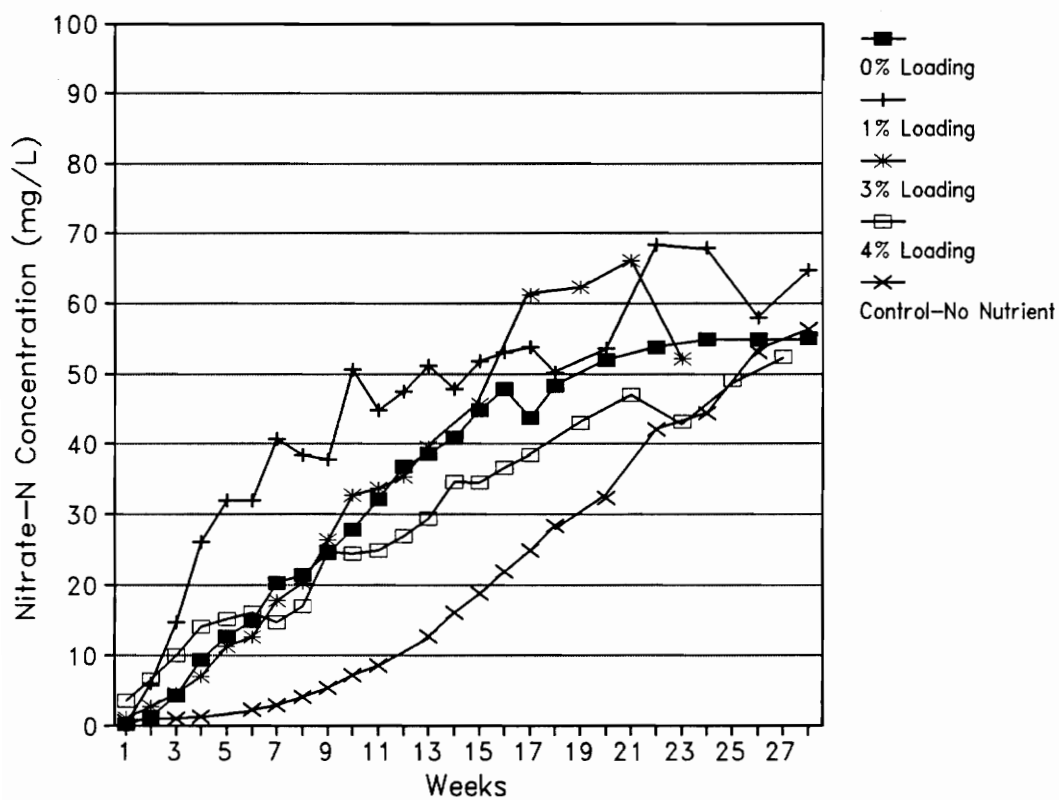


Figure 20 - Leachate nitrate concentrations over time - Columns without lime additions.

loadings, especially with columns containing nutrients and no lime. These columns showed that the higher the residual loading the lower the sulfate concentrations in the leachate. The columns with both lime and nutrients, with some exceptions, follow this pattern as well. Figures 21 and 22 show that leachate concentrations varied little among different loadings and all were decreasing with time, with one exception. The exception is the column which displayed pooling of water. This suggests a flush out of sulfate through the entire column regardless of loading.

Powdered Activated Carbon (PAC)

The columns with PAC additions showed little variation from what was previously reported for other columns. Table 11 shows that the mean leachate concentrations were slightly higher for iron and zinc, but were close to values reported for the controls of manganese and aluminum.

The most interesting aspect of the PAC columns was the extremely high concentrations of cadmium found in the soil profiles. As shown in Table 11, the concentration of cadmium in the topsoil layer and the lower soil layer for one column (V - 430 ug/kg) had significantly higher reported values than all other columns in the study. This aspect needs further study because the residuals measured no cadmium, yet the detection in the two PAC columns is significant. The limited number of columns studied (two), the type of PAC used (unused Nunchar brand), and the fact that one of the columns pooled (S) suggest that further research should be performed on the PAC residuals.

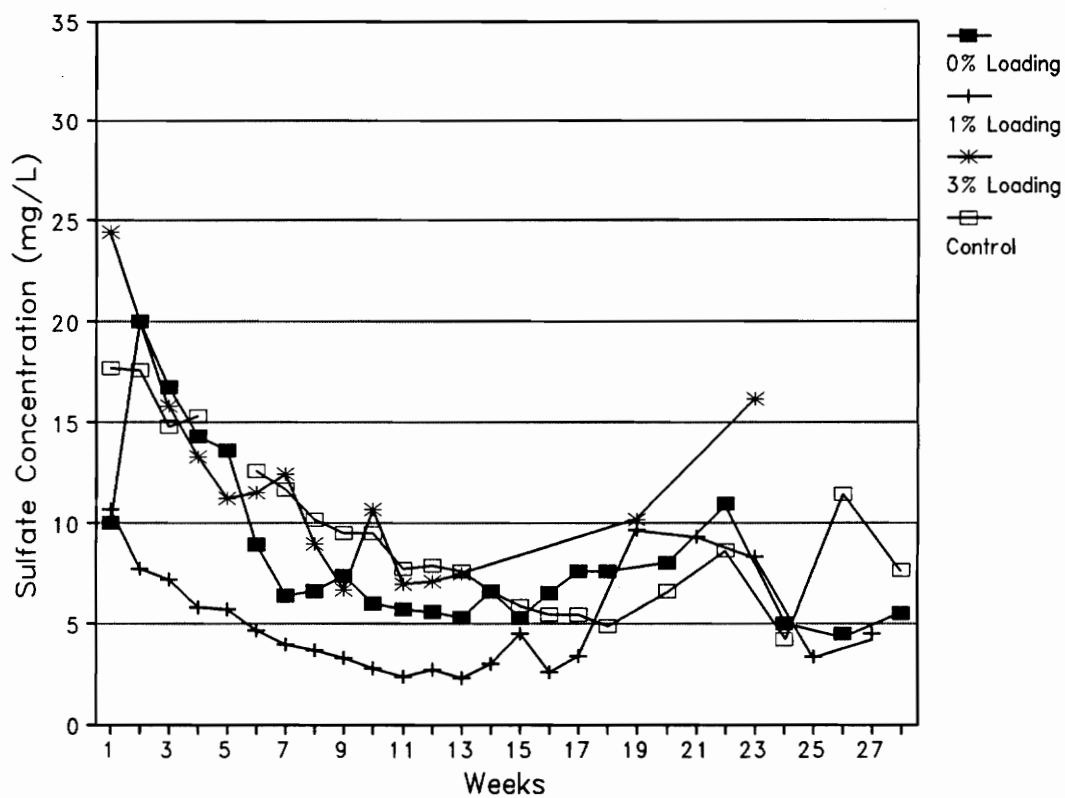


Figure 21 - Leachate sulfate concentrations over time - Columns with lime additions.

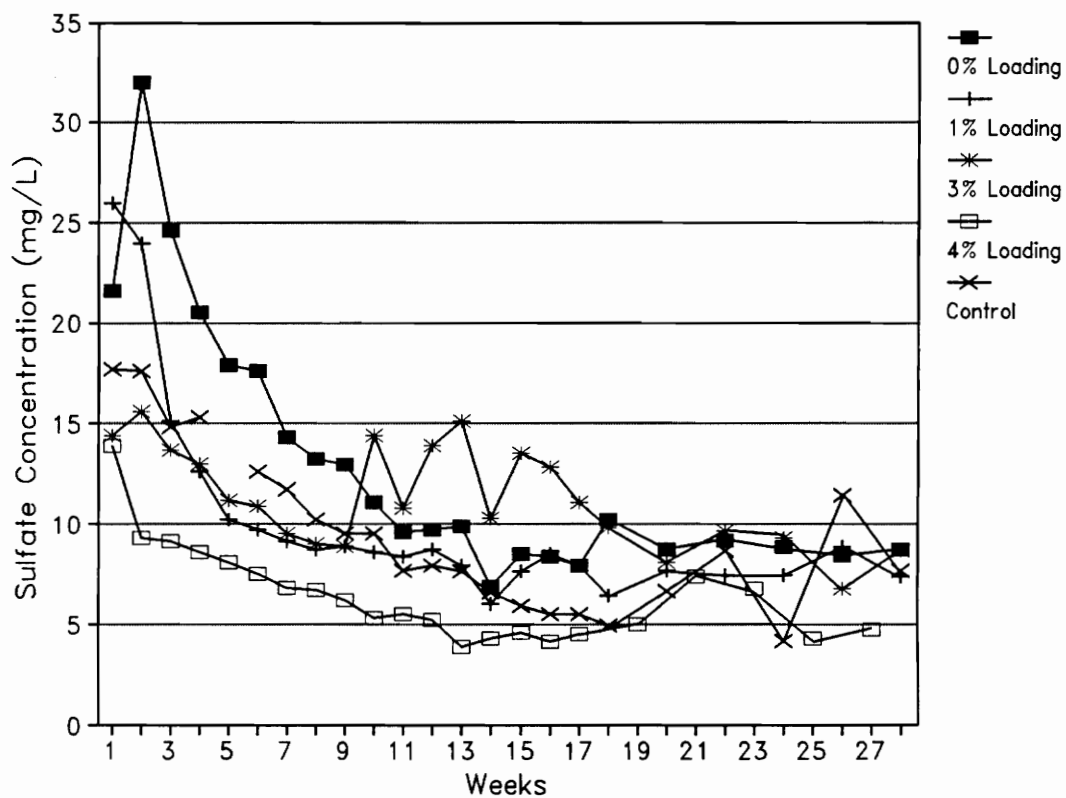


Figure 22 - Leachate sulfate concentrations over time - Columns without lime additions.

Table 11

Comparison of Mean and Range Values for Controls and PAC Columns - mg/L

<u>Weekly Leachate</u>	<u>Controls</u>	<u>PAC</u>
Al mean (ug/L)	81	18
range (ug/L)	4 - 1590	4 - 101
Fe mean	.20	.66
range	.04 - .46	.03 - 1.2
Mn mean	.13	.13
range	.05 - .29	.06 - .22
Zn mean	.54	.80
range	.04 - 1.8	.16 - 3.4

Soil - Cadmium - ug/kg

Depth in inches

0 - 4	113	370
8 - 12	42	33
16 - 20	68	18
24 - 28	41	225*

* - One column exhibited a concentration of 430 ug/kg.

pH

The pH in the soil columns had an important influence on leachate characteristics. These influences have been considered in the discussion of each individual element. Because rainwater was added to the columns at pH 4.7, and some leachate pH was below 4.7, the leachate pH appears to be influenced by some other factor, possibly the pH of some soil column section. However, it also appears, as would be expected, that the flow rate through the column influenced pH. The pH through the soil columns also varied from one column to another, even with similar topsoil treatment.

The pH of the soil with depth, as shown in Figures 23 and 24, indicates that the pH of the soil usually, but not always, decreased with depth. In columns receiving residuals, the top layer had a higher pH because the sludge acted as a buffer to the soil (Bugbee and Frink, 1985). It also appears that residuals did not greatly effect the pH of the soil past the first four inches of depth, again suggesting little movement of residuals through the top layer into the groundwater system.

Discussion Summary

Table 12 provides a summary of the measured elements and their observed fate from the residual loadings.

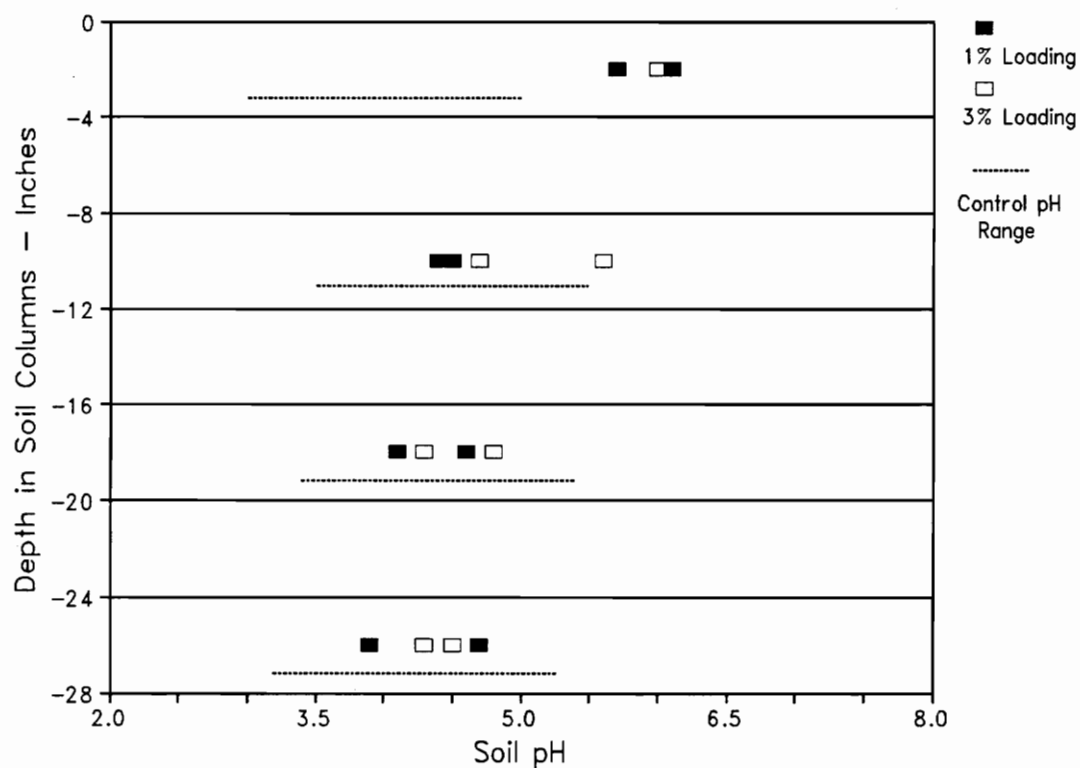


Figure 23 - Soil pH values at various soil depths - Columns with lime additions. Shows measured control pH ranges (dashed lines).

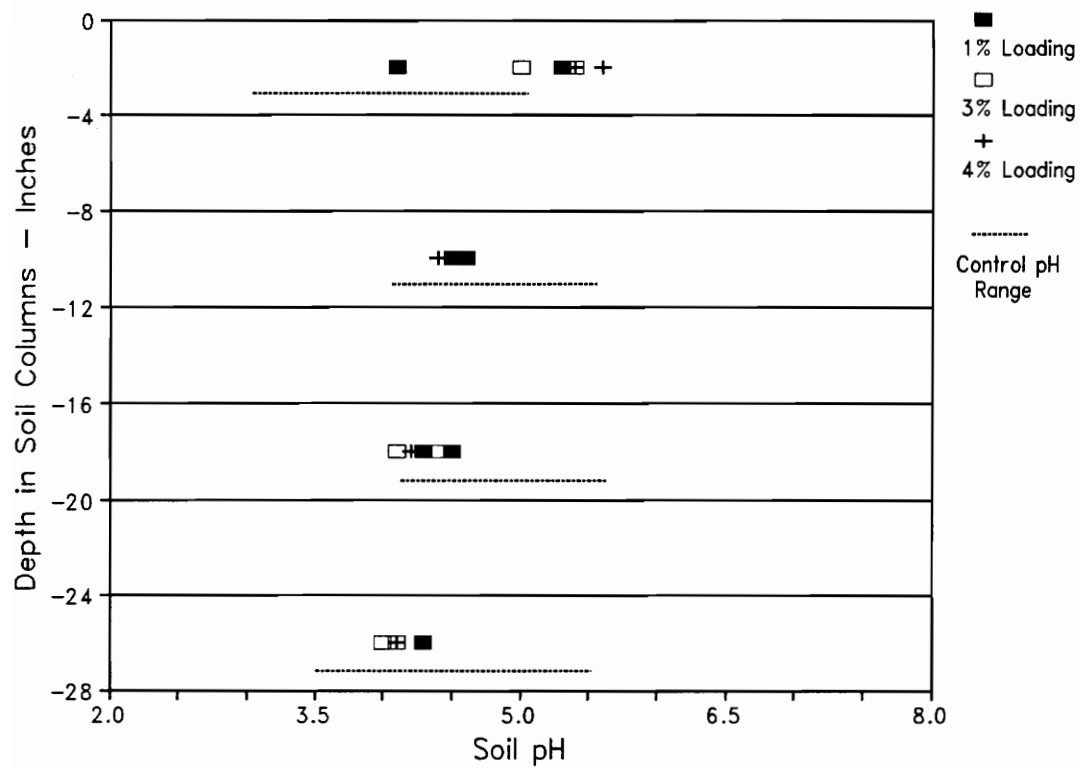


Figure 24 - Soil pH values at various soil depths - Columns without lime additions. Shows measured control pH ranges (dashed lines).

Table 12

Summary of Results

<u>METALS</u>	<u>FATE</u>	<u>COMMENTS</u>
Aluminum	Remained in the topsoil through the duration.	Appears that Al in leachate from column soil.
Boron	From lack of soil profile evidence, it appears to have washed out of the column.	Further research needed on boron.
Cadmium	Direct correlation of movement through the soil profile is impossible.	Literature suggests movement through soil profile. Can not confirm here.
Calcium	Readily moved out of the topsoil into the lower soil profile	Wash out continues steadily.
Chromium	Soil profile data suggests movement out of column.	Lack of leachate data - need further research.
Copper	No mobility out of the topsoil.	Mass balance shows no leaching of Cu.
Iron	Little mobility, if any, from the topsoil.	Range of controls makes an accurate depiction difficult.
Magnesium	Like calcium, moved through the soil profile easily.	Washing out at a slower rate than Ca.
Manganese	No mobility out of topsoil.	Consistent concentrations in soils.
Zinc	Appears to be mobile.	Appears to be function of soil rather than residuals.

Table 12, continued.

<u>ANIONS</u>	<u>FATE</u>	<u>COMMENTS</u>
Chloride	Movement through the soil profile.	Wash out of chloride within columns.
Nitrite - nitrogen	Only three columns exhibited any concentrations at all.	Not significant.
Nitrate - nitrogen	Mobility - increasing concentrations.	Result of no plant growth and soil disturbance.
Phosphate - phosphorous	No mobility - some controls show low concentrations.	Associated with aluminum binding.
Sulfate	Mobility through column.	Decreased in concentration over time with each column.
<u>pH</u>	Leachate pH was highly variable, appears to be function of soil. No decrease was readily observed. Soil pH was higher in topsoil in columns with residuals added.	Can not be sure where leachate pH is changing, but could not be associated with buffer topsoil, because of variability and low values.

V. CONCLUSIONS

The following summarize the research conclusions:

- (1) Regardless of lime and/or nutrient additions, up to a four percent alum residuals loading (ODW), did not degrade leachate quality beyond observed control ranges.
- (2) Nitrate and zinc were the only components that consistently degraded the leachate quality beyond VWCB Groundwater Standards, but were within ranges of observed control concentrations.
- (3) Mobility of aluminum, iron, copper, manganese, and phosphate - phosphorous was not observed through soil profiles with respect to the control columns.
- (4) Metals in the leachate appeared to originate from the soil and not from the residuals, and measured concentrations generally increased with lower pH, regardless of residuals, lime, and nutrients.

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APPENDIX A

Preliminary Leachate Data

Reported in mg/L unless noted

Preliminary Alum Sludge Analysis

<u>Element</u>	<u>Concentration (mg/L)</u>
TKN	14,382
P	1,375
K	1,397
Ca	6,528
Mg	882
Na	420
S	6,442
Zn	164
Mn	6,652
Cu	843
Fe	19,670
Al	153,785
B	82
Cd	None detected
Cr	147

Alkalinity
(as mg CaCO₃ per liter)

Initial alkalinity after running distilled water through columns to establish relative flow rates.

Column	Alkalinity
A	48
B	100
C	127
D	57
F	8
G	80
J	106
K	76
ZZ	--
M	45
N	124
O	82
P	75
Q	83
R	106
S	50
T	48
U	69
V	24
X	25
Z	62

APPENDIX B

Leachate Data

Reported in mg/L unless noted

COLUMN KEY

Column	Description
A	CONTROL NO ADDITIVES TO SOIL
B	3% LOADING WITH NUTRIENTS
C	0% LOADING WITH NUTRIENTS
D	1% LOADING WITH NUTRIENTS
F	CONTROL NO TOP SOIL
G	CONTROL NO TOP SOIL
H	0% LOADING WITH LIME AND NUTRIENTS
J	3% LOADING WITH LIME AND NUTRIENTS
K	1% LOADING WITH LIME AND NUTRIENTS
ZZ	4% LOADING WITH NUTRIENTS
M	3% LOADING
N	CONTROL NO ADDITIVES TO SOIL
O	3% LOADING WITH NUTRIENTS
P	0% LOADING WITH NUTRIENTS
Q	1% LOADING WITH NUTRIENTS
R	0% LOADING WITH LIME AND NUTRIENTS
S	2% LOADING W/ 2.2% PAC, LIME AND NUTRIENTS
T	1% LOADING WITH LIME AND NUTRIENTS
U	3% LOADING WITH LIME AND NUTRIENTS
V	2% LOADING W/ 2.2% PAC, LIME AND NUTRIENTS
X	4% LOADING WITH NUTRIENTS
Z	3% LOADING

Control column no additions to topsoil - Column A

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)	19	11		25	8		89
Calcium		13.3		5.5	6.2	5.1	5.4
Chloride	8.30	9.20	8.60	7.60		7.40	6.80
Iron				0.03	0.07	0.14	
Magnesium		0.33		0.40	0.40	0.50	1.50
Manganese		0.10		0.10	0.09	0.09	0.06
Nitrate	0.5	0.9	0.9	1.2		2.2	2.8
Nitrite			0.10				
pH (-log[H+])	6.7	6.8	6.1			5.3	
Phosphate	0.30	0.10	0.10				
Sulfate	17.7	17.6	14.8	15.3		12.6	11.7
Zinc		0.96			0.83	0.85	0.58
Flow/week (mL)							

WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	122	248	375	15	17	12	512
Calcium		5.7	6.7	32.7	15.6	14.3	13.3
Chloride	7.10	7.20	7.50	7.70	6.90	7.00	6.20
Iron	0.03	0.05	0.21		0.12	0.21	0.28
Magnesium		1.90	2.30	2.20	3.20	3.50	4.90
Manganese	0.06	0.08	0.10		0.07	0.11	0.08
Nitrate	4.0	5.4	7.2	8.5		12.7	16.1
Nitrite						0.13	
pH (-log[H+])	4.9				6.2	5.6	
Phosphate							0.10
Sulfate	10.2	9.5	9.5	7.7	7.9	7.6	6.6
Zinc	0.67	0.52	0.63	0.06	0.36	0.36	0.42
Flow/week (mL)							

WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	19	19		13		848	1590
Calcium	18.9	19.5	17.9	16.0		20.4	16.6
Chloride	9.70	5.70	5.60	6.40		6.13	5.77
Iron			0.51	0.21	0.18	0.08	0.04
Magnesium	5.10	7.90	10.12	7.74		10.78	9.90
Manganese	0.09	0.09	0.10	0.11	0.08	0.12	0.14
Nitrate	18.8	22.0	25.0	28.4		32.3	42.0
Nitrite				0.01		0.02	
pH (-log[H+])		6.2		5.4	5.8	4.0	4.7
Phosphate	0.02		0.11	6.10		0.60	0.21
Sulfate	5.9	5.5	5.5	4.9		6.6	8.7
Zinc	0.43	0.52	0.53	0.64	0.54	0.60	0.86
Flow/week (mL)				190		202	174

WEEKS=>	24	26	28	Mean
Aluminum (ppb)	24	1420	15	270
Calcium	35.3	33.5	51.9	17.7
Chloride	5.96	5.15	5.25	6.96
Iron	0.13	0.25		0.16
Magnesium	12.89	11.09	15.22	5.59
Manganese	0.12	0.13	0.16	0.10
Nitrate	44.3	53.0	56.4	18.32
Nitrite				0.06
pH (-log[H+])	5.5	4.8	4.9	5.5
Phosphate	0.29			0.79
Sulfate	4.2	11.4	7.7	9.5
Zinc	0.57	1.37	0.88	0.63
Flow/week (mL)	212	288	248	219

3% Loading with nutrients - Column B

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)	40	6	15		15		15
Calcium			36.2		15.8	12.3	6.7
Chloride	5.4	7.1	6.6	6.4	6.4	6.6	6.3
Iron		0.06	0.19		0.50	0.50	
Magnesium		0.40	0.50		0.40	0.40	1.10
Manganese		0.07	0.07		0.08	0.08	0.08
Nitrate	0.6	1.3	1.3	1.7	1.9	2.0	2.5
pH (-log[H+])	6.9	6.2	6.6			5.6	
Sulfate	14.4	15.6	13.7	13.0	11.2	10.9	9.5
Zinc		0.88	0.65		0.62	0.77	0.52
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	13	11	29	12	17	35	42
Calcium		5.8	18.9	18.0	17.9	14.4	14.1
Chloride	7.1	7.2	10.4	9.8	9.3	8.6	8.6
Iron		0.04	0.06		0.04	0.03	0.03
Magnesium		1.30	2.70	2.10	2.40	2.50	2.70
Manganese	0.09	0.11					0.06
Nitrate	3.2	3.3	6.4	4.9	5.0	4.8	4.6
pH (-log[H+])	5.7				6.9	6.3	
Sulfate	9.0	8.9	14.4	10.8	13.9	15.1	10.3
Zinc	0.37	0.58	0.12	0.10	0.08	0.11	0.26
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	30	15		6		72	267
Calcium	16.6	11.4	9.5	7.7		8.7	2.8
Chloride	9.6	8.7	8.7	7.2		7.9	8.6
Iron	0.06		0.03	0.06	0.13		0.03
Magnesium	2.90	4.90	9.06	1.94		3.17	2.46
Manganese	0.06	0.07	0.11	0.15	0.16	0.16	0.12
Nitrate	6.1	4.8	5.0	5.0		5.1	6.3
pH (-log[H+])		6.4		5.7	6.4	4.8	4.9
Sulfate	13.5	12.8	11.1	9.8		8.1	9.6
Zinc	0.12	0.24	0.28	0.47	0.47	0.67	0.39
Flow/week (mL)				125		86	124
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	357	57	30	54			
Calcium	5.1	18.5	29.9	14.2			
Chloride	8.7	7.6	6.4	7.8			
Iron	0.04			0.12			
Magnesium	2.42	1.89	4.44	2.48			
Manganese	0.17	0.12	0.17	0.11			
Nitrate	8.7	7.6	7.7	4.3			
pH (-log[H+])	4.3	5.6	5.4	5.8			
Sulfate	9.3	6.8	8.7	11.3			
Zinc	0.42	0.29	0.30	0.40			
Flow/week (mL)	112	186	25	110			

0% Loading with nutrients - Column C

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)	21	7	9		10		14
Calcium		93.1			91.4	74.8	25.8
Chloride	7.7	7.3	7.1	6.5	6.3	6.3	5.9
Iron							
Magnesium		0.80	1.10		1.40	1.80	4.20
Manganese		0.10	0.11		0.10	0.09	0.09
Nitrate	0.1	1.3	4.2	9.3	12.7	14.9	20.3
pH (-log[H+])	7.3	6.3	6.6			5.7	
Sulfate	21.6	32.0	24.6	20.5	17.9	17.6	14.3
Zinc		1.16	1.09		0.94	0.80	0.47
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	10	11	14	10	7	12	29
Calcium		26.8	31.2	36.4	42.0	42.6	46.9
Chloride	5.9	5.7	5.5	6.1	6.1	6.4	5.4
Iron		0.06	0.05		0.05	0.03	0.03
Magnesium		5.90	6.70	6.50	8.60	8.70	9.90
Manganese	0.07	0.10	0.11	0.12	0.12	0.14	0.13
Nitrate	21.5	24.6	27.9	32.2	36.7	38.6	40.8
pH (-log[H+])	5.9				6.8	6.2	
Sulfate	13.2	12.9	11.1	9.6	9.7	9.9	6.9
Zinc	0.50	0.56	0.57	0.67	0.68	0.77	0.67
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	24	35		26		51	18
Calcium	54.0	53.1	53.5	44.7		52.6	43.0
Chloride	5.5	6.0	4.8	6.9		4.9	5.9
Iron	0.04		0.03	0.07	0.03	0.03	0.03
Magnesium	10.40	10.56	18.08	10.34		13.68	13.82
Manganese	0.15	0.13	0.13	0.13	0.13	0.15	0.10
Nitrate	44.8	47.8	43.6	48.3		51.8	53.8
pH (-log[H+])		6.8		6.4	6.9	6.4	6.8
Sulfate	8.5	8.4	7.9	10.2		8.7	9.2
Zinc	0.63	0.56	0.53	0.48	0.51	0.51	0.40
Flow/week (mL)				192		273	245
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	58	10	32	20			
Calcium	39.2	51.1	51.5	50.2			
Chloride	5.3	4.8	5.3	6.0			
Iron	0.06	0.03		0.04			
Magnesium	14.03	10.96	12.32	8.49			
Manganese	0.14	0.10	0.12	0.12			
Nitrate	54.8	54.8	55.0	32.2			
pH (-log[H+])	6.2	5.6	5.7	6.4			
Sulfate	8.8	8.4	8.8	13.1			
Zinc	0.42	0.37	0.21	0.61			
Flow/week (mL)	218	218	240	231			

1% Loading with nutrients - Column D

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)	12	5		12	9		148
Calcium		40.1		31.1	36.4	32.0	27.7
Chloride	8.4	10.4	9.1	8.3	7.5	6.9	6.4
Iron		0.50		0.20		0.40	0.60
Magnesium		1.20		2.50	2.60	3.20	9.90
Manganese		0.10	0.11		0.11	0.11	0.17
Nitrate	0.2	6.0	14.8	26.0	32.0	32.0	40.7
Nitrite							
pH (-log[H+])	7.5	6.7	6.6			5.6	
Sulfate	26.0	24.0	15.1	12.6	10.2	9.7	9.1
Zinc		0.37		0.61	0.51	0.62	0.55
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	436	557	614	648	650	712	852
Calcium		28.6	35.0	35.6	38.0	39.1	39.4
Chloride	6.5	6.2	5.9	6.7	4.7	7.8	6.9
Iron	0.68	0.48	0.67	0.26	0.90	0.90	0.63
Magnesium		11.90	13.00	13.60	13.00	15.30	
Manganese	0.15	0.16	0.17	0.14	0.20	0.22	0.20
Nitrate	38.4	37.7	50.5	44.9	47.4	51.1	47.8
Nitrite							
pH (-log[H+])	4.6				4.2	4.5	
Sulfate	8.7	8.9	8.6	8.4	8.7	7.9	6.0
Zinc	1.00	0.59	0.52	0.49	0.49	0.51	0.48
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	898	728		832		1070	113
Calcium	42.8	43.2	51.6	35.7		41.9	41.1
Chloride	7.3	6.1	6.5	5.3		6.0	9.1
Iron	0.12	0.34	0.69	0.54	0.52	0.69	0.27
Magnesium	15.80	13.73	21.34	16.98		18.00	22.00
Manganese	0.18	0.17	0.19	0.20	0.19	0.27	0.19
Nitrate	51.8	53.0	53.7	50.1		53.6	68.4
Nitrite		0.01					0.02
pH (-log[H+])		4.5		4.2	4.2	4.3	6.1
Sulfate	7.6	8.5	7.9	6.4		7.7	7.5
Zinc	0.48	0.39	0.38	0.54	0.48	0.66	0.34
Flow/week (mL)				214		127	193
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	14	790	353	473			
Calcium	49.5	57.0	59.2	40.3			
Chloride	8.1	5.7	6.8	7.1			
Iron	0.04	0.43	0.37	0.49			
Magnesium	23.80	15.05	17.07	13.16			
Manganese	0.20	0.19	0.19	0.17			
Nitrate	67.9	58.0	64.8	43.1			
Nitrite				0.01			
pH (-log[H+])	6.1	4.2	4.9	5.2			
Sulfate	7.4	8.9	7.4	10.1			
Zinc	0.32	0.31	0.28	0.50			
Flow/week (mL)	170	230	160	182			

Control column without topsoil - Column F

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)							9
Calcium						33.6	14.9
Chloride					10.7	10.8	9.1
Iron						0.06	
Magnesium						3.60	2.60
Manganese							0.07
Nitrate						0.1	0.3
pH (-log[H+])						5.9	
Sulfate					30.8	30.6	21.2
Zinc						0.61	0.74
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	9	9	15	35	36	11	44
Calcium		5.9	6.5	6.7	6.7	6.7	7.5
Chloride	9.1	8.4	7.8	8.0	7.5	7.2	7.3
Iron	0.03	0.16	0.09	0.03	0.09	0.07	
Magnesium		2.20	2.30	2.10	2.40	2.20	2.90
Manganese	0.09	0.10	0.08	0.07	0.08	0.07	0.06
Nitrate	0.4	0.1	0.1	0.0	0.1	0.2	0.5
pH (-log[H+])	5.6				5.7	5.7	
Sulfate	19.5	19.6	19.9	20.6	20.0	19.4	15.8
Zinc	0.64	0.35	0.27	0.24	0.18	0.14	0.12
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	30	36		28		16	7
Calcium	6.2	5.5	6.6	4.6		7.6	3.8
Chloride	7.1	6.1	5.8	4.9		5.2	4.9
Iron	0.03		0.07	0.10			0.03
Magnesium	2.30	5.90	12.89	2.24		3.65	3.04
Manganese	0.05		0.05	0.07		0.09	
Nitrate	0.2	0.1	0.1	0.1		0.4	0.4
pH (-log[H+])		5.6		5.4	6.7	5.9	6.6
Sulfate	19.5	18.8	17.0	18.7		18.6	18.5
Zinc	0.13	0.09	0.08	0.16	0.14	0.38	0.16
Flow/week (mL)				206		222	197
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	7	15	8	20			
Calcium	4.8	2.0	47.7	9.8			
Chloride	4.9	4.8	4.8	7.1			
Iron		0.03		0.07			
Magnesium	2.99	1.63	5.10	3.53			
Manganese	0.06	0.04	0.15	0.07			
Nitrate	0.5	0.4	0.6	0.3			
pH (-log[H+])	6.3	5.8	6.0	5.9			
Sulfate	19.8	19.5	28.4	20.9			
Zinc	0.18	0.08	0.03	0.25			
Flow/week (mL)	118	184	172	183			

Control column without topsoil - Column G

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)							8
Calcium						39.5	26.4
Chloride						7.3	6.6
Iron						0.06	
Magnesium						3.80	2.80
Manganese							0.08
Nitrate							0.0
pH (-log[H+])						6.2	
Sulfate						20.0	18.2
Zinc						0.46	0.47
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	18	27	18	56	12	13	21
Calcium		20.0	16.4	24.7	27.1	19.4	14.7
Chloride	6.6	6.0	5.8	6.0	5.6	5.6	5.0
Iron		0.09	0.04		0.07	0.07	
Magnesium		2.50	2.20	2.00	1.80	1.90	2.40
Manganese		0.07	0.05	0.05	0.09	0.07	0.05
Nitrate	0.1	0.3	0.4	0.4	0.6	0.9	1.0
pH (-log[H+])	6.2				7.0	6.2	
Sulfate	16.7	15.3	14.0	13.2	12.8	12.0	9.1
Zinc	0.12	0.21	0.10	0.29	0.20	0.11	0.08
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	19	32		18		52	9
Calcium	22.4	17.8	18.5	14.4		22.8	9.3
Chloride	4.9	4.2	4.0	3.7		4.2	3.4
Iron			0.03	0.06			0.04
Magnesium	1.70	6.20		2.11		3.34	2.33
Manganese	0.08	0.05	0.06	0.09		0.07	
Nitrate	1.0	1.4	1.4	1.3		1.4	2.0
pH (-log[H+])		7.0		7.1	7.4	6.8	7.3
Sulfate	11.3	10.5	8.7	9.7		10.1	8.9
Zinc	0.21	0.11	0.13	0.20	0.12	0.15	0.10
Flow/week (mL)				190		179	308
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	11	13	7	21			
Calcium	15.3	10.8	70.8	23.0			
Chloride	3.4	3.1	3.1	4.9			
Iron	0.04	0.04		0.05			
Magnesium	2.28	1.58	3.87	2.68			
Manganese	0.05	0.01	0.06	0.06			
Nitrate	2.1	2.2	2.7	1.1			
pH (-log[H+])	6.8	6.4	6.3	6.7			
Sulfate	8.8	13.5	8.0	12.3			
Zinc	0.10	0.08	0.09	0.18			
Flow/week (mL)	243	280	272	245			

0% loading with lime and nutrients - Column H

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)	14	5	7		13		94
Calcium		35.2	52.9		67.6	52.8	25.7
Chloride	3.2	6.4	6.8	6.9	6.0	5.7	5.8
Iron					0.03		0.18
Magnesium		0.80	2.10		3.70	3.10	7.30
Manganese		0.11	0.09		0.14	0.13	0.12
Nitrate	0.2	4.0	15.5	21.0	40.0	36.0	36.9
pH (-log[H+])	7.4	6.6	6.7			6.2	
Sulfate	10.0	20.0	16.7	14.3	13.6	8.9	6.4
Zinc		0.88	0.64		0.85	0.91	1.02
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	534	860	268	46	652	1130	1850
Calcium		29.5	39.9	47.5	44.8	41.5	46.5
Chloride	5.8	6.0	5.3	5.6	7.8	6.2	6.8
Iron	0.09	0.26	0.29		0.36	0.46	0.19
Magnesium		9.60	12.00	12.00	14.00	13.20	
Manganese	0.13	0.17	0.15	0.15	0.18	0.18	0.18
Nitrate	36.6	38.3	47.6	53.6	51.0	57.1	59.4
pH (-log[H+])	4.7				4.7	4.6	
Sulfate	6.6	7.4	6.0	5.7	5.6	5.3	6.6
Zinc	1.20	1.04	0.97	0.65	0.74	0.81	0.77
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	1005	1242		2575		2200	2980
Calcium	53.5	57.6	54.1	46.3		59.0	53.5
Chloride	6.7	5.5	5.0	5.4		5.1	7.9
Iron	0.24	0.35	0.46	0.36	0.09	0.96	0.76
Magnesium	17.10	10.96	25.92	20.15		21.34	22.00
Manganese	0.17	0.19	0.20	0.21	0.24	0.25	0.23
Nitrate	61.9	66.1	66.1	71.7		74.9	73.0
pH (-log[H+])		4.7		4.2	6.5	4.4	5.1
Sulfate	5.3	6.5	7.6	7.6		8.0	11.0
Zinc	0.67	0.70	0.75	0.84	1.39	1.57	1.52
Flow/week (mL)				156		146	210
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	20	1930	1005	922			
Calcium	74.0	40.7	112.8	51.8			
Chloride	6.8	5.1	6.6	6.0			
Iron	0.05	0.33	0.26	0.30			
Magnesium	24.72	18.30	20.28	13.61			
Manganese	0.28	0.25	0.29	0.18			
Nitrate	79.6	85.6	91.8	50.8			
pH (-log[H+])	5.3	4.7	5.3	5.4			
Sulfate	5.0	4.5	5.6	8.4			
Zinc	1.03	1.17	1.88	1.00			
Flow/week (mL)	149	180	196	173			

3% loading with lime and nutrients - Column J *

WEEKS=>	1	2	3	4	5*	6	7
Aluminum (ppb)	12	3	4	41	15		15
Calcium		68.4	16.8	12.5	14.6	16.5	9.7
Chloride	5.1	8.4	6.3	5.2	5.0	5.6	5.1
Iron		0.20	0.30	0.30	0.20	0.20	
Magnesium		1.30	1.00	0.90	0.10	1.20	2.80
Manganese		0.16	0.13	0.09	0.08	0.15	0.10
Nitrate	0.2	0.7		2.9	2.6	3.2	4.1
pH (-log[H+])	7.1	6.4	6.5			5.1	
Sulfate	14.8	22.0	12.9	10.8	10.6	10.0	9.5
Zinc		2.83	2.08	1.93	1.87	1.20	0.84
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	12	11	15	57	23	40	22
Calcium		12.1	10.8	20.2	15.0	11.9	15.0
Chloride	5.3	5.7	4.5	6.9	6.8	6.5	6.4
Iron		0.11	0.04	0.05	0.10	0.09	
Magnesium		3.60	3.50	4.40	3.80	3.50	4.40
Manganese	0.12	0.17	0.09	0.06	0.18	0.15	0.13
Nitrate	4.5	4.9	3.8	3.4	3.5	3.8	4.0
pH (-log[H+])	5.8				6.3	5.9	
Sulfate	9.5	9.8	7.9	10.1	9.9	9.4	7.4
Zinc	1.18	1.12	0.70	0.49	0.72	0.90	0.72
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	24	13		23			252
Calcium	12.5	12.4	12.5	11.0			9.7
Chloride	6.1	5.3	5.3	5.7			
Iron			0.04	0.11			0.12
Magnesium	4.00	8.70	16.46	4.71			2.90
Manganese	0.12	0.12	0.14	0.14	0.13		0.05
Nitrate	4.5	4.7	4.3	4.4			
pH (-log[H+])		6.3		6.4	7.0		7.2
Sulfate	8.6	8.3	7.8	8.5			
Zinc	0.86	0.66	0.59	0.36	0.57		0.18
Flow/week (mL)				66			10
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	12	18		32			
Calcium	8.7	4.6		15.5			
Chloride	6.7	6.5		5.9			
Iron		0.03		0.14			
Magnesium	3.82	2.73		3.89			
Manganese	0.11	0.11		0.12			
Nitrate	3.5	3.1		3.5			
pH (-log[H+])	6.1	6.0		6.3			
Sulfate	9.5	9.8		10.4			
Zinc	0.45	0.40		0.98			
Flow/week (mL)	130	117		81			

1% loading with lime and nutrients - Column K

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)		11	11	28	19		26
Calcium		17.0	15.8	8.4	8.9	12.3	12.6
Chloride		6.5	6.3	5.6	5.1	5.3	4.9
Iron		0.12	0.24	0.34	0.25	0.24	
Magnesium		0.70	0.70	0.70	0.80	0.90	3.00
Manganese					0.05		
Nitrate		1.0	1.3	2.9	6.2	5.2	8.0
Nitrite							
pH (-log[H+])		7.2	7.6			5.7	
Sulfate		10.7	7.7	7.2	5.8	5.7	4.7
Zinc		0.36	0.15	0.50	0.35	0.22	0.31
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	21	24	97	118	24	41	154
Calcium		22.4	32.8	37.5	68.6	32.1	43.9
Chloride	5.0	5.1	4.8	5.6	5.4	6.6	6.1
Iron							
Magnesium		3.90	6.50	8.70	8.60	10.60	12.30
Manganese					0.05		
Nitrate	11.7	18.6	26.3	27.6	30.6	35.1	42.0
Nitrite				0.40		1.30	
pH (-log[H+])	6.0				7.4	6.5	
Sulfate	4.0	3.7	3.3	2.8	2.4	2.7	2.3
Zinc	0.50	0.14	0.18	0.17	0.04	0.04	0.11
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	78	23		28		2640	1890
Calcium	44.4	47.1	53.3	34.4		32.9	32.3
Chloride	6.3	5.8	5.2	5.4		6.1	7.2
Iron			0.04	0.23		1.29	1.01
Magnesium	14.20	9.59	14.92	16.54		17.73	19.93
Manganese	0.07	0.12		0.15	0.12	0.23	0.23
Nitrate	47.7	54.5	49.6	55.9		58.2	67.2
Nitrite							0.01
pH (-log[H+])		6.3		6.2	6.7	4.1	5.3
Sulfate	3.0	4.5	2.6	3.4		9.7	9.3
Zinc	0.22	0.54	0.15	0.56	0.47	0.89	0.76
Flow/week (mL)				202		113	186
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	3160	2560	3630	729			
Calcium	40.7	24.6	122.6	35.5			
Chloride	6.5	5.7	6.6	5.8			
Iron	0.80	0.89	0.45	0.49			
Magnesium	19.44	13.60	18.79	9.63			
Manganese	0.21	0.22	0.28	0.16			
Nitrate	58.7	63.7	66.5	33.6			
Nitrite				0.57			
pH (-log[H+])	4.0	4.0	4.0	5.8			
Sulfate	8.4	3.4	4.5	5.1			
Zinc	0.68	0.69	0.77	0.38			
Flow/week (mL)	164	186	80	155			

4% loading with nutrients - Column ZZ

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)		27	6	35	11		13
Calcium							13.7
Chloride		10.0	4.9	5.0	4.9	5.2	4.6
Iron				0.03			
Magnesium							3.60
Manganese				0.06	0.07	0.07	0.06
Nitrate		3.5	6.5	10.0	14.0	15.2	16.0
pH (-log[H+])		7.0	7.2			5.8	
Sulfate		13.9	9.3	9.1	8.6	8.1	7.5
Zinc		0.45	0.72	0.29	0.61	0.67	0.50
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	13	46	81	27	20	32	17
Calcium		13.9	17.6	63.5	86.5	24.1	26.7
Chloride	4.9	5.0	5.0	5.3	5.4	5.5	6.0
Iron	0.07	0.22	0.34		0.45		0.16
Magnesium		3.70	5.10	5.70	7.70	6.20	7.20
Manganese	0.07	0.08	0.09	0.06	0.12	0.08	0.09
Nitrate	14.7	17.0	24.8	24.4	25.0	26.9	29.3
pH (-log[H+])	6.0				6.9	6.6	
Sulfate	6.8	6.7	6.2	5.3	5.5	5.2	3.9
Zinc	0.39	0.60	0.63	0.38	0.63	0.40	0.56
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	33	20		175		360	835
Calcium	33.7	33.6	39.5	28.8		32.6	28.3
Chloride	6.3	5.8	6.5	6.4		7.0	7.2
Iron		0.10	0.16	0.72		0.68	0.19
Magnesium	8.80	8.90	9.59	10.16		11.70	11.09
Manganese	0.10	0.09	0.11	0.10	0.08	0.12	0.11
Nitrate	34.6	34.4	36.6	38.4		43.0	47.0
pH (-log[H+])		6.3		5.3	7.1	4.4	5.4
Sulfate	4.3	4.6	4.1	4.5		5.0	7.4
Zinc	0.58	0.52	0.68	0.62	0.38	0.85	0.67
Flow/week (mL)				152		182	318
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	1565	955	37	215			
Calcium	32.4	27.9	34.1	31.6			
Chloride	7.5	6.8	8.7	6.1			
Iron	0.14	0.05		0.25			
Magnesium	13.81	12.01	11.44	8.54			
Manganese	0.11	0.13	0.11	0.09			
Nitrate	43.3	49.2	52.4	27.6			
pH (-log[H+])	4.3	4.5	5.5	5.9			
Sulfate	6.8	4.3	4.8	6.4			
Zinc	0.79	0.70	0.38	0.56			
Flow/week (mL)	218	226	236	222			

3% loading without additions - Column M

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)		6	7	28	12		19
Calcium							16.0
Chloride		6.5	6.7	5.7	6.1	6.2	6.2
Iron				0.27	0.27		
Magnesium							2.70
Manganese		0.09	0.09	0.09	0.08	0.06	0.05
Nitrate		0.1	0.2	0.3	0.4	0.5	0.9
pH (-log[H+])		6.7	6.9			6.0	
Sulfate		28.8	24.9	24.0	22.8	21.5	19.6
Zinc		1.63	1.76	1.87	1.35	0.96	0.85
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	11	9	24	31	12	20	11
Calcium		4.1	9.1	95.9	15.4	20.2	10.6
Chloride	6.8	7.4	7.1	7.9	8.2	8.3	8.5
Iron							
Magnesium		1.20	2.60	5.90	2.80	2.80	3.10
Manganese	0.06	0.06	0.06		0.08	0.05	0.04
Nitrate	1.4	1.8	1.8	1.7	2.0	2.2	2.7
pH (-log[H+])	6.1				7.0	6.7	
Sulfate	18.0	17.1	17.7	16.7	16.2	15.3	11.1
Zinc	0.66	0.82	0.74	0.39	0.54	0.31	0.46
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	29	24		18		164	29
Calcium	22.7	9.7	23.7	9.0		9.5	13.3
Chloride	9.0	8.5	8.6	8.0		9.4	9.6
Iron						0.07	
Magnesium	3.20	3.00	6.16	3.70		4.62	3.39
Manganese				0.05			0.04
Nitrate	2.9	3.2	3.0	3.7		3.9	4.3
pH (-log[H+])		6.6		6.1	7.2	6.0	6.8
Sulfate	13.9	13.5	11.7	11.5		11.1	11.4
Zinc	0.24	0.34	0.18	0.29	0.24	0.32	0.28
Flow/week (mL)				170		216	255
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	22	32	14	26			
Calcium	6.3	6.9	35.3	18.1			
Chloride	9.6	9.2	9.5	7.9			
Iron				0.20			
Magnesium	3.60	3.08	3.39	3.45			
Manganese	0.04	0.03	0.02	0.06			
Nitrate	4.3	4.6	4.2	2.3			
pH (-log[H+])	6.0	6.1	6.3	6.5			
Sulfate	11.4	11.6	12.0	16.4			
Zinc	0.28	0.06	0.10	0.64			
Flow/week (mL)	238	290	226	233			

Control column with topsoil - Column N

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)							24
Calcium						17.2	9.4
Chloride						3.6	3.3
Iron						0.62	0.08
Magnesium						1.50	1.50
Manganese						0.09	0.06
Nitrate						0.0	0.8
Nitrite							
pH (-log[H+])						6.1	
Sulfate						18.6	16.3
Zinc						1.73	0.58
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	11	8	17	15	12	18	7
Calcium		9.9	17.4	43.2	51.1	28.1	29.1
Chloride	3.7	4.1	4.2	4.3	4.3	4.8	5.1
Iron					0.03	0.03	
Magnesium		1.50	1.90	1.80	3.10	2.90	4.10
Manganese	0.05	0.06	0.07	0.09	0.09	0.09	0.08
Nitrate	3.0	5.2	7.9	8.8	11.8	14.7	20.2
Nitrite				0.20		0.70	
pH (-log[H+])	6.2				7.2	6.9	
Sulfate	13.2	11.0	9.1	8.1	7.1	6.5	5.1
Zinc	0.32	0.32	0.34	0.30	0.17	0.16	0.14
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	18	13		7		22	8
Calcium	30.0	38.2	46.2	31.4		41.5	35.6
Chloride	3.9	4.4	4.0	3.9		4.1	5.4
Iron						0.04	
Magnesium	4.10	4.50	8.23	6.07		7.52	7.04
Manganese	0.08	0.09	0.08	0.09	0.07	0.11	0.09
Nitrate	22.2	25.1	27.1	27.6		37.6	42.8
Nitrite		0.03	0.03				0.28
pH (-log[H+])		6.8		6.5	7.0	5.8	6.8
Sulfate	5.8	5.6	4.5	4.9		5.4	4.3
Zinc	0.16	0.15	0.14	0.16	0.18	0.28	0.19
Flow/week (mL)				182		182	262
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	5	4	8	12			
Calcium	49.4	35.9	67.6	34.2			
Chloride	6.7	4.9	6.3	4.5			
Iron				0.16			
Magnesium	9.02	7.00	7.48	4.66			
Manganese	0.08	0.09	0.10	0.08			
Nitrate	43.7	53.9	55.6	22.7			
Nitrite	0.54			0.30			
pH (-log[H+])	6.0	6.0	6.2	6.5			
Sulfate	4.7	6.1	5.0	7.9			
Zinc	0.19	0.21	0.12	0.31			
Flow/week (mL)	120	267	189	200			

3% loading with nutrients - Column 0

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)							17
Calcium						16.4	6.1
Chloride						5.9	5.4
Iron						0.08	
Magnesium						1.30	1.50
Manganese						0.06	
Nitrate						1.1	2.7
pH (-log[H+])						6.2	
Sulfate						10.0	7.6
Zinc						0.50	0.28
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	12	9	49	28	56	48	602
Calcium		5.5	7.5	23.4	27.3	16.3	18.0
Chloride	6.2	6.0	5.5	5.9	5.6	5.6	5.2
Iron			0.04		0.03		0.16
Magnesium		1.80	2.80	3.30	3.40	5.30	7.70
Manganese					0.08	0.09	0.08
Nitrate	4.6	7.0	11.2	12.6	17.8	20.3	26.4
pH (-log[H+])	6.3				7.2	6.8	
Sulfate	6.9	5.8	4.8	4.1	3.3	3.4	3.1
Zinc	0.09	0.15	0.16	0.11	0.16	0.20	0.24
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	37	290		17		1220	10
Calcium	24.2	22.8	32.3	25.3		26.2	25.1
Chloride	6.0	5.7	5.8	5.3		7.2	6.4
Iron	0.03	0.15		0.30	0.20	0.13	0.95
Magnesium	9.70	10.30	12.10	11.35		13.73	16.72
Manganese	0.09	0.11	0.08	0.11	0.13	0.10	0.18
Nitrate	32.6	33.6	35.2	39.5		45.7	61.1
pH (-log[H+])		5.1		6.3	6.6	4.2	5.1
Sulfate	2.9	3.5	3.1	3.3		6.3	7.5
Zinc	0.21	0.26	0.20	0.28	0.36	0.26	0.34
Flow/week (mL)				206		160	260
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)		2860	1880	476			
Calcium	31.6	25.7	60.8	23.2			
Chloride	7.4	6.3	5.2	5.9			
Iron	1.54	1.21	0.09	0.38			
Magnesium	18.48	19.40	18.39	9.25			
Manganese	0.17	0.18	0.16	0.11			
Nitrate	62.2	66.0	52.1	29.5			
pH (-log[H+])	4.2	4.0	4.8	5.6			
Sulfate	8.3	3.6	2.3	5.0			
Zinc	0.31	0.26	0.36	0.25			
Flow/week (mL)	248	180	228	214			

0% loading with nutrients - Column P*

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)							8
Calcium						31.0	13.8
Chloride						5.5	5.5
Iron						0.07	
Magnesium						3.80	3.00
Manganese						0.21	0.05
Nitrate						0.0	0.2
pH (-log[H+])						6.1	
Sulfate						16.5	13.9
Zinc						2.94	1.43
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	7	7	12	11	10	8	10
Calcium		12.5	11.2	12.3	14.3	5.5	12.5
Chloride	5.3	8.1	5.3	5.2	5.1	5.2	5.0
Iron							0.03
Magnesium		2.60	2.90	2.60	3.00	1.30	2.90
Manganese	0.13	0.17	0.15	0.14	0.14	0.15	0.10
Nitrate	0.4	0.5	0.6	0.5	0.6	0.7	0.9
pH (-log[H+])	6.2				7.2	6.9	
Sulfate	12.9	13.7	12.7	12.5	12.0	11.9	9.3
Zinc	2.05	1.60	1.13	0.97	0.72	0.76	0.61
Flow/week (mL)							
WEEKS=>	15	16	17 *	18	19	20	22
Aluminum (ppb)	12	34		7		28	
Calcium	9.2	12.3	15.0	12.3		17.2	13.0
Chloride	4.4	4.8	4.2	4.6		4.5	4.2
Iron							
Magnesium	2.60	2.70	8.40	4.62		6.56	5.59
Manganese	0.06	0.13	0.12	0.15		0.11	
Nitrate	1.9	2.7	4.2	6.6		6.8	9.4
pH (-log[H+])		6.4		6.4	7.4	6.3	7.2
Sulfate	9.8	9.5	8.1	7.5		7.5	7.2
Zinc	0.60	0.66	0.71	1.05	0.78	0.61	0.34
Flow/week (mL)				280		120	110
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	76	33	13	18			
Calcium	17.6	13.0	39.4	15.4			
Chloride	5.1	4.9	4.9	5.1			
Iron	0.04		0.03	0.04			
Magnesium	6.55	6.12	5.32	4.15			
Manganese	0.08	0.08	0.01	0.12			
Nitrate	10.9	11.4	11.2	3.9			
pH (-log[H+])	6.4	6.2	6.0	6.6			
Sulfate	6.5	6.6	6.7	10.3			
Zinc	0.49	0.38	0.26	0.95			
Flow/week (mL)	92	82	178	144			

1% loading with nutrients - Column Q

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)							9
Calcium						60.7	47.2
Chloride						5.2	5.2
Iron						0.12	
Magnesium						3.30	5.60
Manganese						0.14	0.09
Nitrate						4.8	19.2
Nitrite							
pH (-log[H+])						6.6	
Sulfate						20.0	15.3
Zinc						0.62	0.43
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	22	10	20	25	16	18	12
Calcium		33.0	35.3	46.4	46.7	46.6	53.1
Chloride	5.1	5.2	6.1	5.6	5.0	6.0	5.8
Iron	0.04				0.04		
Magnesium		7.90	10.10	12.60	14.20	16.70	
Manganese	0.10	0.08	0.11	0.17	0.17	0.20	0.17
Nitrate	21.6	24.9	29.2	43.0	47.8	50.3	58.9
Nitrite	0.20	0.30	0.10	0.60	0.14	0.16	
pH (-log[H+])	6.8				7.2	6.6	
Sulfate	13.3	11.4	7.4	8.6	8.1	7.3	6.3
Zinc	0.32	0.34	0.25	0.30	0.31	0.74	0.49
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	35	34		25		682	918
Calcium	53.9	63.9	74.9	55.4		84.6	55.0
Chloride	4.9	4.8	4.6	5.2		5.3	7.2
Iron				0.03		0.47	0.63
Magnesium	21.70	18.35	23.89	27.76		31.50	29.57
Manganese	0.23	0.22	0.25	0.36	0.31	0.30	0.32
Nitrate	67.5	73.1	76.6	80.7		95.8	95.1
Nitrite	0.01		0.03				
pH (-log[H+])		6.6		6.5	7.2	4.6	5.4
Sulfate	7.6	7.3	6.2	7.1		9.8	8.4
Zinc	0.43	0.38	0.33	0.59	0.54	0.80	0.89
Flow/week (mL)				220		184	238
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	1520	1380	1195	370			
Calcium	86.9	50.9	98.9	58.4			
Chloride	5.3	5.2	6.5	5.5			
Iron	0.14	0.37	0.60	0.27			
Magnesium	41.62	37.93	30.58	20.83			
Manganese	0.34	0.35	0.28	0.22			
Nitrate	91.6	103.8	114.2	61.0			
Nitrite				0.19			
pH (-log[H+])	4.5	4.4	4.6	5.9			
Sulfate	7.3	9.1	7.0	9.3			
Zinc	1.04	0.56	0.84	0.54			
Flow/week (mL)	178	183	120	187			

0% loading with lime and nutrients - Column R

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)							9
Calcium						41.9	42.2
Chloride						5.2	
Iron						0.10	
Magnesium						1.90	4.60
Manganese							0.03
Nitrate						2.0	
Nitrite							
pH (-log[H+])						7.2	
Sulfate						15.9	
Zinc						0.10	0.52
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	10	11	18	18	16	18	16
Calcium		46.9	49.3	59.7	58.8	51.2	65.6
Chloride	5.5	5.4	5.3	6.0	6.4	6.8	6.6
Iron							
Magnesium		10.00	12.40	14.20	15.50	15.40	
Manganese				0.05	0.05	0.07	0.05
Nitrate	28.3	34.9	39.2	48.1	49.6	46.0	51.3
Nitrite	0.20	0.10	0.20	0.20	0.62	0.48	
pH (-log[H+])	7.2				7.5	7.0	
Sulfate	10.0	8.4	6.9	6.3	5.7	4.8	4.0
Zinc	0.06	0.06	0.06	0.07	0.05	0.05	0.04
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	24	20		15		25	43
Calcium	55.3	60.6	65.2	54.3		56.6	38.5
Chloride	5.9	5.5	6.2	6.8		4.9	6.3
Iron							
Magnesium	18.30	12.06	16.98	18.35		21.91	19.54
Manganese	0.06	0.08	0.09	0.10	0.09	0.09	0.10
Nitrate	50.4	54.7	60.6	53.6		58.4	66.1
Nitrite							
pH (-log[H+])		7.5		7.9	7.6	6.6	8.1
Sulfate	4.9	4.4	4.6	5.5		5.0	4.5
Zinc	0.04	0.04	0.05	0.06	0.05	0.08	0.06
Flow/week (mL)				206		200	200
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	48	19	15	20			
Calcium	73.1	62.7	93.5	57.4			
Chloride	5.3	4.9	6.5	5.9			
Iron				0.10			
Magnesium	27.28	23.63	25.87	16.12			
Manganese	0.11	0.10	0.13	0.08			
Nitrate	64.8	67.3	81.6	50.4			
Nitrite				0.30			
pH (-log[H+])	6.9	7.0	6.8	7.3			
Sulfate	3.9	5.6	3.7	6.1			
Zinc	0.07	0.03	0.05	0.08			
Flow/week (mL)	172	200	232	202			

2% loading with PAC, lime and nutrients - Column S*

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)							10
Calcium						35.2	22.3
Chloride						9.6	
Iron							
Magnesium						3.10	2.40
Manganese						0.22	0.22
Nitrate						1.7	
pH (-log[H+])						6.9	
Sulfate						16.8	
Zinc						2.59	0.98
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	6	4	6	11	5	7	7
Calcium		12.6	9.9	13.2	11.4	9.8	12.8
Chloride	9.5	9.6	9.1	10.0	10.8	9.3	9.3
Iron							
Magnesium		2.30	2.20	2.30	2.40	2.30	3.20
Manganese	0.18	0.18	0.17	0.16	0.16	0.18	0.14
Nitrate	2.3	5.2	2.4	1.9	1.9	2.0	1.8
pH (-log[H+])	6.9				7.1	7.1	
Sulfate	11.6	11.7	11.8	12.2	12.5	12.0	9.7
Zinc	3.38	2.72	2.58	1.68	1.41	1.95	1.04
Flow/week (mL)							
WEEKS=>	15	16	17 *	18	19	20	22
Aluminum (ppb)				7		15	9
Calcium		12.6	14.9	8.5		8.8	4.8
Chloride		9.5	9.2	7.6		9.0	8.4
Iron							
Magnesium		2.90	1.72	3.21		3.83	3.04
Manganese		0.09	0.16	0.14	0.11	0.11	0.13
Nitrate		1.8	1.8	2.0		2.1	2.9
pH (-log[H+])				7.0	7.5	6.8	7.7
Sulfate		13.1	11.0	9.8		10.4	10.0
Zinc		0.93	0.66	0.61	0.51	0.44	0.53
Flow/week (mL)				114		180	70
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	10	14	7	8			
Calcium	6.8	3.0	36.7	14.0			
Chloride	7.5	8.3	8.8	9.1			
Iron				NA			
Magnesium	3.34	2.64	3.52	2.77			
Manganese	0.11	0.12	0.12	0.15			
Nitrate	2.3	3.0	3.6	2.4			
pH (-log[H+])	6.8	6.8	6.5	7.0			
Sulfate	9.0	12.7	8.8	11.4			
Zinc	0.44	0.33	0.36	1.28			
Flow/week (mL)	98	72	110	107			

1% loading with lime and nutrients - Column T

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)							8
Calcium						39.5	22.8
Chloride						5.9	
Iron							
Magnesium						2.40	2.70
Manganese						0.18	0.12
Nitrate						0.1	
Nitrite							
pH (-log[H+])						6.7	
Sulfate						22.4	
Zinc						0.57	1.28
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	7	7	7	30	31	10	17
Calcium		23.6	27.7	58.3	72.9	63.8	85.6
Chloride	7.4	5.3	5.1	4.8	5.5	6.4	7.0
Iron							
Magnesium		3.90	4.50	6.10	7.90	8.90	
Manganese	0.14	0.15	0.18	0.24	0.25	0.28	0.26
Nitrate	10.5	12.3	15.1	29.9	35.4	42.5	52.8
Nitrite						0.93	
pH (-log[H+])	6.8				7.0	6.8	
Sulfate	15.6	14.9	14.3	9.1	8.8	9.4	6.0
Zinc	1.12	1.07	1.05	1.42	1.54	1.53	1.58
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	21	34		32		20	10
Calcium	101.0	88.6	101.8	93.8		63.6	57.0
Chloride	9.6	6.6	5.2	6.3		5.2	8.4
Iron				0.03	0.03		
Magnesium	11.20	11.40	10.52	12.45		16.76	13.64
Manganese	0.31	0.30	0.32	0.37	0.21	0.24	0.28
Nitrate	46.2	50.1	51.2	54.9		65.7	71.5
Nitrite	0.02	0.02		0.09		0.02	0.55
pH (-log[H+])		7.2		7.1	7.0	6.6	7.0
Sulfate	11.2	8.6	8.5	8.8		9.9	8.3
Zinc	4.08	2.44	3.38	3.21	1.73	0.78	0.90
Flow/week (mL)				182		208	228
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	12	12	17	17			
Calcium	91.7	50.7	104.3	67.5			
Chloride	5.7	8.2	6.8	6.4			
Iron				0.03			
Magnesium	17.55	10.87	11.79	9.54			
Manganese	0.26	0.28	0.15	0.24			
Nitrate	58.5	62.1	52.4	41.8			
Nitrite	0.05	0.38		0.26			
pH (-log[H+])	6.2	6.6	6.5	6.8			
Sulfate	7.7	9.4	10.8	10.8			
Zinc	0.89	0.40	0.47	1.55			
Flow/week (mL)	194	216	262	215			

3% loading with lime and nutrients - Column U

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)							10
Calcium						22.7	18.4
Chloride						8.3	
Iron							
Magnesium						3.30	4.70
Manganese							0.06
Nitrate						1.0	
Nitrite							
pH (-log[H+])						6.8	
Sulfate						24.4	
Zinc						0.32	0.22
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	10	6	17	26	13	10	11
Calcium		20.0	31.2	32.8	31.8	30.8	40.3
Chloride	8.2	7.9	7.4	7.3	7.8	6.9	8.0
Iron							0.11
Magnesium		6.10	7.60	6.90	8.40	8.90	12.50
Manganese	0.06	0.06			0.06	0.07	0.09
Nitrate	15.1	19.5	25.4	24.9	29.2	30.1	35.6
Nitrite	0.10	0.60	0.30	0.20	0.28	0.23	
pH (-log[H+])	6.6				7.0	6.9	
Sulfate	15.8	13.3	11.2	11.5	12.4	9.0	6.7
Zinc	0.33	0.27	0.04	0.20	0.20	0.21	0.34
Flow/week (mL)							
WEEKS=>	15	16	17*	18	19	20	22
Aluminum (ppb)	24	24		37			
Calcium	44.4	56.3	68.6	52.2			
Chloride	10.7	6.0	6.2	6.8			
Iron				0.12			
Magnesium	14.70	13.86	11.62	15.58			
Manganese	0.07		0.06	0.08	0.10		
Nitrate	44.0	44.7	45.8	46.8			
Nitrite	0.30	0.02	0.02	0.04			
pH (-log[H+])		7.8		7.7	7.2		
Sulfate	10.7	7.0	7.1	7.5			
Zinc	0.21	0.08	0.13	0.19	0.22		
Flow/week (mL)				256			
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	284		15	37			
Calcium	98.4		45.3	42.4			
Chloride	8.4		9.3	7.8			
Iron	0.24			0.16			
Magnesium	22.17		11.40	10.55			
Manganese	0.14		0.02	0.07			
Nitrate	33.4		28.9	30.3			
Nitrite	0.52		0.55	0.26			
pH (-log[H+])	7.7		7.0	7.2			
Sulfate	10.2		16.2	11.6			
Zinc	0.46		0.02	0.21			
Flow/week (mL)	14		26	99			

2% loading with PAC, lime and nutrients - Column V

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)							13
Calcium						9.6	9.1
Chloride						8.1	
Iron							0.03
Magnesium						2.50	2.60
Manganese						0.08	0.06
Nitrate						0.3	
pH (-log[H+])						6.8	
Sulfate						26.8	
Zinc						0.83	0.19
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	5	4	10	11	5	25	34
Calcium		11.9	14.2	26.5	23.2	22.5	31.1
Chloride	6.8	6.9	7.1	9.2	7.8	7.3	6.7
Iron					0.21	1.20	1.17
Magnesium		3.70	4.90	5.50	6.60	7.20	9.60
Manganese	0.06	0.06	0.07	0.09	0.12	0.16	0.12
Nitrate	6.4	9.6	15.7	19.8	22.0	28.3	31.1
pH (-log[H+])	6.6				4.4	6.5	
Sulfate	19.6	17.1	14.3	17.6	12.1	12.2	8.8
Zinc	0.16	0.35	0.30	0.29	0.31	0.40	0.36
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	40	37		47		101	24
Calcium	33.3	29.1	29.5	23.6		23.9	17.2
Chloride	6.4	6.3	5.9	6.2		6.3	7.1
Iron	0.78	0.67	0.84	1.00	0.95	0.96	0.48
Magnesium	9.70	9.00	6.91	9.28		9.15	7.70
Manganese	0.12	0.10	0.12	0.12	0.11	0.13	0.11
Nitrate	36.8	30.1	29.4	28.6		23.2	23.5
pH (-log[H+])		5.2		5.2	4.8	5.0	6.4
Sulfate	5.7	10.8	13.1	13.2		14.3	14.2
Zinc	0.41	0.28	0.28	0.31	0.32	0.35	0.25
Flow/week (mL)				110		90	102
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	87	16	8	29			
Calcium	23.4	34.8	27.9	23.0			
Chloride	6.8	5.9	7.3	7.0			
Iron	0.10	0.18		0.66			
Magnesium	9.28	8.23	7.70	7.03			
Manganese	0.11	0.12	0.12	0.10			
Nitrate	23.3	25.6	25.8	22.3			
pH (-log[H+])	6.9	6.4	6.5	5.9			
Sulfate	14.4	14.8	15.4	14.4			
Zinc	0.25	0.31	0.20	0.32			
Flow/week (mL)	82	93	64	90			

4% loading with nutrients - Column X

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)							25
Calcium						17.4	8.4
Chloride						8.7	
Iron							
Magnesium						2.20	2.10
Manganese						0.08	0.08
Nitrate						4.8	
pH (-log[H+])						6.7	
Sulfate						15.1	
Zinc						0.47	0.34
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	125	315	467	172	86	25	768
Calcium		10.6	13.6	31.2	45.9	20.9	22.5
Chloride	6.3	6.1	6.1	10.4	7.9	7.0	5.9
Iron	0.06		0.16				0.18
Magnesium		2.90	4.00	5.30	5.60	6.70	7.20
Manganese	0.09	0.09	0.20	0.07	0.09	0.11	0.12
Nitrate	9.6	11.9	17.8	21.7	19.1	23.7	24.2
pH (-log[H+])	5.5				6.3	6.5	
Sulfate	9.5	9.4	10.4	10.8	7.3	6.4	5.5
Zinc	0.24	0.50	0.52	0.30	0.37	0.41	0.50
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	30	268		1060		5020	1380
Calcium	33.7	30.6	34.5	23.8		27.6	21.6
Chloride	15.8	6.0	6.0	6.5		6.6	6.2
Iron		0.06	0.28	0.08	0.40	0.10	0.29
Magnesium	10.30	8.60	8.32	8.80		12.72	10.82
Manganese	0.17	0.14	0.21	0.20	0.21	0.20	0.21
Nitrate	32.7	33.2	36.5	36.4		45.4	49.6
pH (-log[H+])		5.0		4.3	4.3	4.5	4.9
Sulfate	8.0	6.1	9.1	9.2		6.5	10.6
Zinc	0.46	0.41	0.56	0.65	0.67	0.82	0.65
Flow/week (mL)				132		156	240
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	1510	1078	1055	837			
Calcium	38.1	18.3	42.1	25.9			
Chloride	6.4	5.5	6.7	7.3			
Iron	0.39	0.15	0.34	0.21			
Magnesium	14.69	9.11	12.89	7.78			
Manganese	0.22	0.21	0.20	0.15			
Nitrate	48.2	53.0	59.1	31.0			
pH (-log[H+])	4.1	4.7	4.9	5.1			
Sulfate	7.7	4.6	5.3	8.3			
Zinc	0.64	0.59	0.56	0.51			
Flow/week (mL)	236	226	185	196			

3% loading without additions - Column Z

WEEKS=>	1	2	3	4	5	6	7
Aluminum (ppb)							80
Calcium						28.7	23.3
Chloride						7.6	
Iron							
Magnesium						1.60	1.20
Manganese						0.09	0.06
Nitrate						0.6	
pH (-log[H+])						6.9	
Sulfate						17.7	
Zinc						0.37	0.23
Flow/week (mL)							
WEEKS=>	8	9	10	11	12	13	14
Aluminum (ppb)	24	9	27	25	9	22	40
Calcium		6.9	22.2	35.7	26.9	23.1	26.7
Chloride	6.6	7.5	6.8	7.2	7.1	6.7	6.7
Iron							
Magnesium		1.30	2.20	1.50	1.40	1.80	1.90
Manganese	0.07	0.07				0.05	
Nitrate	1.8	2.3	1.9	2.6	3.1	3.6	4.4
pH (-log[H+])	6.1				6.7	6.9	
Sulfate	12.7	13.0	11.2	9.4	9.2	8.3	6.3
Zinc	0.21	0.56	0.16	0.03	0.04	0.10	0.05
Flow/week (mL)							
WEEKS=>	15	16	17	18	19	20	22
Aluminum (ppb)	24	41		50		37	27
Calcium	25.2	24.3	24.3	14.1		20.3	10.6
Chloride	7.5	6.6	6.3	6.9		6.5	6.9
Iron				0.11	0.06		
Magnesium	2.40	1.40	1.01	2.73		4.09	2.90
Manganese				0.06	0.06		
Nitrate	5.0	5.3	5.5	5.9		5.8	7.4
pH (-log[H+])		7.2		6.7	7.0	6.3	7.8
Sulfate	8.4	7.2	8.0	8.3		9.0	6.8
Zinc	0.06	0.03	0.10	0.27	0.14	0.07	0.17
Flow/week (mL)				210		196	220
WEEKS=>	24	26	28	Mean			
Aluminum (ppb)	52	15	51	33			
Calcium	19.2	15.0	23.7	21.8			
Chloride	6.3	6.4	6.2	6.8			
Iron				0.09			
Magnesium	4.26	3.39	2.82	2.23			
Manganese		0.02	0.03	0.06			
Nitrate	7.8	8.8	8.6	4.7			
pH (-log[H+])	7.0	7.2	6.7	6.9			
Sulfate	6.5	5.9	6.7	9.1			
Zinc	0.09	0.03		0.15			
Flow/week (mL)	225	238	200	215			

APPENDIX C

Soil Profile Data

Reported in mg/L unless noted

Control columns without topsoil

Depths (inches)	Columns=> Aluminum	F	G
0 - 4			
8 - 12		37920	21610
16 - 20		39170	31710
24 - 28		39035	39165
	Boron		
0 - 4			
8 - 12		29.9	19.1
16 - 20		35.6	33.4
24 - 28		40.8	26.2
	Calcium		
0 - 4			
8 - 12		1979	931
16 - 20		3485	2590
24 - 28		3235	2152
	Cadmium (ppb)		
0 - 4			
8 - 12		40.0	70.0
16 - 20		55.0	40.0
24 - 28		55.0	70.0
	Chromium		
0 - 4			
8 - 12		41.5	20.0
16 - 20		27.5	22.0
24 - 28		44.0	26.5
	Copper		
0 - 4			
8 - 12		8.3	7.0
16 - 20		8.5	7.9
24 - 28		7.1	7.5
	Iron		
0 - 4			
8 - 12		16130	8380
16 - 20		31995	23270
24 - 28		29835	12585
	Magnesium		
0 - 4			
8 - 12		1673	972
16 - 20		1664	1391
24 - 28		1661	1732
	Manganese		
0 - 4			
8 - 12		34.1	80.3
16 - 20		32.8	39.5
24 - 28		26.5	29.6
	pH (-log[H+])		
0 - 4			
8 - 12		4.9	4.7
16 - 20		5.0	4.7
24 - 28		4.8	4.8
	Zinc		
0 - 4			
8 - 12		31.3	25.4
16 - 20		39.6	30.5
24 - 28		33.1	27.8

Control columns with topsoil

Depths (inches)	Columns=>	A	N
0 - 4	Aluminum	9955	11560
8 - 12		43120	22615
16 - 20		24730	39775
24 - 28		38020	38390
	Boron		
0 - 4		15.3	11.9
8 - 12		28.6	15.1
16 - 20		27.2	36.3
24 - 28		25.5	23.4
	Calcium		
0 - 4		727	525
8 - 12		2548	1055
16 - 20		2358	4885
24 - 28		1539	2558
	Cadmium (ppb)		
0 - 4		105.0	100.0
8 - 12		50.0	23.0
16 - 20		230.0	25.0
24 - 28		50.0	18.0
	Chromium		
0 - 4		18.5	16.0
8 - 12		35.0	23.0
16 - 20		21.0	25.0
24 - 28		18.5	18.0
	Copper		
0 - 4		5.3	4.5
8 - 12		8.3	6.1
16 - 20		6.3	8.8
24 - 28		6.4	6.6
	Iron		
0 - 4		4099	4253
8 - 12		17940	7885
16 - 20		22745	41705
24 - 28		13325	17390
	Magnesium		
0 - 4		489	551
8 - 12		2103	1060
16 - 20		1073	1611
24 - 28		1603	1650
	Manganese		
0 - 4		85.3	61.5
8 - 12		38.4	58.2
16 - 20		29.5	37.5
24 - 28		33.7	40.5
	pH (-log[H+])		
0 - 4		4.2	3.6
8 - 12		4.6	4.3
16 - 20		4.3	4.6
24 - 28		4.1	4.9
	Zinc		
0 - 4		21.4	19.9
8 - 12		36.6	31.9
16 - 20		25.5	36.8
24 - 28		33.9	30.1

0% Loading with nutrients

Depths (inches)	Columns=>	C	P
0 - 4	Aluminum	16590	11065
8 - 12		30430	28410
16 - 20		30295	44060
24 - 28		44840	54800
	Boron		
0 - 4		19.7	9.6
8 - 12		25.6	24.6
16 - 20		32.0	42.5
24 - 28		34.1	31.6
	Calcium		
0 - 4		965	663
8 - 12		2006	1958
16 - 20		2699	5170
24 - 28		3019	3603
	Cadmium (ppb)		
0 - 4		80.0	115.0
8 - 12		40.0	25.0
16 - 20		65.0	35.0
24 - 28		55.0	15.0
	Chromium		
0 - 4		25.5	14.0
8 - 12		38.5	23.0
16 - 20		26.5	26.0
24 - 28		26.5	25.0
	Copper		
0 - 4		5.8	4.1
8 - 12		7.1	5.8
16 - 20		7.2	9.5
24 - 28		8.7	8.8
	Iron		
0 - 4		5765	4083
8 - 12		13390	17450
16 - 20		25775	45465
24 - 28		27375	23600
	Magnesium		
0 - 4		886	563
8 - 12		1481	1273
16 - 20		1327	1811
24 - 28		1906	2446
	Manganese		
0 - 4		60.0	66.2
8 - 12		49.1	67.6
16 - 20		44.0	33.2
24 - 28		32.5	38.5
	pH (-log[H+])		
0 - 4		5.0	5.2
8 - 12		4.7	5.4
16 - 20		4.9	5.2
24 - 28		4.4	5.1
	Zinc		
0 - 4		25.5	20.5
8 - 12		35.2	26.2
16 - 20		33.3	46.7
24 - 28		36.0	36.8

0% Loading with lime and nutrients

Depths (inches)	Columns=>	H	R
0 - 4	Aluminum	13695	11185
8 - 12		39850	38500
16 - 20		38610	35820
24 - 28		38650	38150
0 - 4	Boron	17.9	10.1
8 - 12		26.6	25.5
16 - 20		40.0	24.5
24 - 28		23.7	24.6
0 - 4	Calcium	970	717
8 - 12		2096	2915
16 - 20		4705	2648
24 - 28		1168	1548
0 - 4	Cadmium (ppb)	105.0	140.0
8 - 12		35.0	35.0
16 - 20		35.0	25.0
24 - 28		30.0	20.0
0 - 4	Chromium	21.0	15.5
8 - 12		28.0	23.0
16 - 20		27.0	20.0
24 - 28		24.0	14.0
0 - 4	Copper	5.2	5.1
8 - 12		7.5	6.6
16 - 20		8.8	6.0
24 - 28		5.8	5.6
0 - 4	Iron	4947	4260
8 - 12		16115	24010
16 - 20		42235	23700
24 - 28		12815	14760
0 - 4	Magnesium	736	586
8 - 12		1781	1655
16 - 20		1574	1535
24 - 28		1598	1664
0 - 4	Manganese	77.2	60.3
8 - 12		34.4	38.5
16 - 20		30.3	33.4
24 - 28		31.4	36.5
0 - 4	pH (-log[H+])	4.7	4.3
8 - 12		4.5	4.3
16 - 20		4.2	4.1
24 - 28		4.0	3.9
0 - 4	Zinc	27.3	23.6
8 - 12		31.6	34.8
16 - 20		36.0	33.7
24 - 28		25.4	27.3

1% Loading with nutrients

Depths (inches)	Columns=>	D	Q
0 - 4	Aluminum	12415	12225
8 - 12		38505	40690
16 - 20		44300	41850
24 - 28		39025	34655
	Boron		
0 - 4		16.4	12.4
8 - 12		33.8	22.7
16 - 20		36.3	21.3
24 - 28		27.2	18.6
	Calcium		
0 - 4		707	527
8 - 12		2907	1910
16 - 20		3058	2117
24 - 28		1560	1497
	Cadmium (ppb)		
0 - 4		140.0	80.0
8 - 12		35.0	25.0
16 - 20		60.0	20.0
24 - 28		50.0	0.0
	Chromium		
0 - 4		20.5	15.0
8 - 12		35.5	23.5
16 - 20		37.0	30.0
24 - 28		31.0	0.0
	Copper		
0 - 4		20.1	9.3
8 - 12		9.1	7.8
16 - 20		9.2	6.0
24 - 28		7.5	6.4
	Iron		
0 - 4		4456	4337
8 - 12		28150	16470
16 - 20		29295	13600
24 - 28		13920	10915
	Magnesium		
0 - 4		551	552
8 - 12		1612	1809
16 - 20		1856	1880
24 - 28		1709	1510
	Manganese		
0 - 4		127.6	66.6
8 - 12		39.3	54.4
16 - 20		36.0	39.6
24 - 28		31.8	36.9
	pH (-log[H+])		
0 - 4		5.3	4.1
8 - 12		4.6	4.5
16 - 20		4.3	4.5
24 - 28		4.3	4.3
	Zinc		
0 - 4		22.2	19.4
8 - 12		32.4	31.2
16 - 20		39.0	31.0
24 - 28		31.9	26.2

1% Loading with lime and nutrients

Depths (inches)	Columns=>	K	T
0 - 4	Aluminum	11960	12670
8 - 12		39165	41080
16 - 20		37365	44720
24 - 28		39695	43390
	Boron		
0 - 4		19.0	11.9
8 - 12		27.8	27.4
16 - 20		26.7	44.0
24 - 28		29.3	24.8
	Calcium		
0 - 4		1452	982
8 - 12		2498	3226
16 - 20		2047	6410
24 - 28		2129	2195
	Cadmium (ppb)		
0 - 4		170.0	160.0
8 - 12		40.0	20.0
16 - 20		35.0	15.0
24 - 28		60.0	65.0
	Chromium		
0 - 4		23.5	16.0
8 - 12		26.0	22.0
16 - 20		22.5	25.0
24 - 28		22.0	15.0
	Copper		
0 - 4		21.2	8.9
8 - 12		9.8	8.3
16 - 20		7.2	9.5
24 - 28		8.2	7.2
	Iron		
0 - 4		8580	4425
8 - 12		19775	26015
16 - 20		18420	51600
24 - 28		20830	16390
	Magnesium		
0 - 4		701	765
8 - 12		1773	1736
16 - 20		1627	1807
24 - 28		1641	1888
	Manganese		
0 - 4		132.8	81.6
8 - 12		35.7	50.7
16 - 20		32.6	34.6
24 - 28		31.8	42.3
	pH (-log[H+])		
0 - 4		6.1	5.7
8 - 12		4.4	4.5
16 - 20		4.1	4.6
24 - 28		3.9	4.7
	Zinc		
0 - 4		40.3	36.4
8 - 12		28.6	33.2
16 - 20		30.0	40.8
24 - 28		30.5	38.0

2% Loading with PAC, lime and nutrients

Depths (inches)	Columns=>	S	V
	Aluminum		
0 - 4		12860	12550
8 - 12		46400	41640
16 - 20		50750	41395
24 - 28		47810	46400
	Boron		
0 - 4		24.1	9.4
8 - 12		26.8	26.0
16 - 20		29.5	38.6
24 - 28		46.3	31.9
	Calcium		
0 - 4		1283	868
8 - 12		3129	2889
16 - 20		2928	5440
24 - 28		5045	3534
	Cadmium (ppb)		
0 - 4		210.0	535.0
8 - 12		45.0	20.0
16 - 20		20.0	15.0
24 - 28		20.0	430.0
	Chromium		
0 - 4		14.5	16.0
8 - 12		17.0	14.0
16 - 20		22.0	21.0
24 - 28		22.0	14.5
	Copper		
0 - 4		16.8	14.5
8 - 12		7.2	7.2
16 - 20		7.8	8.8
24 - 28		9.1	7.2
	Iron		
0 - 4		4427	4370
8 - 12		24205	22255
16 - 20		25540	45745
24 - 28		46385	29195
	Magnesium		
0 - 4		919	688
8 - 12		2055	1804
16 - 20		2119	1764
24 - 28		2055	2009
	Manganese		
0 - 4		118.2	112.6
8 - 12		38.3	40.7
16 - 20		36.2	36.6
24 - 28		35.9	40.3
	pH (-log[H+])		
0 - 4		6.1	5.1
8 - 12		4.8	4.7
16 - 20		4.5	4.8
24 - 28		4.5	4.7
	Zinc		
0 - 4		44.8	40.1
8 - 12		48.8	31.9
16 - 20		46.3	40.5
24 - 28		44.1	36.7

3% Loading no additions

Depths (inches)	Columns=>	M	Z
0 - 4	Aluminum	14285	14885
8 - 12		39080	41760
16 - 20		40910	42275
24 - 28		46435	42085
0 - 4	Boron	8.1	8.4
8 - 12		27.3	30.8
16 - 20		45.2	26.7
24 - 28		33.7	20.6
0 - 4	Calcium	724	736
8 - 12		3031	2746
16 - 20		5120	1511
24 - 28		2230	1103
0 - 4	Cadmium (ppb)	115.0	65.0
8 - 12		25.0	75.0
16 - 20		20.0	235.0
24 - 28		30.0	90.0
0 - 4	Chromium	18.5	17.0
8 - 12		33.0	36.0
16 - 20		34.0	22.5
24 - 28		20.0	17.0
0 - 4	Copper	37.0	20.3
8 - 12		8.5	7.5
16 - 20		8.1	5.7
24 - 28		6.6	5.4
0 - 4	Iron	4908	5115
8 - 12		25950	28300
16 - 20		47080	15650
24 - 28		21285	12285
0 - 4	Magnesium	502	632
8 - 12		1697	1685
16 - 20		1651	1773
24 - 28		2080	1686
0 - 4	Manganese	265.1	165.3
8 - 12		32.8	34.5
16 - 20		31.8	33.7
24 - 28		39.6	35.7
0 - 4	pH (-log[H+])	5.4	5.0
8 - 12		4.6	4.5
16 - 20		4.6	4.2
24 - 28		4.3	4.1
0 - 4	Zinc	19.5	24.3
8 - 12		34.0	31.1
16 - 20		38.2	29.4
24 - 28		32.1	27.9

3% Loading with nutrients

Depths (inches)	Columns=>	B	O
0 - 4	Aluminum	15520	14695
8 - 12		34020	38400
16 - 20		46040	42250
24 - 28		37120	59000
0 - 4	Boron	20.8	11.9
8 - 12		26.7	21.9
16 - 20		50.1	43.9
24 - 28		23.7	34.1
0 - 4	Calcium	1292	750
8 - 12		1677	1945
16 - 20		6420	5415
24 - 28		1136	2209
0 - 4	Cadmium (ppb)	135.0	120.0
8 - 12		45.0	50.0
16 - 20		70.0	50.0
24 - 28		120.0	30.0
0 - 4	Chromium	24.0	19.0
8 - 12		35.0	31.0
16 - 20		34.5	32.5
24 - 28		20.5	20.5
0 - 4	Copper	45.0	28.9
8 - 12		7.2	8.2
16 - 20		10.8	9.1
24 - 28		8.3	8.1
0 - 4	Iron	9320	4604
8 - 12		14490	15930
16 - 20		53150	51450
24 - 28		12800	22140
0 - 4	Magnesium	526	594
8 - 12		1531	1760
16 - 20		1770	1674
24 - 28		1508	2586
0 - 4	Manganese	254.2	121.8
8 - 12		40.3	57.6
16 - 20		28.6	34.3
24 - 28		33.2	40.9
0 - 4	pH (-log[H+])	5.4	5.0
8 - 12		4.6	4.6
16 - 20		4.4	4.1
24 - 28		4.1	4.0
0 - 4	Zinc	26.6	24.8
8 - 12		30.2	38.5
16 - 20		42.5	40.0
24 - 28		26.8	41.4

3% Loading with lime and nutrients

Depths (inches)	Columns=>	J	U
0 - 4	Aluminum	14275	14095
8 - 12		21785	38420
16 - 20		35185	48270
24 - 28		36335	47720
	Boron		
0 - 4		17.4	10.8
8 - 12		20.1	21.1
16 - 20		37.6	38.1
24 - 28		28.7	25.2
	Calcium		
0 - 4		1074	997
8 - 12		1307	2390
16 - 20		4371	4933
24 - 28		2264	2081
	Cadmium (ppb)		
0 - 4		100.0	105.0
8 - 12		35.0	50.0
16 - 20		60.0	60.0
24 - 28		140.0	30.0
	Chromium		
0 - 4		23.0	15.0
8 - 12		17.0	18.0
16 - 20		25.0	21.0
24 - 28		19.0	14.0
	Copper		
0 - 4		41.6	10.8
8 - 12		6.6	7.9
16 - 20		9.7	9.5
24 - 28		6.8	7.1
	Iron		
0 - 4		4541	5285
8 - 12		11145	20105
16 - 20		38965	42575
24 - 28		17560	18235
	Magnesium		
0 - 4		630	785
8 - 12		1038	1685
16 - 20		1439	2005
24 - 28		1604	2108
	Manganese		
0 - 4		235.2	144.0
8 - 12		67.2	50.7
16 - 20		32.1	36.8
24 - 28		30.3	42.8
	pH (-log[H+])		
0 - 4		6.0	6.0
8 - 12		5.6	4.7
16 - 20		4.8	4.3
24 - 28		4.5	4.3
	Zinc		
0 - 4		28.4	25.9
8 - 12		23.2	33.8
16 - 20		34.8	50.2
24 - 28		27.8	34.8

4% Loading with nutrients

Depths (inches)	Columns=>	ZZ	X
	Aluminum		
0 - 4		15770	16265
8 - 12		35260	34845
16 - 20		36790	39305
24 - 28		40895	39505
	Boron		
0 - 4		17.8	9.4
8 - 12		24.6	18.5
16 - 20		43.8	40.6
24 - 28		26.4	21.6
	Calcium		
0 - 4		986	831
8 - 12		1855	1775
16 - 20		5735	4519
24 - 28		1806	1254
	Cadmium (ppb)		
0 - 4		22.0	100.0
8 - 12		24.0	85.0
16 - 20		24.5	55.0
24 - 28		20.0	45.0
	Chromium		
0 - 4		22.0	13.0
8 - 12		24.0	13.0
16 - 20		24.5	17.0
24 - 28		20.0	17.5
	Copper		
0 - 4		52.2	31.2
8 - 12		7.8	6.1
16 - 20		9.5	8.5
24 - 28		6.0	5.4
	Iron		
0 - 4		5055	5090
8 - 12		14790	15155
16 - 20		50500	46080
24 - 28		15410	13270
	Magnesium		
0 - 4		550	665
8 - 12		1592	1517
16 - 20		1433	1564
24 - 28		1700	1677
	Manganese		
0 - 4		279.9	189.4
8 - 12		52.4	57.6
16 - 20		32.8	35.7
24 - 28		34.6	37.1
	pH (-log[H+])		
0 - 4		5.6	5.4
8 - 12		4.4	4.6
16 - 20		4.3	4.2
24 - 28		4.1	4.1
	Zinc		
0 - 4		21.5	24.3
8 - 12		31.3	28.3
16 - 20		42.9	36.0
24 - 28		28.9	29.4

APPENDIX D

Soil Profile Mean and Standard Deviations

Reported in mg/L unless noted

Mean +/- standard deviation = hi/low value

Depths (inches)	Columns=>	A,N Top & A,N,F,G	Below		
	Aluminum	mean	std.dev.	low value	hi value
0 - 4		10758	1135	9623	11892
8 - 12		31316	10845	20471	42162
16 - 20		33846	7098	26748	40945
24 - 28		38653	541	38112	39193
	Boron				
0 - 4		13.6	2.4	11.2	16.0
8 - 12		23.2	7.2	16.0	30.4
16 - 20		33.1	4.2	28.9	37.3
24 - 28		29.0	8.0	21.0	36.9
	Calcium				
0 - 4		626	143	483	769
8 - 12		1628	771	857	2399
16 - 20		3329	1145	2184	4474
24 - 28		2371	712	1658	3083
	Cadmium (ppb)				
0 - 4		102.5	3.5	99.0	106.0
8 - 12		45.8	19.6	26.1	65.4
16 - 20		87.5	95.8	-8.3	183.3
24 - 28		48.3	21.9	26.4	70.1
	Chromium				
0 - 4		17.3	1.8	15.5	19.0
8 - 12		29.9	10.1	19.8	40.0
16 - 20		23.9	3.0	20.9	26.8
24 - 28		26.8	12.1	14.6	38.9
	Copper				
0 - 4		4.9	0.5	4.3	5.4
8 - 12		7.4	1.1	6.3	8.5
16 - 20		7.9	1.1	6.8	9.0
24 - 28		6.9	0.5	6.4	7.4
	Iron				
0 - 4		4176	109	4067	4285
8 - 12		12584	5197	7387	17780
16 - 20		29929	8924	21005	38852
24 - 28		18284	7985	10298	26269
	Magnesium				
0 - 4		520	44	477	564
8 - 12		1452	534	918	1986
16 - 20		1434	268	1166	1703
24 - 28		1661	54	1608	1715
	Manganese				
0 - 4		73.4	16.8	56.6	90.2
8 - 12		52.7	21.2	31.6	73.9
16 - 20		34.8	4.5	30.3	39.4
24 - 28		32.6	6.1	26.5	38.6
	pH (-log[H+])				
0 - 4		3.8	1.0	2.8	4.8
8 - 12		4.6	1.0	3.6	5.6
16 - 20		4.6	1.0	3.6	5.6
24 - 28		4.5	1.0	3.5	5.5
	Zinc				
0 - 4		20.7	1.1	19.6	21.7
8 - 12		31.3	4.6	26.7	35.9
16 - 20		33.1	6.3	26.8	39.4
24 - 28		31.2	2.8	28.4	34.0

Mean +/- standard deviation = hi/low value

Depths (inches)	Columns=>	All Controls & 0% w/ nutrient			
	Aluminum	mean	std.dev.	low value	hi value
0 - 4		12293	2943	9350	15235
8 - 12		30684	8482	22202	39166
16 - 20		34957	7221	27736	42177
24 - 28		42375	6584	35791	48959
	Boron				
0 - 4		14.1	4.4	9.7	18.5
8 - 12		23.8	5.7	18.1	29.5
16 - 20		34.5	5.1	29.4	39.6
24 - 28		30.3	6.5	23.7	36.8
	Calcium				
0 - 4		720	184	536	904
8 - 12		1746	625	1121	2371
16 - 20		3531	1223	2308	4754
24 - 28		2684	758	1926	3442
	Cadmium (ppb)				
0 - 4		100.0	14.7	85.3	114.7
8 - 12		41.3	17.3	24.0	58.7
16 - 20		75.0	77.3	-2.3	152.3
24 - 28		43.8	22.2	21.6	66.1
	Chromium				
0 - 4		18.5	5.0	13.5	23.5
8 - 12		30.2	9.2	20.9	39.4
16 - 20		24.7	2.6	22.1	27.3
24 - 28		26.4	9.4	17.0	35.8
	Copper				
0 - 4		4.9	0.8	4.2	5.7
8 - 12		7.1	1.1	6.0	8.1
16 - 20		8.0	1.2	6.9	9.2
24 - 28		7.5	1.0	6.5	8.5
	Iron				
0 - 4		4550	814	3736	5364
8 - 12		13529	4472	9057	18001
16 - 20		31826	9756	22070	41582
24 - 28		20685	7316	13369	28001
	Magnesium				
0 - 4		622	179	444	801
8 - 12		1427	421	1006	1848
16 - 20		1479	267	1212	1747
24 - 28		1833	318	1514	2151
	Manganese				
0 - 4		68.2	11.7	56.6	79.9
8 - 12		54.6	17.6	37.0	72.2
16 - 20		36.1	5.3	30.8	41.4
24 - 28		33.5	5.3	28.3	38.8
	pH (-log[H+])				
0 - 4		4.1	1.0	3.1	5.1
8 - 12		4.7	1.0	3.7	5.7
16 - 20		4.7	1.0	3.7	5.7
24 - 28		4.5	1.0	3.5	5.5
	Zinc				
0 - 4		21.8	2.5	19.3	24.4
8 - 12		31.1	4.6	26.5	35.7
16 - 20		35.4	7.4	28.0	42.8
24 - 28		33.0	3.5	29.5	36.4

Mean +/- standard deviation = hi/low value

Depths (inches)	Columns=>	All Controls & 0% w/ Lime & Nutrient			
	Aluminum	mean	std.dev.	low value	hi value
0 - 4		11599	1557	10042	13155
8 - 12		33936	9339	24596	43275
16 - 20		34969	5834	29135	40803
24 - 28		38568	466	38102	39035
	Boron				
0 - 4		13.8	3.5	10.3	17.3
8 - 12		24.1	5.8	18.3	29.9
16 - 20		32.8	5.9	26.9	38.7
24 - 28		27.4	6.7	20.7	34.0
	Calcium				
0 - 4		735	183	552	917
8 - 12		1921	793	1128	2713
16 - 20		3445	1114	2331	4559
24 - 28		2033	770	1263	2803
	Cadmium (ppb)				
0 - 4		112.5	18.5	94.0	131.0
8 - 12		42.2	16.2	26.0	58.4
16 - 20		68.3	80.0	-11.6	148.3
24 - 28		40.5	21.0	19.5	61.5
	Chromium				
0 - 4		17.8	2.5	15.2	20.3
8 - 12		28.4	8.3	20.1	36.7
16 - 20		23.8	3.2	20.6	26.9
24 - 28		24.2	10.7	13.5	34.9
	Copper				
0 - 4		5.0	0.4	4.7	5.4
8 - 12		7.3	0.9	6.4	8.2
16 - 20		7.7	1.3	6.4	9.0
24 - 28		6.5	0.7	5.8	7.3
	Iron				
0 - 4		4390	379	4011	4769
8 - 12		15077	6112	8965	21188
16 - 20		30942	9198	21744	40139
24 - 28		16785	6635	10150	23420
	Magnesium				
0 - 4		590	105	486	695
8 - 12		1541	438	1103	1978
16 - 20		1474	217	1257	1691
24 - 28		1651	49	1602	1700
	Manganese				
0 - 4		71.1	12.2	58.8	83.3
8 - 12		47.3	18.5	28.8	65.8
16 - 20		33.8	4.0	29.9	37.8
24 - 28		33.0	5.0	28.0	38.0
	pH (-log[H+])				
0 - 4		4.0	1.0	3.0	5.0
8 - 12		4.5	1.0	3.5	5.5
16 - 20		4.4	1.0	3.4	5.4
24 - 28		4.2	1.0	3.2	5.2
	Zinc				
0 - 4		23.1	3.2	19.9	26.3
8 - 12		31.9	3.9	28.1	35.8
16 - 20		33.7	5.0	28.6	38.7
24 - 28		29.6	3.4	26.2	33.0

APPENDIX E
Regression Analysis Output

Regression analysis output - Aluminum

Columns without lime

Regression Output:

Constant	1.10
Std Err of Y Est	1.58
R Squared	0.25
No. of Observations	8.00
Degrees of Freedom	6.00

X Coefficient(s)	0.00
Std Err of Coef.	0.00

Columns with lime

Regression Output:

Constant	1.80
Std Err of Y Est	1.33
R Squared	0.24
No. of Observations	6.00
Degrees of Freedom	4.00

X Coefficient(s)	-0.00
Std Err of Coef.	0.00

Columns with no additions

Regression Output:

Constant	2.13
Std Err of Y Est	1.81
R Squared	0.27
No. of Observations	4.00
Degrees of Freedom	2.00

X Coefficient(s)	-0.01
Std Err of Coef.	0.01

Regression analysis output - Iron

Columns without lime

Regression Output:

Constant	0.175
Std Err of Y Est	0.165
R Squared	0.071
No. of Observations	8.000
Degrees of Freedom	6.000
X Coefficient(s)	0.025
Std Err of Coef.	0.037

Columns with lime

Regression Output:

Constant	0.233
Std Err of Y Est	0.183
R Squared	0.033
No. of Observations	6.000
Degrees of Freedom	4.000
X Coefficient(s)	-0.022
Std Err of Coef.	0.060

Columns with no additions

Regression Output:

Constant	0.160
Std Err of Y Est	0.055
R Squared	0.036
No. of Observations	4.000
Degrees of Freedom	2.000
X Coefficient(s)	-0.005
Std Err of Coef.	0.018

Regression analysis output - Manganese

Columns without lime

Regression Output:

Constant	0.15
Std Err of Y Est	0.04
R Squared	0.12
No. of Observations	8.00
Degrees of Freedom	6.00

X Coefficient(s)	-0.01
Std Err of Coef.	0.01

Columns with lime

Regression Output:

Constant	0.17
Std Err of Y Est	0.07
R Squared	0.14
No. of Observations	6.00
Degrees of Freedom	4.00

X Coefficient(s)	-0.02
Std Err of Coef.	0.02

Columns with no additions

Regression Output:

Constant	0.09
Std Err of Y Est	0.01
R Squared	0.82
No. of Observations	4.00
Degrees of Freedom	2.00

X Coefficient(s)	-0.01
Std Err of Coef.	0.00

Regression analysis output - Zinc

Columns without lime

Regression Output:

Constant	0.68
Std Err of Y Est	0.18
R Squared	0.34
No. of Observations	8.00
Degrees of Freedom	6.00

X Coefficient(s)	-0.07
Std Err of Coef.	0.04

Columns with lime

Regression Output:

Constant	0.71
Std Err of Y Est	0.64
R Squared	0.00
No. of Observations	6.00
Degrees of Freedom	4.000

X Coefficient(s)	-0.011
Std Err of Coef.	0.208

Columns with no additions

Regression Output:

Constant	0.470
Std Err of Y Est	0.293
R Squared	0.032
No. of Observations	4.000
Degrees of Freedom	2.000

X Coefficient(s)	-0.025
Std Err of Coef.	0.098

VITA

James J. Kupa was born on November 3, 1957 in Meshoppen, PA. Raised in Tunkhannock, PA., he (finally) received his Bachelor of Science degree in Earth and Environmental Sciences at Wilkes College in May, 1981. After moving to Northern Virginia, he worked in restaurants for two years. His first professional job was at the Meridian Corporation in Alexandria, VA. where he started in October, 1983.

He was married in 1984 to Mary Ann Paratore, who presented him with his son, Charles, in 1987. He returned to school part-time in 1988 and went full-time to Virginia Tech in the Fall of 1989.

He is now most likely to be found down south with his wife, son and (impending) daughter, solving environmental problems and enjoying life to its fullest.

A handwritten signature in black ink that reads "James Kupa". The signature is written in a cursive, flowing style with a large initial 'J'.