EFFECTS OF SOIL TEXTURE, SOIL DEPTH, AND TREATMENT ON SEPTIC TANK EFFLUENT RENOVATION

by

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(ABSTRACT)

This study compared the effects of soil texture, soil depth, and additional treatment, by constructed wetland (CW) and recirculating sand filter (RSF) systems, on wastewater renovation in a texture group 2 (loam) and a texture group 3 (clay loam) soil. The soils with depths of 15, 30, and 45 cm were placed in the columns with a Gidding's hydraulic soil probe in order to retain the soils structure *in situ*. The texture group 2 columns were dosed with septic tank effluent (STE), constructed wetland effluent (CWE), and recirculating sand filter effluent (RSFE) at 685 cm^3 per day and the texture group 3 columns were dosed at 670 cm^3 per day with the same effluents. These dosing events were split into 2 separate (12 h) events. The leachate from both groups of soil columns were analyzed for fecal coliforms (FC), biochemical oxygen demand (BOD_5), ammonium (NH_4-N), nitrate (NO_3-N), phosphate (PO_4-P), pH, total dissolved solids (TDS), electrical conductivity (EC), and chloride.

In the texture group 2 soil the reduction in fecal coliform numbers was 88% and 99%, respectively, for the CW and the RSF and, in the texture group 3 soil was 91% and 99%, respectively, for the CW and the RSF. There was a reduction in BOD_5 concentrations of 32% and 69% ,respectively, for the CW and the RSF. There was a 42%

and 84% decrease in NH_4 concentrations, respectively, for the CW and the RSF. These reductions show that treatment of STE by CW or RSF can be substituted for soil depth in texture group 2 and 3 soils and will improve drainfield performance. Texture group 2 soils are less effective at STE renovation than texture group 3 soils at all soil depths. This was evidenced by higher FC counts and concentrations of BOD, N, and P in the leachates from these columns.

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1.0 INTRODUCTION

On-Site wastewater renovation is a practical alternative to traditional centralized sewer systems for rural communities. All on-site systems use soil absorption as the final step in the wastewater renovation process. Many soils are marginally suited for installation of on-site wastewater treatment and disposal systems (OSWTDS) because of depth to rock, restricting soil horizon, or separation distance to a water table. With these limitations, additional treatment of septic tank effluent (STE) by either constructed wetlands (CW) or recirculating sand filters (RSF) prior to soil application may allow for a reduction in suitable soil depth and still not pose any treat to ground and surface water quality. Therefore, an investigation on the effects of soil depth, additional treatment, and soil texture group on household wastewater renovation was initiated in May of 1993 for a texture group 3 (clay loam) soil and April of 1995 for a texture group 2 (loam) soil at the Kentland Research farm (Whitethorn, VA).

Renovation ability was measured by the extent of biological and chemical contamination of the leachate collected from undisturbed soil columns dosed with three types of wastewater; septic tank effluent (STE), constructed wetland (vegetated subsurface bed) effluent (CWE), and recirculating sand filter effluent (RSFE). The three effluent types were applied to three soil depths 15, 30, and 45 cm of both texture group 2 (loam) and group 3 (clay-loam) subsoils and was replicated three times.

The objectives of this study are to:

1) evaluate the ability of CW and RSF to provide treatment of STE

2) evaluate wastewater renovation potential of drainfields where STE, CWE, and RSFE are applied, and

3) evaluate wastewater renovation potential of drainfields with 15, 30 and 45 cm of texture group 2 or 3 soils below the drainfield.

1.1 LITERATURE REVIEW

The increasing population in Virginia will continue to rely on greater use of on-site wastewater treatment and disposal systems (OSWTDS), thus the potential for ground and surface water degradation from these systems will increase (Stolt and Reneau, 1991). "Only 32% of the nations soils are suitable for conventional OSWTDS, suggesting that effective use and evaluation of alternative OSWTDS" (Stolt and Reneau, 1991), as well as conventional OSWTDS is necessary. "Subsurface soil absorption systems are sewage disposal systems which utilize the soil to further treat and dispose of effluent from a treatment works in a manner that does not result in point source discharge and does not create a nuisance, health hazard, or ground or surface water problem" (VDH, 1994)

Texture group 2 soils include soils with the textures of sandy loam, loam, and sandy clay loam and texture group 3 soils include soils with the textures of clay loam, silty clay loam, and silt loam (VDH, 1994). Soil structure and texture play an important role in wastewater movement and renovation. Coarser textured soils normally have higher hydraulic conductivities and thus contaminants associated with STE's may have longer and more rapid travel distances therefore increasing the potential for ground and surface water contamination (Stolt and Reneau, 1991). These contaminants can pose a serious health and environmental risk (Hagedorn et al., 1981; Enfield, 1982), as they can lead to outbreaks of waterborne disease and/or increased levels of eutrifying nutrients, primarily nitrates and phosphates, in ground and surface waters.

Tare and Bokil (1982) stressed the importance of texture in wastewater treatment in soils. For soils with >40% fines, percolation rates decreased dramatically but leachate collected from the finer textured columns was of higher quality than the leachate collected from coarser textured soils. However, other important characteristics such as soil structure and landscape position may be equally or more important on any particular site.

Bouma (1975) may have put it best when he said that the "general aim" of on-site systems is to achieve "adequate purification of effluent while maintaining adequate infiltration into and percolation through the soil." The term adequate here would have to be defined by VDH (1994) regulations. Proper OSWTDS performance depends on the soils ability to transmit and renovate wastewater (Reneau et al., 1989). Bouma (1975) states that, the mandatory percolation test insufficiently expresses the capacity of a soil to infilter and transmit wastewater effluents. He further states that the only useful wastewater treatment purpose is as a "parameter ranking different soils."

There are approximately 15,000 soil series in the United States (Edmonds, 1995). Soil series consist of a characteristic profile with a unique arrangement of diagnostic horizons and occur in a variety of physiographic provinces, landscape positions and climatic regions. The number of different phases of all soil series in the United States is in the hundreds of thousands.

Associated with this complex suite of soil units are the local geologic and hydrologic conditions which modify greatly the soils capacity to accept and renovate household wastewaters. This complex association of soils and geologic conditions provides an infinite spectrum of soil capabilities for accepting and renovating wastewater and eliminates the use of generalizations for the use of soils as a medium for wastewater renovation (Miller and Wolf, 1975).

Beven and Germann (1982) indicate the importance of large continuous macropores on soil hydraulic conductivity. These hydraulic pathways are not well described by a Darcey approach to flow through a porous media. As Hursh (1944) eloquently put it "porosity is not a factor of individual soil particle size but rather of structure determined by aggregates which form a three-dimensional lattice pattern which is permeated by biological channels. A single dead-root channel, worm-hole or insect burrow may govern both the draining of water and escape of air through a considerable block of soil" (Hursh, 1944).

According to Miller and Wolf (1975) the hydraulic character of a soil may be determined more by its structure than its texture. Infiltration capacity reduction with clear water is due to slaking of fines (clay, fine silt) into the pores. Anderson and Bouma (1977) indicate that the larger macropores and planner voids between structural units were the main flow channels during saturated flow. They also believed that the unexplained rapid movement of fecal bacteria through pedal soils was due to the macropores between structural units. The reduction in infiltrative capacity associated with STE is contributed to by the physical, chemical, and biological constituents that make up the effluent. "Movement of effluent away from an OSWTDS can be visualized as two interdependent flow processes: infiltration of effluent across the gravel-soil interface and percolation of effluent through the surrounding regolith" (Reneau et al., 1989).

Schwartz and Bendixen (1970) believed that greater depth of unsaturated soil serves to increase the absorptive capacity of the soil system by allowing the infiltering water to come into contact with a greater mass of soil. They stated that one possible way the soil may be modified is through cultivation of various common forms of vegetation. "Roots loosen the soil, permitting greater infiltration of liquid, and the plants assimilate nutrient elements removed by the soil from the waste stream". They also stated that there was other advantages to the plant component, such as dispersal of liquids by evapo-transpiration and protection against freezing and that native grasses can serve adequately. Further they observed that 1.5 m (5 ft) was a adequate depth in general. The function of depth to groundwater is to "assure good biological treatment and good hydraulics in a soil system" (Schwartz and Bendixen, 1970). They determined that between 0.6 m (2 ft) and 1.2m (4 ft) as a minimum critical depth for proper treatment and to insure adequate aeration of the soil absorption system. They also state that the hydraulic longevity of the drainfield can be increased by a factor of 2 by having a vegetative cover on the soil surface.

A cross section of a typical soil absorption system which has been in service for several years shows ponded effluent in the gravel bed caused by the biological mat that forms at the interface of the bed and soil. Flow of effluent will be impeded through this mat but is not stopped. This will lead to variances in the unsaturated flow below the mat and saturated flow in the bed itself (Sikora and Corey, 1976). Bouma (1976) noted that "crusting and clogging of seepage beds in such soils as loams and silt loams, which are highly or moderately permeable initially, may result in insufficient absorption followed by unacceptable surface discharge."

Magdoff and Bouma (1975) described the genesis of the crust in a soil that received STE that was treated by a sand filter. This crust forms as a surface sludge at the soil gravel interface and reduces the permeability of the soil at or in the infiltrative surface. Kropf et al. (1974) examined OSWTDS and the phenomenon of soil clogging. Specifically they tried to determine the effluent application rate that would produce an equilibrium between growth and die-off of microbial biomas. According to their measurements there was no rate either continuous or intermittent that produced higher infiltration rates of the wastewater. They believed that a more steady state would result from a system that was continuously ponded verses the ups and downs of a system experiencing alternating aerobic/anaerobic conditions. However, a continuously ponded system would reduce renovation performance of the absorption field and would limit organic matter decomposition. Whereas, in a system that is aerobic organic matter decomposition and renovation performance would be greater.

Gupta and Swartzendruber (1962) demonstrated the reduction in hydraulic conductivity under prolonged flow in a uniform quartz sand. With the main cause for the reduction being the activity and growth of bacteria in the sand. Allison (1947), discussed the effect that microorganisms have on soils that are submerged for prolonged time intervals, in that they clog pores with the products of growth, cells, and slime. He also believed that any aggregate disintegration was due to biological causes such as microbial attack on organic materials which help bind soil aggregates together. Of the 2 methods for reduction in permeability, the clogging of pores by microbes and their by-products seemed more prevalent than the slaking of fines into pores.

Bouma (1975) stated that subsurface soil disposal of household wastes involves processes of unsaturated flow and that conductivity curves for each soil must be available for proper description of water movement. Bouma (1975) states that the infiltration rates decrease and tensions below the biological mat increase as the resistance of the biological mat increases. He noted that in loam soils the reduction in hydraulic conductivity at low tensions (high matric potentials) is less abrupt than in sand due to the finer pores. This led to ponding of effluent on the loam soils where, under similar conditions, there was no ponding in sandy soils. Bouma (1975) reported that for clay loam soils this effect will be more pronounced than in the loam soils. "Consideration of unsaturated flow phenomena and the physical effects of barriers, such as the clogging of the infiltrative surface with the biological mat or compacted layers, is essential to describe soil hydraulics during waste disposal" (Bouma 1975). It is important to understand that pretreatment of STE does not increase flow capacity through a soil, but rather reduces the clogging mat permeability (Laak, 1974). This means that for effluents that are treated the permeability at the gravel soil interface should remain higher for longer periods of time. Cogger and Carlile (1984) reported that for saturated soils there was a reduction in renovation performance compared to OSWTDS on more well drained sites. This was detailed by higher fecal coliform counts and longer migration distances, and elevated N levels in shallow wells near a low pressure distribution (LPD) system. This demonstrates the importance of the aeration status and infiltrative capacity of the soil absorptive system.

The characteristics of the wastewater flow from individual households can impact the performance of OSWTDS. Household wastewater use can vary greatly creating an intermittent flow pattern of wastes that vary widely in strength and volume (Siegrist et al., 1976). There are basically four major ways in which water is generated by an individual residence: (1) toilet usage; (2) bathing; (3) clothes and dishwashing; and if required (4) water softening. Toilet usage can be subdivided into fecal toilet flush and non-fecal flush. The non-fecal toilet flush is comprised of urine discharge and other bathroom solids such as hair. Fecal toilet flush will contain human enteric organisms. Bennett et al. (1975) discusses the water use and wastewater characteristics and demonstrates that wastewater generation and strength was highly dependent on the bathing habits of individuals living in the home. The work done by Bennett et al. (1975) demonstrates the intermitted nature of conventional subsurface absorption systems dosing regime, and the need for a more uniform distribution system such as a low pressure distribution (LPD) system.

Brown et al. (1979) relied on fecal coliforms as an indicator of enteric microorganism pollution. He reported, based on field studies in sandy soils (VDH Texture group 1), that fecal coliforms were detected as far as 30 m from the source of application of STE. Yet they reported that in a finer textured soil (Typic Udivluvent, sandy clay) fecal coliform and coliphage migration was slight at 120 cm vertical distance from the bottom of the drainline trench. For all of the soils they studied, the greatest concentration of coliforms and coliphages was within 10 to 15 cm of the drainfield line. Brown et al. (1979) reported that fecal coliform populations decreased greatly with increased distance from the drainline line.

"The fate of enteric microorganisms in wastewater as they contact soil is an important consideration in land application of wastewater" (Gerba et al., 1975). Moisture is a principle factor in determining the survival of bacteria in the soil. Gerba, et al. (1975) reports that for all soils tested bacterial survival was greatest in the rainy season. Soil moisture, temperature, pH, and availability of organic matter can also influence the longevity of enteric bacteria in the soil environment. "These factors also regulate the growth of antagonistic organisms which can indirectly effect enteric pathogen populations" (Gerba et al., 1975). The straining of bacteria at the soil surface appears to be the main limitation in the travel through soils. Gerba et al. (1975) concluded that when suspended particles, including bacteria, accumulate on the soil surface, as water passes through the soil these particles themselves become part of the filter (biological mat), and such a filter is capable of removing even finer particles, by bridging or sedimentation, before they reach and clog the soil surface. "This phenomenon will in fact largely be dominant if only a portion of the suspended particles are larger than the pore openings. As soon as a few such particles have accumulated, they become the straining surface for finer particles" (Gerba et al., 1975). Formation of this biological mat therefore restricts bacterial movement from OSWTDS.

The predominant forms of N in household wastewaters are ammonium (NH_4-N) and organic N. The major sources of N are feces and urine which together contain urea, uric acid, ammonia, undigested proteins from foodstuffs, and bacterial cells (Sikora and Corey, 1976). Ammonium will be oxidized to nitrite then to nitrate (NO_3) in an aerobic environment in the presence of nitrifying bacteria.

Nitrate is an anion and will not be held by the soil cation exchange complex and therefore leaches with water through the soil absorption system and may eventually enter into potable water supplies. This is a health concern in that high levels >10 mg/L NO_3-N (EPA, 1980) are deemed unsafe for drinking purposes. These levels can lead to methemoglobinemia (blue baby syndrome) in infants and cancer in adults from secondary nitrosamines. Whelan and Barrow (1984) discuss how N moves from an seepage pit in sandy Australian soils. Their work indicates that most of the N is in the NH_4^+ species until the N moves through the slime layer and within 0.5 m (20 in) is transformed into NO_3. Except were the saturated zone overlapped into the 0.5 m (20 in) zone under the drainlines resulting in anoxic or anaerobic conditions resulting in NH_4 being the predominant N species in these wet zones. "In all of the systems investigated there was little retention of inorganic N in the sandy soil profiles. Hence the N entering the soil profile below the drainlines either passed into the groundwater or was used by plants" (Whelan and Barrow, 1984). They stated that the oxidation of NH_4 to NO_3 can serve as an index of soil aeration. Nitrogen transformations can be affected by environmental parameters such as pH, organic matter and oxygen (O_2) content of the soil. "Oxidation of NH_4^+ to NO_3^- occurred in the soil immediately below the slime layer (biological mat) and was associated with a decrease in soil solution pH. As a result, the soil pH below this oxidation zone was low, but above it the soil pH was high" (Whelan and Barrow, 1984). However, these factors are secondary when compared to the aeration status of the soil absorptive system (Sikora and Corey, 1976). Klausner and Kardos (1975) discussed O_2 relationships in soils used to treat STE. "The extent that soil air differs in O_2 concentration from atmospheric air, is determined by the rate at which O_2 is consumed by microorganisms and respiring plants, and the rate at which it is replenished by diffusion" (Klausner and Kardos, 1975). Zaghoul et al. (1988) stated that the two major BOD_5-removal mechanisms are filtration and biodegradation. This explains the effectiveness of sand filters to reduce BOD_5.

An effluent introduced into an absorption field has the potential to saturate the available exchange sites of a soil with NH_4. After saturation of the exchange complex with NH_4, and if conditions are not suited to nitrification NH_4 moves downward with the leachate water (Brown et al., 1984). Sikora and Corey (1976) determined that the probable N species beneath septic lines of different textural classes are NO_3 in sands, loamy sands, sandy loams, and loams; a mixture of NO_3 and NH_4 in silt loams and some silty clay loams, and NH_4 in clay loams and clays. This would support Whelan and Barrows (1984) conclusion about the oxidation status of NH_4 because with finer textured soils there should be decreased hydraulic conductivity and thus lower aeration in the soil absorptive system resulting in higher NH_4 concentrations below the drain lines. However, this would also be dependent on the loading rate and structure of the soil. Most fine textured soils are usually loaded at lower rates than coarser textured soils.

Thomas and Bendixen (1969) reported that additions of "organic sludge of 4 to 10 mt/yr ha^{-1} were needed to maintain a static organic carbon content of a soil." They also concluded that the frequency of application and the moisture content of the soil were primary factors in the degradation of wastewater organics in soil. It would be expected that aerobic soil conditions and frequent applications would result in higher microbial degradation rates and hydraulic infiltration rates than in soils that are saturated or anoxic. Frequent additions of wastewater organics into the soil should result in a condition in which organic carbon is in equilibrium and available to the microbial populations. This equilibrium should allow these populations to remain constant. "Soil microorganisms can digest about 80% of the organic carbon from STE under a variety of conditions" (Thomas and Bendixen, 1969). They also reported that proper liquid management and organic loading should result in long term continuous operation with only minor changes in the organic carbon content of the soil.

Jones and Lee (1979) state that the potential for a soil to remove P from STE is controlled more by mineralogy of the soil rather than the particle size. Clay minerals and iron and aluminum oxides have relatively high P sorption capacities and at low pH can precipitate as Fe and Al phosphates. "In calcareous (limestone) soils, P would tend to be immobilized by precipitation reactions, forming hydroxyapatite" (Jones and Lee, 1979). They observed that in western Wisconsin the greatest P transport was through aquifers comprised of coarse sand or gravel. These materials would not have the sorption capacities of the calcareous and clay rich soil material previously stated. This complies with the worst case scenario described by Whelan and Barrow (1984) in the sandy soils near Perth, Australia where the soils reached their P sorption capacity after a few years of operation of a OSWTDS. "Langmuir and other P equilibrium methods used to generate P sorption maximums from laboratory data may underestimate soil P sorption under field conditions. The underestimation of P immobilization in soil from P sorption studies may result from the slower long-term reactions or the regeneration of P adsorption sites or both" (Reneau et al., 1989). Sawhney and Starr (1977) investigating P movement from an OSWTDS noted that P moves downward and laterally from the trench at a rate much slower than that predicted from Langmuir P sorption maximums.

Phosphorus in STE originates from 2 main sources: detergents with phosphate builders and human excreta (Alhajjar et al., 1989). Alhajjar et al. (1989) reported that N removal rates were higher in septic tanks that received PO_4-built detergents over CO_3-built detergents, because of higher bacterial populations the PO_4-built detergents developed. They also postulated that this higher bacterial population was due to the additional P in the detergents and that organic matter degradation was higher due to the higher bacterial populations.

Lance (1977) used packed 10 cm columns of calcareous loamy sand to examine P removal from secondary effluent, and reported that even after 7 years 75% to 80% of the P applied would be removed if the infiltration rate was below 15 cm/day. He concluded that there was an initially high rate of removal of PO_4, followed by a decrease which became flow and time dependent, suggesting adsorption or precipitation reactions.

Sand filtration is an economical method of household wastewater renovation. Whether it be of an intermittent or recirculating (Table 1) design significant reductions in BOD_5, total solids, and fecal organisms can be achieved (Pilak and Peters, 1994; Hines, 1975; Chowdhry, 1978; Wert and Paeth, 1985; Wilson et al., 1982; Hines and Favreau, 1974; Loudon and Birnie, 1991; USEPA, 1980).

Table 1. Design criteria for recirculating sand filters (USEPA, 1980).

ITEM	DESIGN CRITERIA
Pre-treatment	Minimum level-sedimentation (septic tank or equivalent)
Hydraulic Loading	0.12 to 0.20 m/day (forward flow)
Media Material	Washed durable granular material (<1% organic matter)
Effective Size (D10)	0.3 to 1.5 mm
Uniformity Coefficient(D60)	<4.0mm (<3.5 mm preferred)
Depth	60 to 90 cm
Distribution	Troughs on surface; splash plates at center or corners; sprinkler distribution
Underdrains	Open joint or perforated pipe within washed durable gravel
Recirculation Ratio	3:1 to 5:1 (5:1 preferred)
Dosing	Flood filter to approx. 5 cm; pump 5 to 10 min. every 30 min.; empty recirculation tank in less than 20 min.
Recirculation Tank	Volume equivalent to at least one day's effluent flow

D10 = size for which 10% of the sands grains are smaller by weight
D60 = size for which 60% of the sands grains are smaller by weight

One major problem reported (Hines, 1975) with the intermittent sand filter design is the foul septic odors as the system is dosed. These noxious odors are gases emitted by anaerobic bacterial degradation of the organics in STE (Hines, 1975). These gaseous by-products of anaerobic degradation are avoided by recirculating a portion of the filtered effluent which is higher in dissolved O_2 back into the filter . In essence the recirculating sand filter is an O_2 rich environment when compared to the intermittent filter system and this allows the recirculating sand filter to be used in areas that are not suitable for odorous discharges. However, most sand filters are covered and discharge below the sand surface thus reducing any noxious odors above ground.

Wetlands also have potential for additional treatment of STE because of their low capital cost and low maintenance requirement. Wetlands remove aquatic pollutants through a complex variety of biological, physical and chemical processes (Gersberg et al., 1985). By using aquatic vegetation that is capable of translocating O_2 from the shoots to the roots. Diffusion of O_2 to the root surface creates an oxidized micro-environment. This oxidized micro-environment allows decomposition of organic matter and growth of nitrifying bacteria (Gersberg et al., 1985). Brix (1994) states that the macrophytes used in constructed wetlands stabilize the surface of the beds, provide good conditions for physical filtration, insulate against frost damage in the winter, and provide a huge surface area for microbial growth.

Many investigators have looked at constructed wetlands as a treatment method for wastewater effluents (Rogers et al., 1991; Gersberg et al., 1984; Gersberg et al., 1985; Williams et al., 1994; Bavor and Andel, 1994; Payne et al., 1992; Huang, 1995). Constructed wetlands will reduce BOD_5, total N, total suspended solids, and fecal coliforms. Kuehn et al. (1993) reported variability in the performance of constructed wetlands that were receiving pulp mill effluent. They believed that BOD_5 removal was significantly effected by the season of the year. However, for municiple or household wastewaters this variability may not be as pronounced as with the pulp mill effluents which varied with the season.

Numerous investigations have been conducted with packed soil columns and their effectiveness in the renovation of wastewaters (Tare and Bokil, 1982; Lance, 1977; Magdoff and Keeney, 1975; Shawhney, 1977; Nagpal 1986). Smith (1972) used packed columns and Tyler and Thomas (1981) used undisturbed soil columns to investigate chloride movement in soils. Bouma (1975) stated that laboratory studies using soil columns can only be meaningful if large undisturbed columns are used. Columns filled with sieved aggregates have different hydraulic characteristics and are not representative of the field. He also believed that the length of the column was of prime importance in the renovation capacity of the soil in the columns. Packed columns may give false weight to the concept of soil texture as the dominant feature when evaluating a potential site for OSWTDS. In this study 20 cm diameter PVC columns were pushed into the soil with a Gidding's hydraulic soil probe in order to retain the soils structure *in situ*.

2.0 MATERIALS AND METHODS

All soil columns were collected from approximately 35 cm below the mineral soil surface and physical and chemical properties are shown in Tables 2 and 3. Columns were placed in a completely randomized design in the lysimeter facility at Kentland Research farm (VDH, 1995) and were replicated three times. Soil depths in the columns are 15, 30, and 45 cm (Figure 1). Influent types consist of CWE, RSFE (Figure 2), and STE. The influent distribution system (Figure 1) is located 30 cm below the soil surface and within a 15 cm layer of 5.0 to 7.5 cm diameter gravel above the column soil . A gas collection system was installed within the gravel distribution layer to facilitate possible future denitrification analysis. Tensiometers were placed in the center of the soil columns to monitor the energy status of water. Thermocouples have been installed in 9 randomly selected columns of the group 2 soil and in all the group 3 columns to monitor soil temperature.

Leachate from the soil columns was analyzed for BOD_5, fecal coliform (FC), nitrogen (NO_3-N, NH_4-N), phosphorus (P), chloride (Cl), pH, electrical conductivity (EC), and total dissolved solids (TDS). Plant growth (dry weight) and tissue total Kjeldahl nitrogen (TKN) were monitored throughout the study period.

2.1 Texture Group 2 Soil

A soil with a loam texture (fine-loamy, mixed, mesic Mollic Hapludalf) was located at Kentland Research farm, and undisturbed 20 cm diameter soil columns (Figure 1) were collected with a Gidding's hydraulic soil probe. Soil particle size analysis was determined with the pipette method (Gee and Bauder, 1986), bulk densities by the soil clod method (Blake and Hartage, 1986), and total porosity by calculation from bulk densities (Danielson and Sutherland, 1986). Cation exchange capacity (CEC) was determined by the ammonium acetate, pH 7.0, method, and extractable bases as described by Thomas (1982). Soil pH was determined by standard pH meter after 1:1 ratio of soil to distilled/deionized water (McLean, 1982). Soil carbon (organic matter) was determined by combustion and volumetric methods described by Nelson and Sommers (1982). Soil properties are shown in Table 2.

Soil column dosing was initiated on March 20, 1995. Sample collection began the week of April 3, 1995. Influent is applied to the soil columns 2 times daily at a total application rate of 685 cm^3/day. This is the application rate that would be applied to this soil if a LPD system was employed under field conditions (VDH, 1994). Tall fescue (*Festuca arundinacea*, Falcon II) was sown in the columns in April of 1995.

2.2 Texture Group 3 Soil

Undisturbed 20-cm-diameter soil columns (Figure 1) were collected with a Gidding's hydraulic soil probe. This soil was characterized (clayey, mixed, mesic Typic Hapludult) by Duncan (1994) and its properties are shown in Table 3. Vegetative cover on these columns consisted of tall fescue (*Festuca arundinacea*, Kentucky 31).

Soil column dosing was initiated on May 27, 1993 at 6 times per day for a total of 670 cm^3/day (Duncan, 1994). This dosing regime was replaced by dosing the columns twice a day at the start of the textural group 2 investigation. It was felt that dosing the soil columns 6 times daily simulated a drip irrigation system and that 2 doses per day would more closely represent an LPD system. Sampling began on June 7, 1993 and continued monthly for the first year of the study, and then quarterly for the second year. Plant growth (dry weight) and tissue TKN was monitored throughout the investigation.

Table 2. Physical and chemical properties of the texture group 2 soil.

Depth	Sand	Silt	Clay	Texture	ρb fm[1]	Pore Space[2]	KSAT	CEC[3]	pH
(cm)	(%)	(%)	(%)	(USDA)	(g cm^{-3})	(%)	(cm hr^{-1})	cmolc/kg	[H^+]
0-23	42.9	39.4	17.7	Loam	1.49	43.8	1.36	11.1	6.18
23-56	43.2	35.3	21.5	Loam	1.71	35.5	0.41	8.1	5.98
56-107	47.0	31.0	22.0	Loam	1.73	34.7	0.05	10.1	6.44
107-142	49.8	30.6	19.6	Loam	1.65	37.7	--	8.9	6.44
142-203	53.9	29.5	16.5	Loam	1.62	38.9	--	8.1	6.50

[1] = Bulk density (Db)at field moisture.

[2] = Pore space (%) = 1 - (Dbfm g cm^3/2.65 g cm^3 assumed particle density) times 100.

[3] Cation exchange capacity determined with ammonium acetate at pH 7.0.

KSAT = Saturated hydraulic conductivity

Table 3. Physical and chemical properties of the texture group 3 soil.

Depth	Sand	Silt	Clay	Texture	ρb fm[1]	Pore Space[2]	KSAT	CEC[3]	pH
(cm)	(%)	(%)	(%)	(USDA)	(g cm^{-3})	(%)	(cm hr^{-1})	cmolc/kg	[H^+]
0-15	39.2	46.7	14.2	Loam	1.63	38.5	12.9	7.5	5.18
15-30	36.5	45.4	18.2	Loam	1.61	39.2	16.0	7.5	6.16
30-45	33.6	39.2	27.2	Clay Loam	1.74	34.3	2.32	6.9	5.71

[1] = Bulk density (Db)at field moisture.

[2] = Pore space (%) = 1 - (Dbfm g cm^3/2.65 g cm^3 assumed particle density) times 100.

[3] Cation exchange capacity determined with ammonium acetate at pH 7.0.

KSAT = Saturated hydraulic conductivity

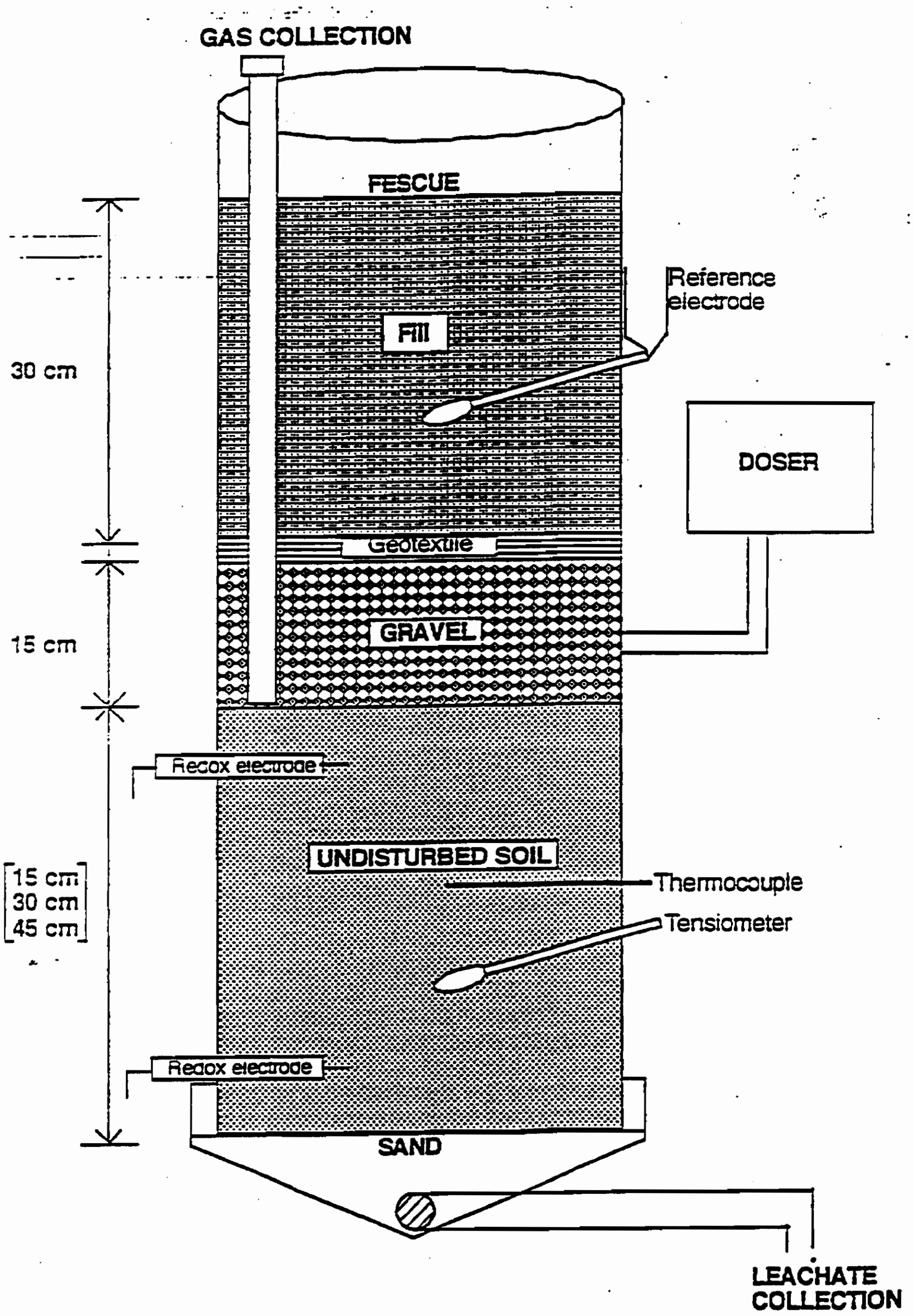

Figure 1. Soil column design (Duncan, 1994)

2.3 Biological analysis

Fecal coliforms (FC) were used as indicators of biological quality of the wastewaters and of the leachate from the soil columns.

Fecal Coliforms

The membrane filter procedure was used to determine FC numbers (APHA, 1992). If leachate samples were positive using the colilert test (Environetics), then fecal coliforms were enumerated using the following procedure. Five aliquots of 0.1, 1, and 10 ml of leachate sample was passed though a 0.45 um filter membrane, 47 mm in diameter, using a vacuum pump. After filtration, the filter was placed on the surface of a 50 x 12 mm petri dish containing mFC agar (Edberg et al., 1988). The petri dishes were inverted and placed in a plastic bag. The plastic bag was submerged into a 44.5 °C water bath for 24 h. After 24 h the plastic bag was removed from the water bath, and allowed to cool. The fecal coliform numbers were determined by counting the number of blue colonies present.

2.4 Chemical Analysis

Leachate samples were collected from the soil columns in plastic bottles. Unfiltered subsamples were analyzed for BOD_5, pH, EC, and TDS, while N, P, and Cl were measured using filtered (vacuum micro-pore cellulosic 0.45 micron filter paper) subsamples.

Biochemical Oxygen Demand (BOD_5)

Subsamples were diluted with the BOD dilution water (BOD dilution water was a mixture of 1 ml phosphate buffer, 1 ml $MgSO_4$, 1 ml $CaCl_2$ and 1 ml $FeCl_3$ solutions in 1000 ml distilled water). BOD_5 was determined using a YSI model 57 dissolved oxygen meter to measure the differences between initial and final DO concentrations after 5 days incubation at 20°C. BOD_5 concentrations were calculated based on DO differences and dilution volumes (APHA, 1985).

Total Kjeldahl Nitrogen (TKN)

Ten ml of unfiltered sample was placed in a 100 ml digestion tube, and 1 g of catalyst mixture (K_2SO_4, HgO, and $CuSO_4$), 3 ml of concentrated H_2SO_4 and a teflon boiling chip was added. The digestion tubes were placed in a heating block at 200°C for 2 h, and then the temperature was raised to 380°C for additional 3 h. After digestion (mixture turned transparent), the mixture was allowed to cool and diluted to 50 ml with distilled water. Samples were mixed thoroughly. A 3 to 4 ml aliquot of sample was taken for NH_3 analysis with an Orion Scientific autoanalyzer using a colorimetric procedure (USEPA, 1979, Method 352.2). A standard curve was prepared from a known standard concentrations of N.

Ammonium and Nitrate

Subsamples were collected for NH_4 and NO_3 analysis with a dual channel Orion Scientific autoanalyzer using a colorimetric procedure (APHA, 1985 and USEPA, 1979). Salicylate and hypochlorite react with NH_4 to form idophenol blue that is proportional to the NH_4 concentration. The blue color formed was intensified with sodium nitrofericyanide. The determination of NO_3 and NO_2 utilized the procedure whereby NO_3 is reduced to NO_2 by a copper-cadmium reductor column. The NO_2 ion reacts with sulfanilamide under acidic conditions to form a diazo compound. This compound then couples with N-1-naphtyl-ethylenediamine dihydrochloride to form a reddish-purple azo dye that is proportional to the NO_2 concentration. A standard curve was prepared from a known standard concentration of NH_4 and NO_3.

Ortho-phosphates

Phosphorus concentrations of the leachate and effluents were measured on filtered samples using the L+-ascorbic acid colorimeteric procedure (USEPA, 1979). Under reductive condition in the presence of ascorbic acid, PO_4^{3-} forms a deep blue colored complex with addition of antimony and molybdate. The intensity of blue color increases with increased PO_4^{3-} concentration in the sample. A Hitachi colorimetric spectrophotometer was used to measure the intensity of blue color in the sample (USEPA, 1979). A standard curve was prepared from a known standard concentrations of PO_4^{3-}.

Electrical Conductivity and Total Dissolved Solids

Electrical conductivity and TDS of the soil column leachate and the effluents were measured on unfiltered samples with a conductivity bridge with the procedure described by USEPA (Method 120.1, 1979).

pH

pH values of the unfiltered leachate and effluents were determined by a glass electrode paired with a reference electrode. Double standard buffer solutions (pH 4 and pH 7) were used to calibrate the pH meter prior to measurement (USEPA, Method 150.1, 1979)

Chloride

Chloride concentrations were determined by a potentiometric titration performed with a digital chloridometer (APHA, 1985). Unfiltered samples were mixed with an acid solution and a gelatin reagent before analysis. The acid solution contained 6.4 ml concentrated nitric acid (HNO_3) and 100 ml glacial acetic acid in 1000 ml volume of distilled water. One ml of sample was combined with 1 ml acid mixture, 2 ml of deionized distilled water, and 4 drops gelatin reagent in a glass vial for automatic titration by the chloridometer. A standard curve was prepared from a known Cl^- standard.

Plant Tissue Nitrogen Content

Plant tissue TKN was determined by a modified micro-Kjeldahl digestion procedure (Bremner and Mulvaney, 1982). A 0.1000 g of tissue sample was first placed in 100 ml digest tube, and then 0.75 g of catalyst mixture, 1.25 ml of concentrated H_2SO_4 and a boiling chip were added. Digestion tubes were placed in a heating block at 200°C for 0.5 h, then adjusted to 410°C for an additional 3 more h. After digestion, the tubes were allowed to cool and diluted to 50 ml with distilled water. Samples were mixed thoroughly and a 3 to 4 ml aliquot was taken for NH_3 analysis using an Orion Scientific autoanalyzer with colorimetric procedure (USEPA, 1979, methods 352.2). A standard curve was prepared from a known standard concentration of N.

Statistical Analysis

Treatment effects were tested using ANOVA in the Statistical Analysis System (SAS, 1985). Duncan's multiple range test was used to determine statistically significant differences ($p < 0.05$) between sample means. If there were differences between influent type and soil depth interactions, a one-way ANOVA means separation test was performed on the nine treatment means.

Table 4. Design characteristics for the recirculating sand filter.

Raw hydraulic loading	0.20 m/d
Recirculation rate	5:1
Raw loading/dose	2200 cm^3
Recirculate loading/dose	11000 cm^3
Filter sand depth	90 cm
Depth-imposed water table	60 cm
Sand effective size (D10)	0.63 mm
Uniformity coefficient(D60)	< 2.91 mm
Number of doses/day	6

D10 = size for which 10% of the sand grains are smaller by weight
D60 = size for which 60% of the sand grains are smaller by weight

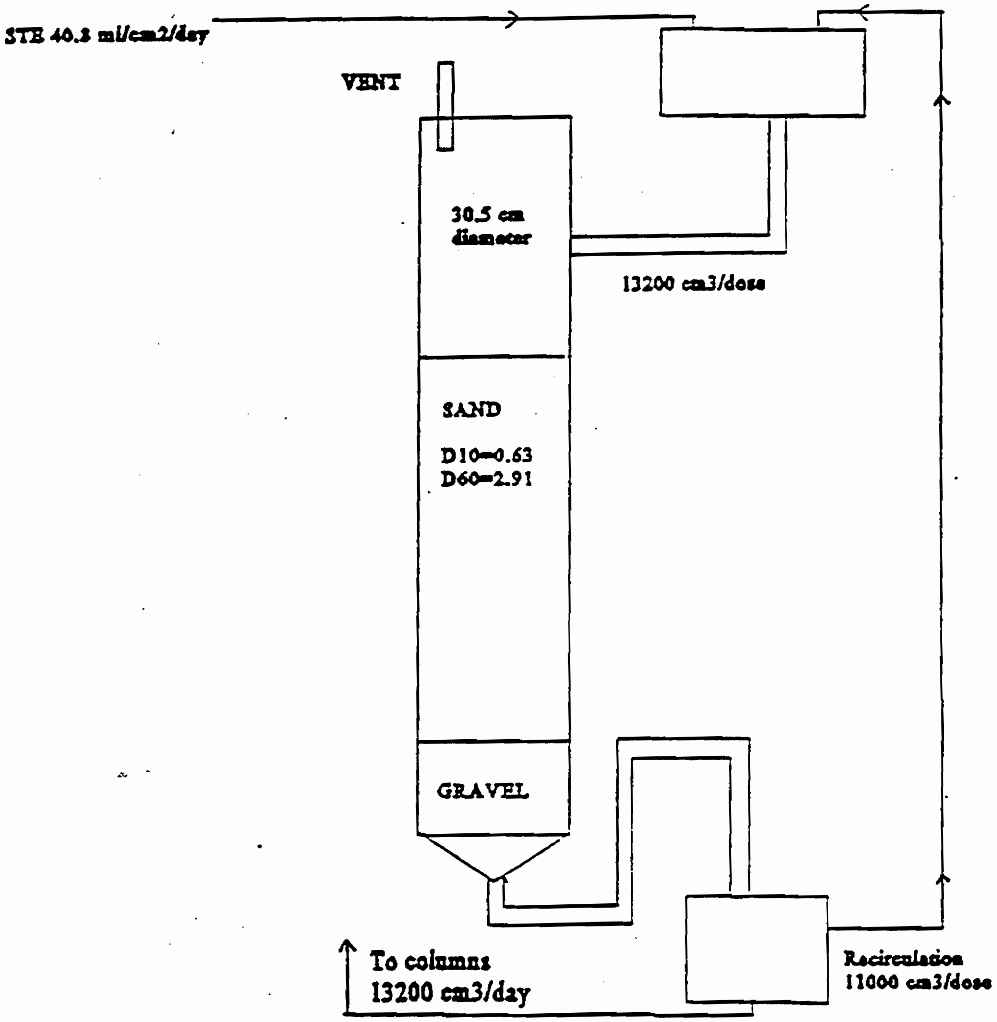

Figure 2. Recirculating sand filter design

3.0 RESULTS AND DISCUSSION

3.1 Biological contaminants

Texture Group 2 Soil

Fecal coliform (FC) counts (Table 5 and Figure 3) showed that additional treatment of STE prior to soil application reduced the number of FC present in the column leachate. The FC counts decreased from 11,450/100 ml to 1380 (88%) and 23 counts/100 ml (99%) after treatment of the STE with the CW and the RSF, respectively.

Soil depth and influent type had a significant impact on FC numbers in the column leachate (Table 5). Where STE was applied to the soil columns the numbers of FC in the leachate from the 15 cm deep columns was higher than those present in any other treatment. Also there was a trend toward decreased FC counts with increased soil depth where STE and CWE were applied to the soil columns. However, at the 30 cm soil depth, there was a trend toward decreased FC counts in the column leachate where RSFE was applied but not where CWE was applied (Table 5). At the 45 cm soil depths there was no reduction in FC counts achieved by additional treatment of STE by either treatment method. Where RSFE was applied FC counts were always low. The FC counts were always <10 organisms per 100 ml for the soil columns that received RSFE and for the 30 and 45 cm soil columns that received CWE.

Table 5. The effect of soil depth and influent type of fecal coliform counts in column leachate texture group 2 soil.

Influent type	Soil depth (cm)	Fecal coliforms (counts/100ml) 4-95 to 10-95	% Reduction
		Column influent	
STE	--	11450	--
CWE	--	1380	87.9
RSFE	--	23	99.8
		Column leachate	
STE	15	198a	98.3
STE	30	6bc	99.9
STE	45	3bc	99.9
CWE	15	11b	99.2
CWE	30	8bc	99.4
CWE	45	4bc	99.7
RSFE	15	3bc	87.0
RSFE	30	2c	91.3
RSFE	45	3bc	87.0

*Means within the same grouping followed by the same letter are not significantly different ($P<0.05$) as determined by Duncan's Multiple Range Test.
STE - septic tank effluent
CWE - constructed wetland effluent
RSFE - recirculating sand filter effluent

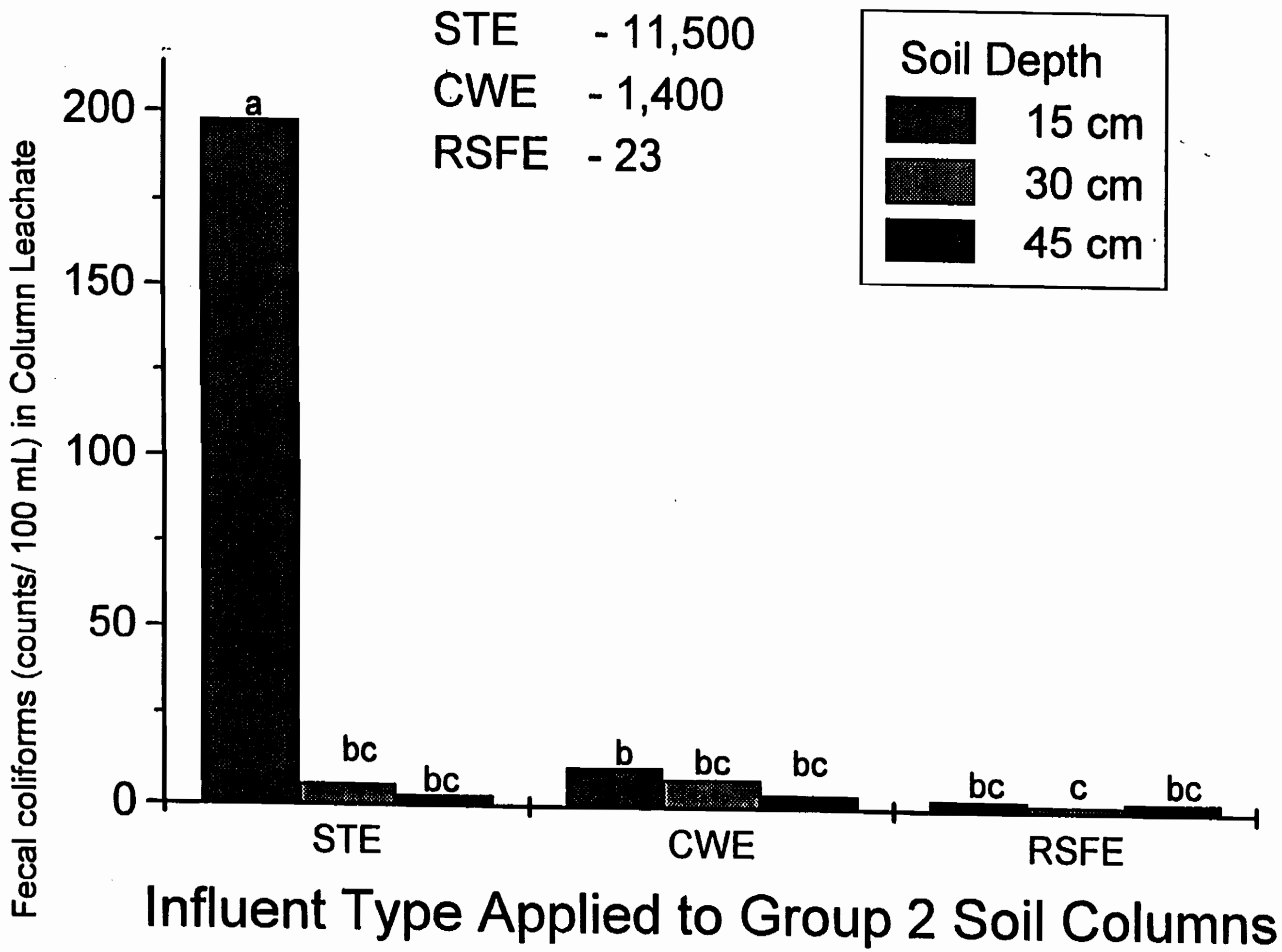

Figure 3. Texture group 2 soil column leachate fecal coliform reductions

Where RSFE was applied to the 15 cm soil columns the FC counts in the leachate was much lower than the 15 cm deep soil columns that received either STE or CWE (Table 5).

There were no differences between CWE and RSFE since values of <10 were arbitrarily assigned a value of 10. A value of <10 counts per 100 ml simply shows that FC were present. The FC counts may actually be much lower than 10. The FC counts were effected by both soil depth and influent type with increasing depth reducing the total numbers of organisms and RSF being significantly better at reducing FC counts. This was expected since the FC counts were much lower in the RSFE (Table 5). However, all soil columns were positive for FC indicating that the data confirms the hypothesis that group 2 soils have less potential for biological renovation of household wastewater than do group 3 soils.

Texture Group 3 Soil

Fecal coliform counts during year 1 (5-93 to 5-94; Duncan, 1994) and year 2 (5-94 to 9-95) of the study showed that additional treatment of STE in a CW or RSF prior to soil application reduced the FC counts (Table 6). The FC counts were reduced from 35,800/100 ml to 3,200 (91%) and 170 counts/100 ml (99%) after additional treatment of the STE with a CW and a RSF, respectively. The FC counts for samples analyzed during year 2 (5-94 to 9-95) were in the same order (STE, CWE, and RSFE) as year 1 results, but the STE had lower counts than the samples collected during year 1 (Table 6).

Table 6. The effect of soil depth and influent type on fecal coliform counts in column leachate texture group 3 soil.

Influent type	Soil depth (cm)	Fecal coliforms (counts/100 ml) 5/93 - 5/94	Fecal coliforms (counts/100 ml) 5/94 - 10/95	% Reductions 5/94 - 10/95
		Column influent		
STE	--	35800	11500	--
CWE	--	3200	1400	87.8
RSFE	--	170	25	99.8
		Column leachate		
STE	15	910a*	23a	99.8
STE	30	70b	24a	99.8
STE	45	0c	0b	100
CWE	15	40bc	5b	99.6
CWE	30	0c	4b	99.7
CWE	45	0c	0b	100
RSFE	15	0c	4b	84.0
RSFE	30	0c	0b	100
RSFE	45	0c	0b	100

*Means within the same grouping followed by the same letter are not significantly different ($P<0.05$) as determined by Duncan's Multiple Range Test
STE - septic tank effluent
CWE - constructed wetland effluent
RSFE - recirculating sand filter effluent

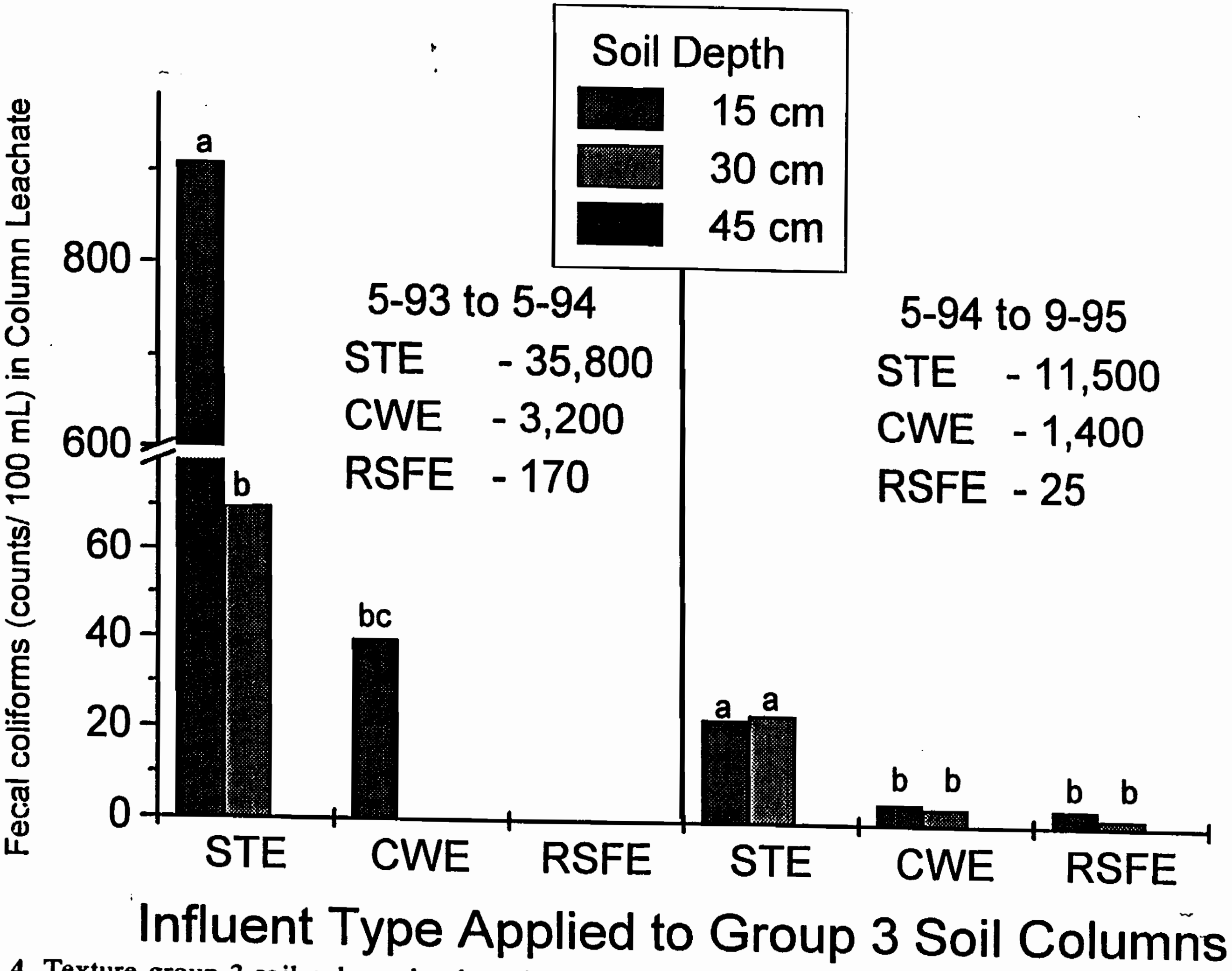

Figure 4. Texture group 3 soil column leachate fecal coliform reductions

The reason for this difference was attributed to a change in occupants at the residence. When the new occupants moved into the residence, the wastewater was initially very weak. This problem persisted intermittently until the beginning of August, 1995 when counts were similar to those in year 1.

Where STE was applied to the soil columns during year 1 there was a decrease in FC counts with increased soil depth and there were no FC present in leachate collected from the 45 cm soil columns. No FC counts were recorded for any soil depth where RSFE was applied to the soil columns.

Samples of column leachate collected during year 2 again showed a decrease in FC counts with increased soil depth. However, FC were present in the leachate from several soil columns for the first time (Table 6). Samples from the 45 cm deep soil columns that received STE, all three soil depths that received CWE, and RSFE were positive for the first time during year 2. It should be noted (Table 6) that in most instances only a few positive samples were recorded. The FC counts were effected by both soil depth and influent type with increasing depth reducing the FC counts and RSF being significantly better at reducing FC counts than CW.

Results from year 2 samples indicate that the depth of coliform penetration into the soil has increased. This is the opposite of what Simon et al. (1986) reported. They observed a reduction of hydraulic flow associated with the build up of the biological mat, which would reduce fecal coliform numbers in the leachate from these soils. It is speculated that the penetration of fecal coliform numbers is the result of changing the dosing regime from 6 times to 2 times daily.

It appears that several smaller doses (6) verses 1 or 2 larger doses improves the renovation performance of the soil. Smaller doses allows for more aeration of the system and a longer contact time between the effluent and the soil matrix. This would account for the improved performance of the system when effluent is applied in several small doses. Comparison of 6 small versus 2 large doses per day may be a comparison similar to that where drip irrigation is employed versus a LPD system.

These data make a strong case for utilizing a technology, such as drip or spray irrigation in shallow soils where STE is applied. Treatment of STE by CW or RSF can be substituted for soil depth.

3.2 Chemical Constituents

BOD$_5$

Texture Group 2 Soil

Treatment of STE by both CW and RSF systems lowered BOD$_5$ concentrations (Table 7 and Figure 5). When STE was treated by either a CW or a RSF, BOD$_5$ concentrations decrease from 90.4 to 61.1 (32%) and 28.0 (69%) mg L^{-1}, respectively. Gersbreg et al. (1984) reported 98% reductions in BOD$_5$ from municiple wastewaters using CW technology. Chowdhry (1978) reported reductions in BOD$_5$ concentrations of 96% and Piluk and Peters (1994) reported reductions of 98%, respectively, from STE treated by RSF.

There was a trend toward decreasing BOD$_5$ with increasing soil depth for STE as well as the other column influents (Table 8). BOD_5 was lower where STE was treated with a RSF than when treated with a CW (Table 7). Concentrations of BOD_5 in all the soil column leachates averaged below 8.1 mg L^{-1} for the columns that received CWE and RSFE, and averaged below 13.1 mg L^{-1} for the all the columns that received STE. These reductions show that treatment of STE by CW or RSF can reduce the travel distance of BOD_5 applied to soil systems.

Texture Group 3 Soil

The BOD_5 concentrations in the STE, CWE, and RSFE changed very little between year 1 and year 2 samples (Table 7). Additional treatment of STE by both the CW and RSF systems resulted in lower BOD_5 concentrations (Table 7 and Figure 6). There was a 38% and 75% reduction in BOD_5 when STE was treated by the CW and the RSF, respectively. The reduction efficiencies reported in the literature (Gersberg, 1986, and Piluk and Peters, 1994) for CW and RSF respectively are 20% to 60% higher than observed in this investigation. Gersberg et al. (1986) noted BOD_5 reductions of 33% from CW systems which are comparable to the reductions observed in this study.

Table 7. Effect of additional treatment on effluent concentrations of selected chemical constituents.

Effluent Type	BOD_5 (ppm)	NH_4-N (ppm)	NO_3-N (ppm)	PO_4-P (ppm)
Texture group 2 soil (4-95 to 10-95)				
STE	90.4	52.1	0.1	5.01
CWE	61.1	30.2	4.9	4.45
RSFE	28.0	8.5	29.3	5.13
Texture group 3 soil (5-93 to 5-94)				
STE	116	38	0.3	3.36
CWE	46	27.7	0.3	2.29
RSFE	6.6	6.87	20.9	3.43
Texture group 3 soil (10-94 to 10-95)				
STE	119	39.7	0.26	3.95
CWE	74	25.9	1.8	3.11
RSFE	30	3.3	23.6	3.75

STE - Septic Tank Effluent
CWE - Constructed Wetland Effluent
RSFE - Recirculating Sand Filter Effluent

Table 8. The effect of soil depth and influent type on selected chemical constituents in column leachate texture group 2 soil (4-95 to 10-95).

Influent Type	Soil Depth	BOD_5	NH_4-N	NO_3-N	PO_4-P
	(cm)	mg L^{-1}			
STE	.	11.3a*	16.7a	3.8c	1.14b
CWE	.	7.6b	10.0b	8.3b	1.07b
RSFE	.	4.6c	5.3c	23.8a	1.84a
o	15	8.8a	13.7a	15.2a	2.3a
o	30	7.1b	10.8a	12.1ab	0.9b
o	45	7.6ab	7.6b	8.7b	0.8b
STE	15	13.1a	24.9a	11.1b	2.8a
STE	30	10.6b	17.6b	0.4c	0.7cd
STE	45	10.5b	8.4cd	0.6c	0.08d
CWE	15	8.0c	11.1c	9.9b	1.3bc
CWE	30	8.1c	10.2c	8.4b	1.4bc
CWE	45	6.9cd	8.7cd	6.6bc	0.6cd
RSFE	15	6.1cd	6.0cd	23.3a	2.9a
RSFE	30	2.6e	4.3d	26.3a	0.7cd
RSFE	45	5.1d	5.6cd	21.5a	1.9b

. average among all soil depths
o average among all influent types
* means followed by the same letter are not significantly different ($p<0.05$) as determined by Duncan's Multiple Range Test
STE - Septic Tank Effluent
CWE - Constructed Wetland Effluent
RSFE - Recirculating Sand Filter Effluent

Table 9. The effect of soil depth and influent type on selected chemical constituents in column leachate texture group 3 soil (10-94 to 10-95).

Influent Type	Soil Depth	BOD_5	NH_4-N	NO_3-N	PO_4-P
	(cm)	mg L^{-1}			
STE	.	8.9a	7.4a	12.2a	0.19a
CWE	.	5.2b	3.2b	7.6a	0.27a
RSFE	.	3.3c	0.76b	11.3a	0.36a
o	15	7.88a*	6.8a	10.3a	0.58a
o	30	4.79b	1.2b	11.6a	0.18b
o	45	4.46b	3.2b	9.3a	0.05b
STE	15	10.1a	12.4a	11.3a	0.30b
STE	30	7.0ab	2.4cd	15.2a	0.21b
STE	45	9.8a	7.5b	9.9a	0.04b
CWE	15	8.5a	6.9bc	7.7a	0.67a
CWE	30	4.4bcd	0.8d	8.9a	0.15b
CWE	45	3.1cd	2.3cd	6.2a	0.05b
RSFE	15	5.4bc	1.4d	11.6a	0.78a
RSFE	30	3.0cd	0.4d	10.5a	0.19b
RSFE	45	1.4d	0.6d	11.9a	0.05b

. average among all soil depths
o average among all influent types
* means followed by the same letter are not significantly different ($p<0.05$) as determined by Duncan's Multiple Range Test
STE - Septic Tank Effluent
CWE - Constructed Wetland Effluent
RSFE - Recirculating Sand Filter Effluent

Table 10. The effect of soil depth and influent type on selected chemical constituents in column leachate from the texture group 3 soil (5-93 to 5-94).

Influent Type	Soil Depth	BOD_5	NH_4-N	NO_3-N	PO_4-P
	(cm)	mg L^{-1}			
Column influent					
STE	--	116	38	0.3	3.4
CWE	--	46	27.7	0.3	2.3
RSFE	--	6.6	6.9	20.9	3.4
Column leachate					
STE	15	2.3a*	1.7a	17.0abc	BDL
STE	30	1.4a	0.34b	19.1ab	BDL
STE	45	1.1a	0.21b	21.3a	BDL
CWE	15	3.9a	1.7a	6.6e	BDL
CWE	30	1.3a	0.25b	13.1cd	BDL
CWE	45	1.2a	0.20b	11.0de	BDL
RSFE	15	1.5a	0.53b	13.9bcd	BDL
RSFE	30	1.2a	0.20b	13.9bcd	BDL
RSFE	45	1.1a	0.23b	15.4abcd	BDL

*Means within the same grouping followed by the same letter are not significantly different ($P<0.05$) as determined by Duncan's Multiple Range Test.
STE - septic tank effluent
CWE - constructed wetland effluent
RSFE - recirculating sand filter effluent
BDL - below detection limits

There was little difference in the BOD_5 concentrations between soil depth where different effluent types were applied. Although, as one would expect, there is a trend toward higher BOD_5 concentrations in the leachate where STE was applied to the columns. The BOD_5 concentration decreased with increasing soil depth for STE as well as the other influents and the BOD_5 concentrations after treatment with RSF where lower than concentrations after treatment with a CW. Concentrations of BOD_5 averaged below 10 mg L^{-1} for all soil depths and treatments except the 15 cm columns that received STE which average slightly over 10 mg L^{-1}.

There was an increase in soil column leachate BOD_5 concentrations exhibited across all soil depths and effluent types (Tables 9 and 10 and Figure 6) from year 1 to year 2. This is attributable to the change in dosing frequency of the soil columns from 6 smaller doses to 2 larger ones per day. Two larger doses saturate the soil for longer periods of time and therefore reduce the available O_2 when compared with several smaller doses. Since BOD removal (organic carbon compound degradation) is enhanced under aerobic conditions one would expect higher degradation rates from systems that are capable of delivering effluent in small increments thus resulting in lower BOD_5 concentrations in the leachate from these systems. Also larger doses will transport BOD_5 to greater depth because of macropore flow. The evidence supports the case that drip or spray irrigation would reduce BOD_5 concentrations by reducing the amount of wastewater that has to percolate through the soil at any one time and allowing for a more aerobic soil environment.

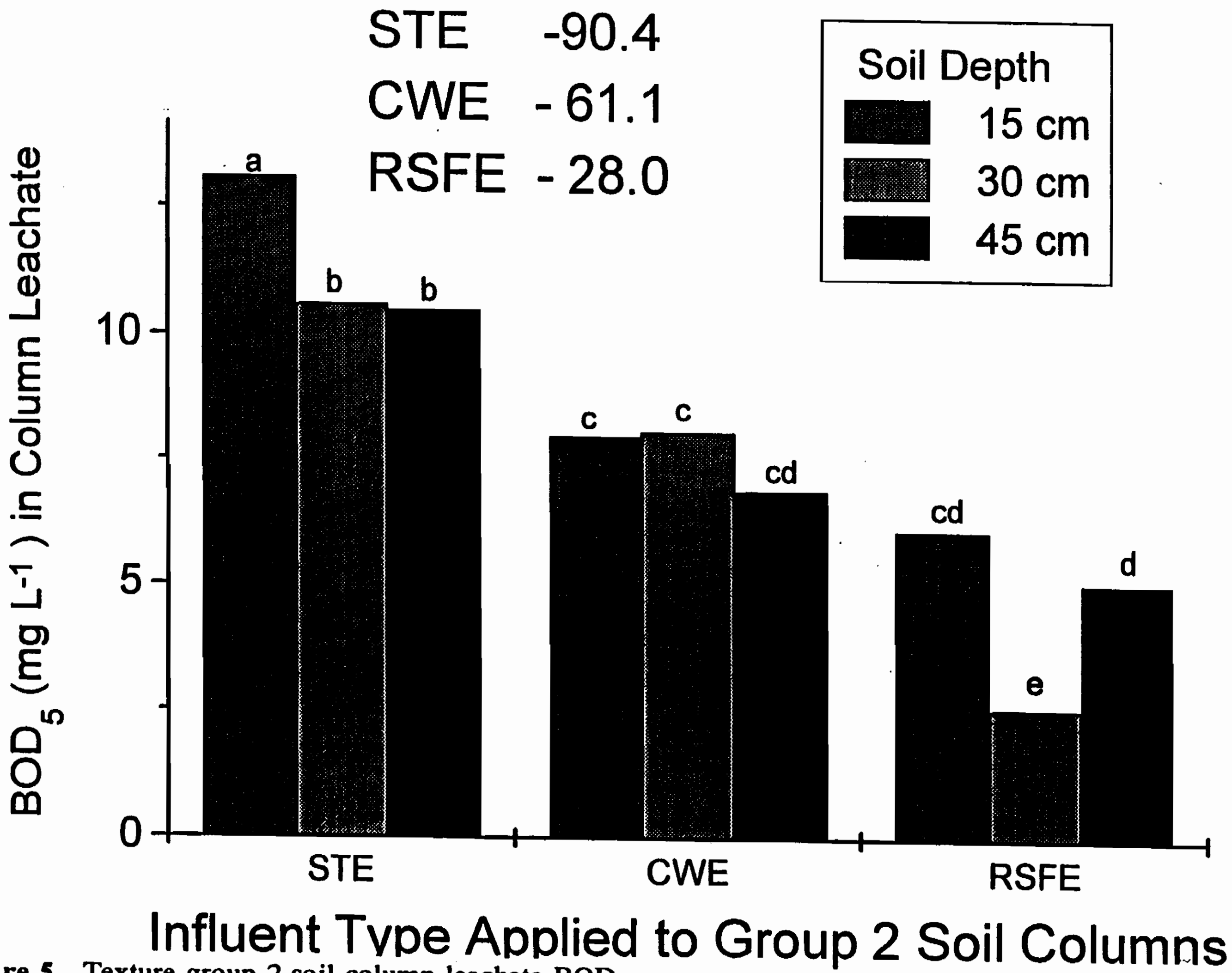

Figure 5. Texture group 2 soil column leachate BOD$_5$

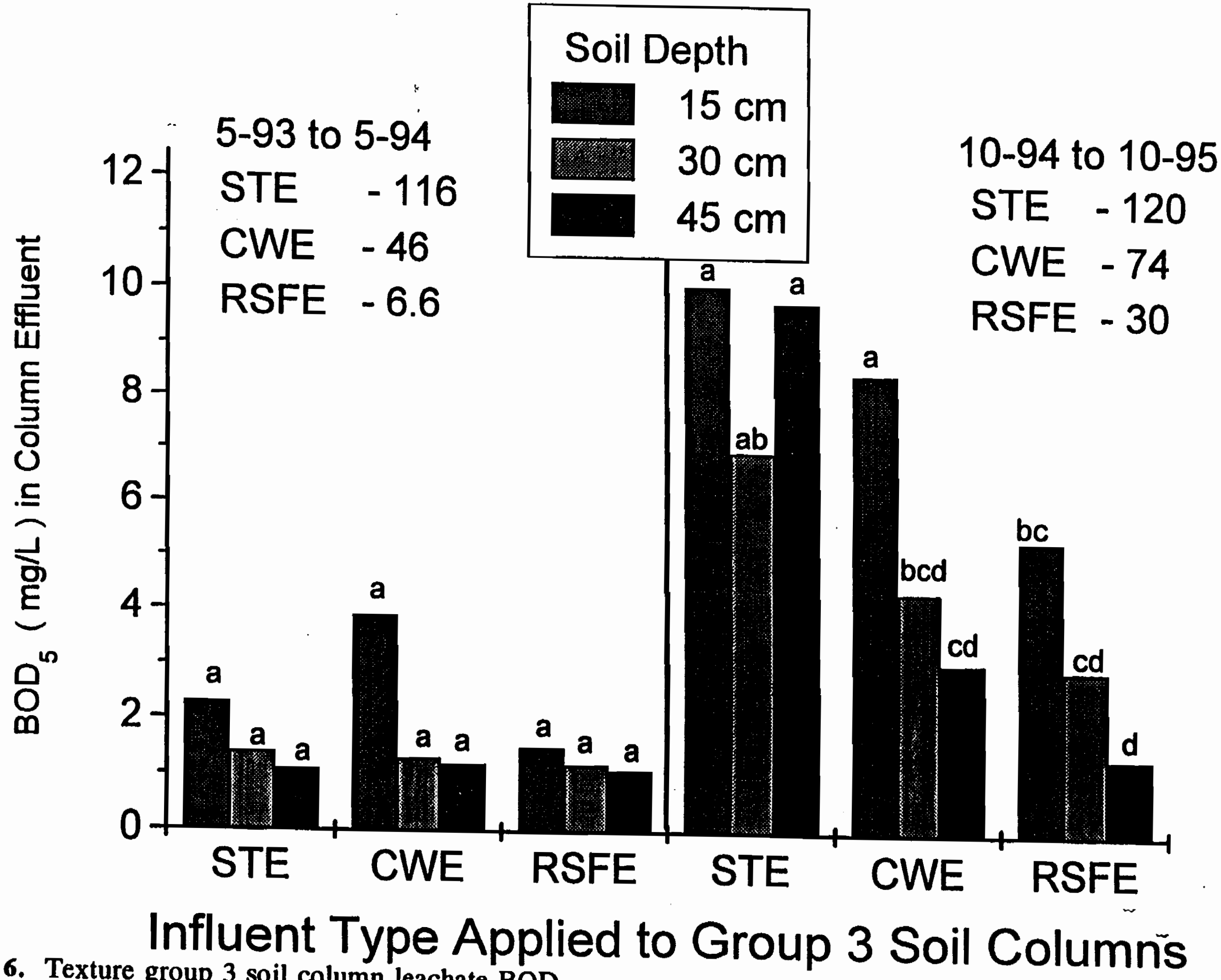

Figure 6. Texture group 3 soil column leachate BOD_5

As expected the leachate from the group 2 soil had higher average BOD concentrations than the group 3 soil at all soil depths except the 15 cm columns that received CWE and the 30 cm columns that received RSFE (Tables 8 and 9). However, these columns leachates were very similar in BOD concentrations and probably do not represent significant differences and are attributed to the inherent natural variabilities of soil systems.

Nitrogen

Texture Group 2 Soil

There was a 42% and 84% decrease in NH_4 concentrations after STE was treated by the CW and the RSF, respectively. There is a trend toward decreasing NH_4 concentrations with increasing soil depth were STE and CWE were applied to the soil columns (Table 7 and Figure 7). This trend does not exist in the soil columns dosed with RSFE because much of the NH_4 was nitrified in the RSF (Table 8). The columns that received STE had decreased NH_4 concentrations with increased soil depth. The NH_4 concentrations decreased from 24.9 to 17.6 mg L^{-1} from the 15 to 30 cm soil depths and to 8.7 mg L^{-1} at the 45 cm soil depth in the columns. Where CWE was applied there was a trend toward decreased NH_4 with increased soil depth. The concentrations of NH_4 were lower at the two shallowest depths than the concentrations present in the leachate from the columns that received STE. Concentrations of NH_4-N in all soil columns that received RSFE were below 7 mg L^{-1}.

Gersberg et al. (1984) reported reductions of total nitrogen (TN) form CW systems of 72%, and Wilson et al. (1982) reported changes in NH_4 concentrations of 99% from a RSF. The reductions in NH_4 in the CW are attributed to NH_3 volatilization, denitrification, and plant uptake by the vegetation in the CW (Huang, 1995). The NH_4 reductions in the RSF are attributable to the oxidation of NH_4 to NO_3 because the RSF is a highly aerobic environment when compared to either ST or CW. Also some N loss via denitrification would be expected in the RSF.

There was a relationship ($p < 0.05$) between increasing soil depth and effluent type and lower NO_3-N concentrations (Table 8 and Figure 8). Column leachate NO_3-N concentrations increased by 98% where RSFE was applied as compared to STE. Leachate from both the 15 cm and 45 cm deep soil columns that received RSFE, averaged 23.3 and 21.5 mg NO_3-N L^{-1}, respectively. The 30 cm columns that received RSFE averaged below 27 mg NO_3-N L^{-1}. All columns that received CWE had an average NO_3-N concentration lower than 10 mg L^{-1}. The 15 cm columns that received STE averaged less than 12 mg NO_3-N L^{-1} and the 30 and 45 cm soil columns averaged lower than 1 mg L^{-1}, however, there was a higher concentration of NH_4 in these columns. It is possible that the low NO_3 concentrations from the 30 and 45 cm columns dosed with STE were the result of denitrification because 4 of the 6 replications at these depths exhibited positive matric potentials and all of these columns are ponding effluent and may be anoxic. Probably NH_4^+ is being absorbed on the exchange sites and these sites have not been saturated in the deeper columns.

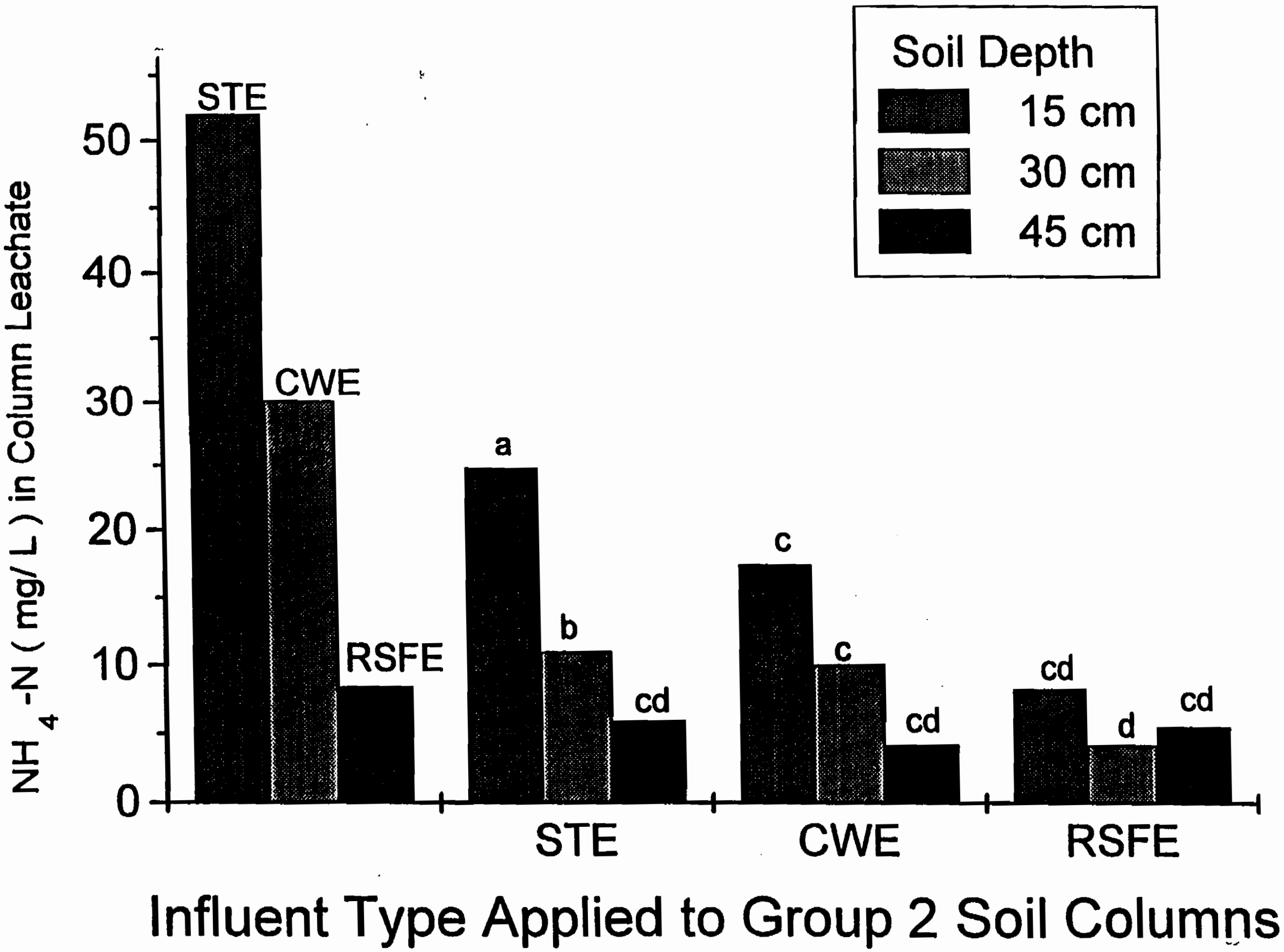

Figure 7. Texture group 2 soil column leachate NH_4-N

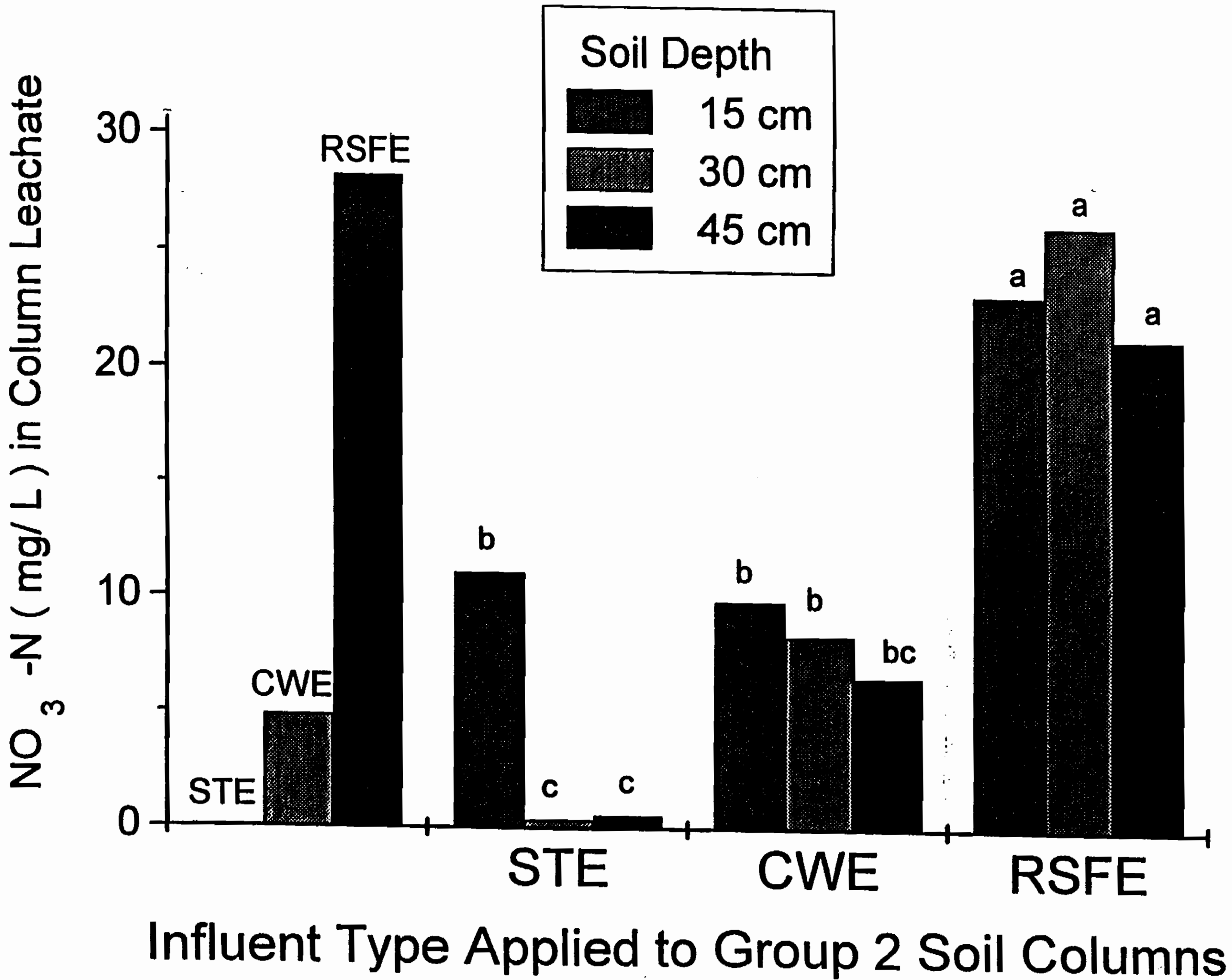

Figure 8. Texture group 2 soil column leachate NO_3-N

Column leachate TKN concentrations were less than 10 mg L^{-1} for all depths except from the 15 cm and 30 cm columns that received STE which were below 20 mg L^{-1}. Concentrations of TKN trend toward lower TKN with increasing soil depth, and additional treatment of STE by CW and RSF resulted in lower TKN concentrations in the column leachates (Table 11).

Texture Group 3 Soil

The average NH_4-N concentrations in the leachate from the 15, 30, and 45 cm deep columns that received CWE were below 7, 1 and 3 mg L^{-1}, respectively. The 15 and 45 cm columns that received STE averaged under 13 and 8 mg L^{-1} respectively, and the 30 cm deep soil columns averaged below 3 mg L^{-1}. All the columns that received RSFE had average NH_4-N concentrations below 2 mg L^{-1} (Table 9).

Concentrations of NH_4-N in the soil column leachates increased from year 1 to year 2 across all soil depths and effluent types (Tables 9 and 10). This is attributed to the change in dosing. Larger doses reduce the aeration status of the soil thereby reducing nitrification or by saturating the exchange sites allowing more NH_4 to leach out of the soil.

The NO_3 concentrations in the column leachates were lower in the current year as compared with year 1 samples (Tables 9 and 10) except for the 15 cm columns that received CWE which increased on average by 1 mg L^{-1}. The lower NO_3^- concentrations in the column leachate in year 2 may reflect enhanced denitrification or the reduced N in the influent or both. The decreases were particularly large in the

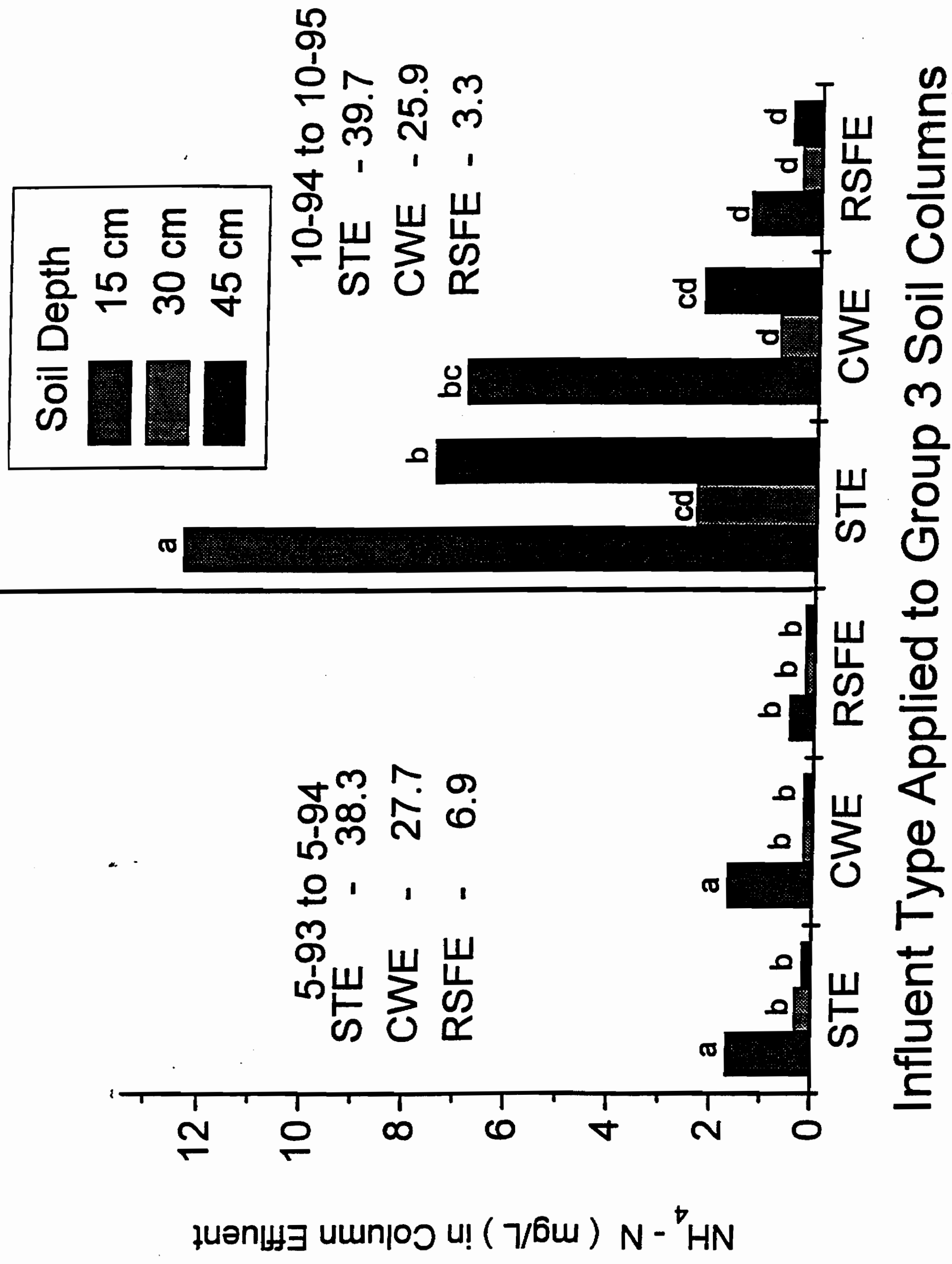

Figure 9. Texture group 3 soil column leachate NH$_4$-N year 1 and 2

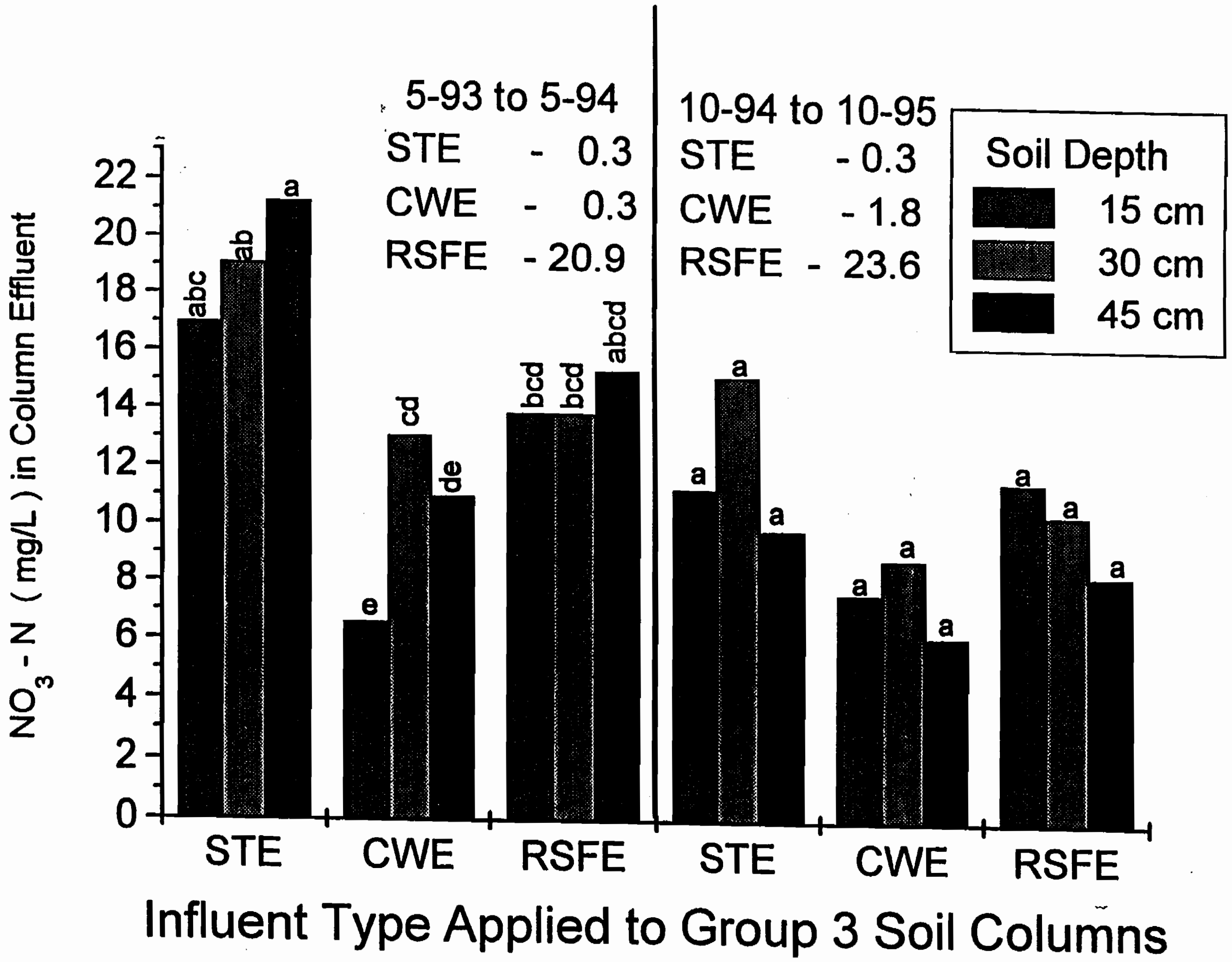

Figure 10. Texture group 3 soil column leachate NO_3-N year 1 and 2.

CWE. This decrease in concentration is attributable to a combination of NH_3 volatilization and denitrification (Huang et al., 1995). The reduction of dosing events per day may have had a large impact on the NO_3-N concentrations by lowering the aeration status of the soil thereby reducing nitrification and increasing denitrification. With respect to NO_3^-, the concentrations had increased on average from 0.3 mg L^{-1} to 2 mg L^{-1} in the CWE. This may be related to the weak effluent that was present during the transition between occupants in the residence since NO_3-N was present in concentrations < 1 mg L^{-1} in the CWE in the past (Duncan , 1994). This change in concentrations probably reflects the decreased N present in the STE during the occupancy change at the residence.

Year 2 leachate NO_3-N concentrations averaged less than 10 mg L^{-1} for all soil columns that received CWE as well as the 45 cm deep soil columns that received STE (Table 9, and Figure 10). All three soil depths that received RSFE as well as the 15 cm soil columns that received STE averaged below 12 mg L^{-1}, and the 30 cm deep soil columns that received STE averaged below 16 mg NO_3-N L^{-1}.

There is little difference in the NO_3-N concentrations in the leachate from the columns that received CWE for both soil textural groups except at the 15 cm depth were the group 2 leachate averaged 2 mg L^{-1} higher. This indicates the effectiveness of CW technology in reducing N from STE. Leachate NO_3-N concentrations were expected to be higher in the group 2 soil than in the group 3 soil for all treatments due to higher porosity in the group 2 soil. This was the case for all the soil columns that received RSFE which averaged over 10 mg L^{-1} higher NO_3 for the group 2 soil when compared to the group 3 soil (Tables 8 and 9). Very little NO_3 (< 1 mg L^{-1}) was detected (Table 8) from the 30 and 45 cm deep group 2 soil columns dosed with STE. Since all of these columns were ponding effluent and may have saturated anoxic conditions, denitrification seems a plausible explanation for the low NO_3-N concentrations present. The 15 cm deep soil columns that received STE for both textural groups were very similar in NO_3 concentrations (Tables 8 and 9). Additional treatment of STE by CW can be utilized to reduce NO_3-N concentrations in groundwater near OSWTDS and can be substituted for depth of soil in both textural groups.

The TKN concentrations increased from year 1 to year 2 across all treatments except for the 30 cm columns that received STE. These columns leachates were comparable to year 1 concentrations. Again this change in concentrations reflects the differences in dosing the columns 2 times daily verses 6 times daily. The concentrations of TKN in the STE and CWE were reduced in year 2 when compared to year 1 concentrations. This reflects the impact of the intermittent occupancy at the residence on the effluents. The RSFE concentrations showed little differences from year 1 to year 2. Regardless of soil depth or treatment type TKN concentrations were below 10 mg L^{-1} for the group 3 soil.

Table 11. Effects of soil depth and influent type on leachate TKN concentrations in texture group 2 and 3 soils.

Influent Type	Soil Depth	TKN group 2 soil	TKN group 3 soil year 1	TKN group 3 soil year 2
	(cm)	mg L^{-1}		
STE	.	14.19a	3.57a	6.61a
CWE	.	6.65a	3.77a	5.23a
RSFE	.	5.96a	3.04a	4.04a
o	15	9.47a	4.31a	6.01a
o	30	9.42a	2.97b	4.94a
o	45	7.90a	3.10b	4.93a
STE	15	15.67a	4.37ab	8.71a
STE	30	17.23a	3.37bc	4.90a
STE	45	9.66a	2.97c	6.23a
CWE	15	9.24a	4.87a	4.34a
CWE	30	5.46a	3.01c	6.23a
CWE	45	5.25a	3.43bc	5.11a
RSFE	15	3.5a	3.70abc	4.97a
RSFE	30	5.58a	2.52c	3.70a
RSFE	45	8.80a	2.90c	3.46a

. average among all soil depths

o average among all influent types

* means followed by the same letter are not significantly different ($p<0.05$) as determined by Duncan's Multiple Range Test

STE - Septic Tank Effluent

CWE - Constructed Wetland Effluent

RSFE - Recirculating Sand Filter Effluent

Phosphorus

Texture Group 2 Soil

There was no change in the PO_4-P concentrations when wastewater was treated by RSF (Table 8). The RSF utilized clean quartz sand which would not sorb or precipitate P significantly. However, the data suggest lower PO_4 (11%) concentrations with CW. Phosphate uptake by the vegetation in the CW or possible precipitation with Ca^{2+} or Mg^{2+} explains the reduction of P by CW (Huang, 1995).

There was an interaction ($p < 0.05$) between soil depth and influent type and for PO_4 concentrations in the soil column leachates. There is a trend toward lower PO_4 concentrations with increasing soil depth in the columns that received STE with the 30 and 45 cm depths being significantly lower than the 15 cm deep columns. This trend continued for the columns that received CWE in as much as the 45 cm deep columns had much lower leachate PO_4 concentrations than either the 15 or 30 cm depths which were not significantly different from each other (Table 8). The 30 cm deep columns that received RSFE were much lower than either the 15 or 45 cm deep columns. This may be due to the effects of macropore water movement resulting in insufficient soil contact and sorption in 2 of the 3 replications at the 45 cm depth. Regardless of treatment type or soil depth leachate PO_4 concentrations averaged below 3 mg L^{-1} resulting in a 41% reduction after soil filtration and reaction with the soil and soil microorganisms. The soil system below an OSWTDS is typically very efficient at removing PO_4 due to preferential exchange sites in the soil (Miller and Wolf, 1975;

Sikora and Corey, 1976) and the soils ability to precipitate P. However, with shallow soils these exchange sites, as well as precipitation maximums may become overloaded resulting in PO_4 being leached from the site.

Texture Group 3 Soil

There were differences in PO_4 concentrations in the column leachates from year 1 to year 2 of the study. Year 1 data showed that no PO_4 was being leached from the columns or that the concentrations were below detectable limits (Table 10). However, year 2 data shows that PO_4 was being leached in detectable concentrations form all soil depths and treatment types (Table 9). This might indicate that the P fixation capacity has been utilized or that the change in dosing is responsible for the P in the leachate collected from the columns during year 2. Applying fewer larger doses would result in less contact with the soil matrix thereby reducing the fixation capacity of the soil for P.

There was evidence ($p < 0.05$) that the PO_4 concentrations were being reduced with increasing soil depth for all effluents during year 2. Regardless of soil depth or treatment type PO_4 concentrations averaged below 1 mg L^{-1}. The group 2 soil leachate PO_4-P concentrations averaged over twice as high as those from the group 3 soil. This was expected because of the lower clay content and higher sand content in the group 2 soil. Coarser textured soils also have a greater porosity allowing for less filtration of an effluent as it percolates through the soil matrix. Mineralogy and clay content of a soil will have a direct relationship with the soils P fixation capacity.

pH, EC, TDS, Cl-

Texture Group 2 Soil

Soil column leachate pH, EC, and TDS were effected by soil depth (Table 12) but not Cl. Leachate from the 15 cm soil deep soil columns had a higher pH and higher concentrations of EC and TDS than the 30 or 45 cm soil depth. There was no interaction ($p < 0.05$) between soil depth and effluent type and there was no difference between effluent for pH, EC, and TDS and Cl. With respect to column leachate, there was no change in Cl concentration as a function of soil depth or influent type. This was expected because Cl is not readily used by microbes or plants, and is not precipitated or adsorbed by soils therefore there is no reduction mechanism for the removal of Cl from the wastewater.

Texture Group 3 Soil

Soil column leachate pH, EC, and TDS were impacted by soil depth with the 15 cm soil depth being higher than the 30 or 45 cm soil depths (Table 13). Leachate pH and TDS were not significantly affected by effluent type. However, EC was effected by effluent type with STE being significantly higher than either CWE or RSFE. Leachate Cl concentrations were not effected by either soil depth or effluent type.

The group 2 soil had lower pH, EC, and TDS, but higher Cl concentrations than the group 3 soil. For both texture group soils there was a parallel relationship between EC and TDS (Tables 12 and 13). The influent pH, EC, and TDS values

Table 12. The effect of soil depth and influent type on selected chemical constituents in column leachate from the texture group 2 soil (4-95 to 10-95).

Influent Type	Soil Depth	pH	EC	TDS	Cl^-
	(cm)	$[H^+]$	(uS/cm)	(ppm)	(ppm)
STE	.	6.93a*	813.8a	405.4a	38.8a
CWE	.	6.80a	801.8a	399.4a	36.3a
RSFE	.	6.74a	763.1a	380.1a	37.7a
o	15	6.98a	908.6a	452.6a	39.0a
o	30	6.69b	763.6b	380.5b	37.5a
o	45	6.79ab	707.4b	352.3b	36.3a
STE	15	7.19a	993.8a	495.2a	40.7a
STE	30	6.66bc	801.0bcd	398.9bcd	38.9a
STE	45	6.95ab	672.1d	334.9d	36.9a
CWE	15	6.88abc	890.7ab	443.8ab	38.1a
CWE	30	6.86abc	768.8bcd	383.3bcd	34.7a
CWE	45	6.66bc	741.1cd	368.9cd	35.9a
RSFE	15	6.88abc	853.4bc	425.0bc	38.3a
RSFE	30	6.55c	719.7cd	358.7cd	38.6a
RSFE	45	6.76bc	709.1d	353.1d	36.2a

. average among all soil depths
o average among all influent types
* means followed by the same letter are not significantly different ($p<0.05$) as determined by Duncan's Multiple Range Test
STE - Septic Tank Effluent
CWE - Constructed Wetland Effluent
RSFE - Recirculating Sand Filter Effluent

Table 13. The effect of soil depth and influent type on selected chemical constituents in column leachate from the texture group 3 soil (10-94 to 10-95).

Influent Type	Soil Depth	pH	EC	TDS	Cl^-
	(cm)		uS/cm	(ppm)	(ppm)
STE	.	7.20a*	929.3a	461.4a	28.8a
CWE	.	7.25a	883.9ab	444.7ab	29.7a
RSFE	.	7.18a	859.8b	427.8b	28.8a
o	15	7.3a	929.3a	462.5a	30.0a
o	30	7.12b	880.3ab	437.1ab	29.6a
o	45	7.21b	857.5b	431.4b	27.7a
STE	15	7.24bc	978.7a	487.3a	30.8a
STE	30	7.03d	910.1ab	449.5ab	29.9a
STE	45	7.34ab	898.8ab	447.3ab	25.3a
CWE	15	7.43a	917.5ab	456.7ab	30.4a
CWE	30	7.15cd	883.3ab	439.8ab	29.9a
CWE	45	7.19bcd	851.1b	438.1ab	29.0a
RSFE	15	7.24bc	898.4ab	447.1ab	28.9a
RSFE	30	7.19bcd	849.7b	422.8b	28.9a
RSFE	45	7.10cd	824.4b	411.5b	28.5a

. average among all soil depths
o average among all influent types
* means followed by the same letter are not significantly different ($p<0.05$) as determined by Duncan's Multiple Range Test
STE - Septic Tank Effluent
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RSFE - Recirculating Sand Filter Effluent

averaged higher in the group 3 soil than the group 2 soil, and group 3 soil Cl levels averaged lower than the group 2 soil, and this may explain the differences in the leachates from the 2 soils.

3.3 Soil Infiltration Rates

Texture Group 2 Soil

Infiltration rates in the group 2 soil columns were effected by effluent type and soil depth (Table 14, and Figure 11). When STE is treated by either CW or RSF infiltration rates will be higher than soils that received untreated STE. As expected with increasing depth of soil; infiltration rates decrease as the percolating water has a more tortuous path than in shallower soil depths. Even though this soils texture is coarser than that of the group 3 soil it has a lower saturated hydraulic conductivity (KSAT) than the group 3 soil (Tables 2 and 3). This is attributed to weaker structural development in the group 2 soil than in the group 3 soil. Also the Bt2 horizon (Appendix 2) of the group 2 soil had the least developed structure, lowest hydraulic conductivity, and the highest bulk density than any other soil horizon in its soil profile. Development of a crust or biological mat at the soil gravel interface reduces hydraulic infiltrative capacities across this barrier (Bouma, 1975; Simon et al., 1986). This reduction could result in hydraulic failure and surface discharge of STE. Figure 11 illustrates the effect of treatment of STE on infiltration rates. Additional treatment of STE results in higher hydraulic infiltration rates allowing for a more aerobic soil environment resulting in longer hydraulic longevity of the soil absorption system.

Texture Group 3 Soil

Soil infiltration rates decreased from year 1 to year 2 for the group 3 soil particularly with respect to the columns that received STE. This may reflect the difference in the dosing regime or the effect of time and effluent type on infiltrative capacities. As Simon et al. (1986) stated temporal reductions in infiltration rates can be attributed to formation of a biological mat or crust. This is postulated as the reason for the reduction in infiltration rates in both soil groups tested. When STE is treated by CW or RSF, infiltration rates were higher. The RSF being superior to CW in maintaining infiltration of the wastewater (Table 14, and Figure 11).

3.4 Soil Water Potential

Texture group 2 soil

Matric potentials are an indicator of the energy status of water within a soil system. The group 2 soil columns had several treatments that had positive matric potentials (Table 15). All 15 cm deep columns were negative indicating that they were not saturated. However, the 30 and 45 cm deep columns that received STE and CWE averaged positive potentials as well as the 45 cm deep columns that received RSFE. These columns are probably saturated and wastewater renovation of this soil may be effected by anoxic conditions associated with saturated soils.

The type of effluent had an impact on matric potentials in the group 2 soil (Table 15). The columns that received STE and CWE averaged positive potentials and the columns that received RSFE averaged negative potentials.

Table 14. Infiltration rates group 2 and group 3 soils.

Influent Type	Soil Depth	Group 2 10/95	Group 3 6/94	Group 3 10/95
	cm	(cm/min)x10^{-3}	(cm/min)x10^{-3}	(cm/min)x10^{-3}
STE	.	9.0a*	53.0a	11.0a
CWE	.	15.3a	76.0a	12.0a
RSFE	.	20.0a	164.0b	244.0b
o	15	19.0b	112.0a	19.0a
o	30	15.0b	70.0a	32.0a
o	45	6.0a	66.0a	10.0a
STE	15	7.0abc	53.0ab	8.0ab
STE	30	6.0ab	64.0abc	22.1b
STE	45	5.0a	45.0a	7.0a
CWE	15	17.0bc	167.0bc	41.0ab
CWE	30	16.0bc	48.0a	11.0ab
CWE	45	13.0bc	80.0abc	8.0ab
RSFE	15	26.0c	588.0c	156.0b
RSFE	30	21.0c	161.0bc	35.2b
RSFE	45	13.0bc	97.0bc	33.2b

. average among all soil depths
o average among all influent types
* means followed by the same letter are not significantly different ($p < 0.05$) as determined by Duncan's Multiple Range Test
STE - Septic Tank Effluent
CWE - Constructed Wetland Effluent
RSFE - Recirculating Sand Filter Effluent

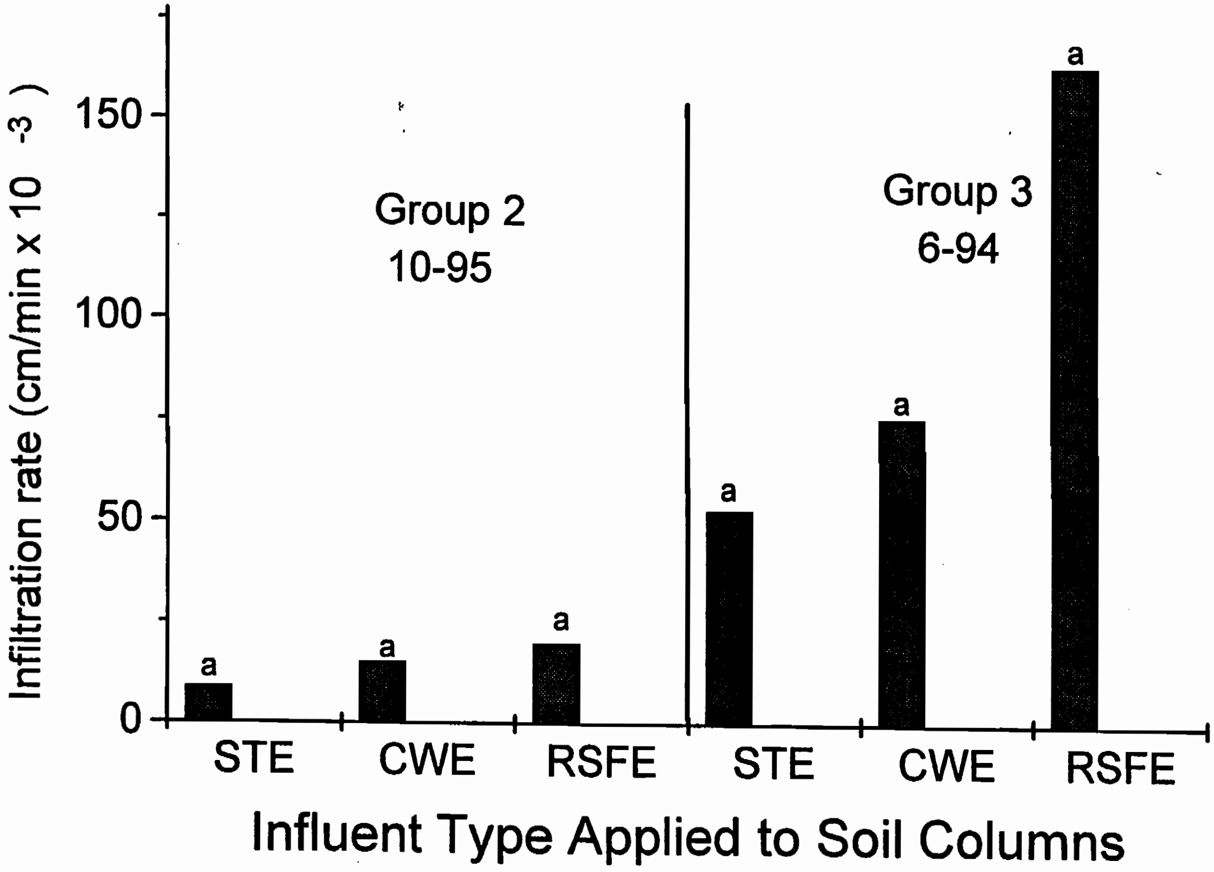

Figure 11. Texture groups 2 and 3 soils infiltration rates.

It should be noted that the columns that received CWE were barely positive when compared to the columns that received STE. Soil depth in the group 2 soil seemed to have an impact on matric potentials, in that, with increasing soil depth the more positive were the potentials (Table 15). This reflects the Bt2 horizon which had the lowest hydraulic conductivity in the group 2 soil profile.

Texture group 3 soil

The average matric potentials in all the group 3 soil columns were negative for year 2. However, they were more positive than the year 1 results (Table 15). This is attributed to the change in the dosing regime of these soil columns, resulting in more saturated conditions than in year 1 of this study. There was no difference based on soil depth in the group 3 soil columns. There was a trend toward more positive potentials were STE was applied when compared to the other effluents. This is attributed to the higher levels of solids in STE when compared CWE or RSFE.

3.5 Soil Temperature

Soil temperatures where highest (24°C) during the summer months of July and August for both soil texture groups and lowest (10°C) in April and October. There was no difference in temperature between soil texture groups or temperatures at any soil depth.

3.6 Plant Tissue Dry Weight and N Content

There was a trend to more plant tissue being produced from the columns that received RSFE and CWE than those that received STE in the group 3 soil columns.

This may be due to higher NO_3 concentrations in the columns dosed with these effluents and tall fescue may have a preference for NO_3 as a N source. It is also possible that less N was available because of N loss. The group 2 soil columns plant tissue was sampled one time because the grass died in most of the columns during the summer.

There is little difference in the plant tissue TKN concentrations between textural groups (Figure 12). Concentrations of TKN between textural groups varied approximately 1/2 to 1 % with the group 3 soil columns being slightly higher in N content than the group 2 soil. This may only reflect the difference in time since the group 3 columns have been growing fescue longer than the group 2 soil columns. It is possible that the varietal differences between the grasses Kentucky 31 (group 3 soil) and Falcon II (group 2 soil) explain the slight difference in N content. That is to say one variety may be genetically pre-disposed to accumulate more N in its tissues than the other. However, it is more likely that since the group 3 soil columns have a well developed turf that has been growing in them with vigorous root systems for a longer time resulted in more N accumulating in the grass tissues from the group 3 soil.

Table 15. Soil matric potentials texture group 2 and 3 soils.

Influent Type	Soil Depth	Matric Potential Group 2 Soil 4/95 to 10/95	Matric Potential Group 3 Soil year 1	Matric Potential Group 3 Soil year 2
	(cm)	(kPa)	(kPa)	(kPa)
STE	.	+0.18a	-0.91a	-0.09a
CWE	.	+0.02a	-0.78a	-0.24a
RSFE	.	-0.75b	-0.92a	-0.59a
o	15	-0.72b	-0.72a	-0.16a
o	30	-0.11b	-0.89a	-0.38a
o	45	+0.28a	-1.02a	-0.38a
STE	15	-0.82b	-0.68a	-0.12a
STE	30	+0.96a	-0.91a	-0.04a
STE	45	+0.41a	-1.15a	-0.11a
CWE	15	-0.59b	-0.59a	-0.03a
CWE	30	+0.29a	-0.77a	-0.47a
CWE	45	+0.37a	-0.96a	-0.21a
RSFE	15	-0.76b	-0.89a	-0.32a
RSFE	30	-1.56b	-0.93a	-0.63a
RSFE	45	+0.07a	-0.95a	-0.82a

. average among all soil depths
o average among all influent types
* means followed by the same letter are not significantly different ($p<0.05$) as determined by Duncan's Multiple Range Test
STE - Septic Tank Effluent
CWE - Constructed Wetland Effluent
RSFE - Recirculating Sand Filter Effluent

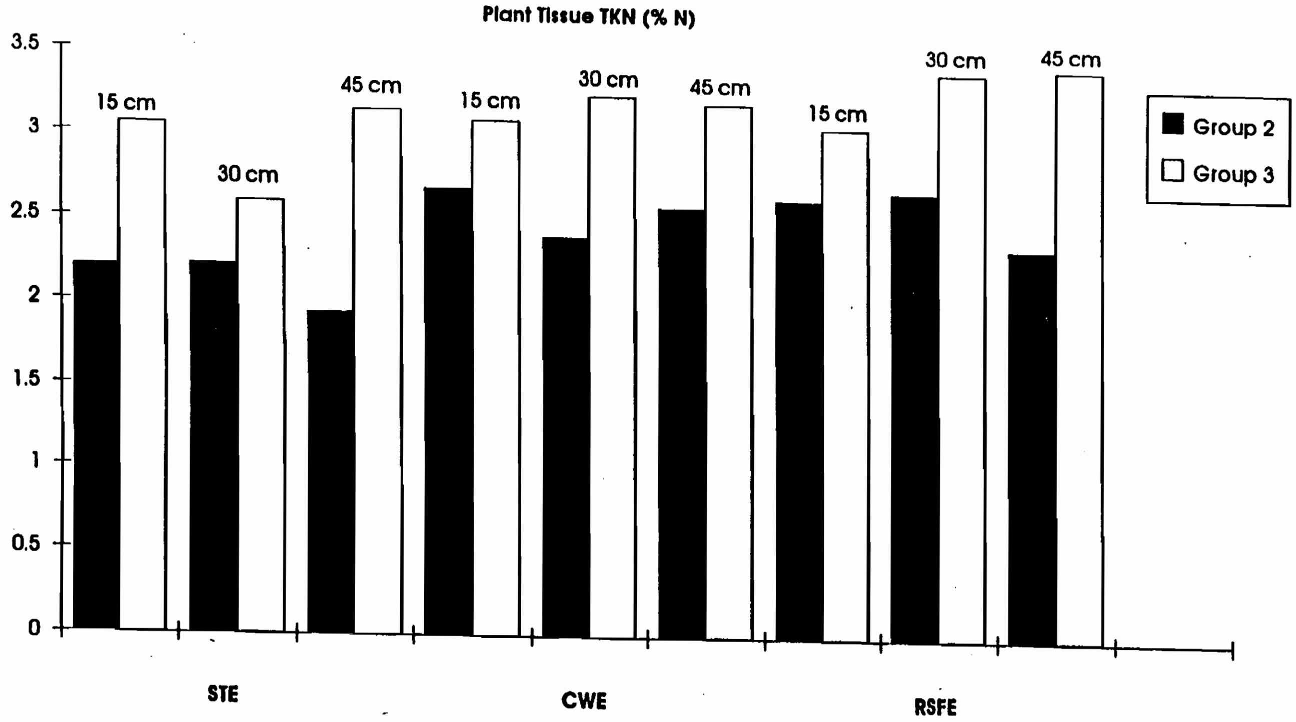

Figure 12. Plant tissue TKN content in the texture group 2 and 3 soil

4.0 Conclusions

The results of this investigation indicate that the group 2 soil has less potential for the biological and chemical renovation of domestic wastewaters when compared with the group 3 soil. This conclusion is evidenced by higher FC counts, BOD_5 values, and concentrations of NH_4, NO_3, and PO_4 in column leachates. The data suggest that the CW and the RSF treatment systems are effective in the renovation of domestic wastewaters regardless of soil textural group. This may enable the use of marginally suited soils in conjunction with these additional treatment systems. Soils of both textural groups provide wastewater renovation even at the 15 cm depth, with the data supporting the conclusion that there is increasing renovation with increasing soil depth and that fecal indicator organisms may penetrate deeper into the soil with increasing time or decreased loading cycles. Both soil texture groups will renovate wastewaters to recreational water standards (USEPA, 1980).

Performance of soil absorption systems will be improved with the utilization of CW and RSF systems and by increasing the number of doses and thereby reducing the amount of water that the system receives per dose. The relationship was evidence by the reduction of renovation performance by the group 3 soil when the dosing regime was reduce from 6 times to 2 times per day. This may enable on-site systems such as drip irrigation to be utilized where LPD or conventional systems are not feasible. A drip irrigation distribution system would increase the renovation potential of a site because of the reduction of wastewater that is being applied at any one time, thus allowing the soil absorptive system to remain aerobic or unsaturated for longer periods of time. These aerobic condition would increase the lifespan of the soil absorption system by allowing higher degradation rates of the organics in the waste stream.

The use of soil texture as a guide can be a reliable method for determination of a soils hydraulic capacity. However, soil structure must be evaluated and considered to make an adequate estimate of a soils hydraulic infiltration capacity. Water will travel the path of least resistance down a gradient. Large continuous macropores, when compared to micropore geometry, will provide said path and therefore cannot be ignored.

Notwithstanding the essentially variable nature of the soil environment at a given location, an evaluation of certain environmental factors has shown that many adverse effects can be overcome once the nature of the effects, such as soil depth, and the result of their interaction with certain operating factors, such as the reduction of FC by RSF, of the on-site system are known.

5.0 Summary

Many soils are marginally suited for installation of on-site wastewater treatment and disposal systems (OSWTDS) because of depth to rock, restricting soil horizon, or separation distance to a water table. With these limitations, additional treatment of septic tank effluent (STE) by either constructed wetlands (CW), or recirculating sand filters (RSF) prior to soil application may allow for a reduction in suitable soil depth and still not significantly degrade ground and surface water quality. Therefore, an investigation into the effects of soil depth, additional treatment, and soil texture group on household wastewater renovation was begun in May of 1993 for a texture group 3 (clay loam) soil and April of 1995 for a texture group 2 (loam) soil at the Kentland Research farm (Whitethorn, VA).

Renovation ability was measured by the extent of biological and chemical renovation of the leachate collected from undisturbed soil columns dosed with three types of wastewater; septic tank effluent (STE), constructed wetland (vegetated subsurface bed) effluent (CWE), and recirculating sand filter effluent (RSFE). The three effluent types were applied to three soil depths 15, 30, and 45 cm of both texture group 2 (loam) and group 3 (clay-loam) subsoils and was replicated three times.

Fecal coliform counts showed that additional treatment of STE prior to soil application reduced the number of FC present in the column leachate. The FC counts decreased from 11,450/100 ml to 1380 (88%) and 23 counts/100 ml (94%) after treatment of the STE with the CW and the RSF, respectively.

Soil depth and influent type impacted FC counts in the column leachate. Where STE was applied to the soil columns the FC counts in the leachate from the 15 cm deep columns were higher than those present for any other treatment. Also there was a trend toward decreased FC counts with increased soil depth where STE and CWE were applied to the soil columns. For both textural groups 2 and 3 the data indicate that 45 cm of soil is sufficient to renovate STE to recreational standards (USEPA, 1980).

Treatment of STE by both CW and RSF systems lowered BOD_5 concentration. When STE was treated by CW and RSF, there was a reduction in BOD_5 concentrations decrease from 90.4 to 61.1(32%) and 28.0 (69%) mg L^{-1}, respectively. Concentrations of BOD_5 in all the group 2 soil column leachates averaged below 8.1 mg L^{-1} for the columns that received CWE and RSFE, and averaged below 13.1mg L^{-1} for the all the columns that received STE. These reductions show that treatment of STE by CW or RSF can be substituted for soil depth in texture group 2 soils. Leachate from the group 3 columns had concentrations of BOD_5 that averaged below 10 mg L^{-1} for all soil depths and treatments except the 15 cm columns that received STE which average slightly over 10 mg L^{-1}. The leachate from the group 2 soil had higher average BOD concentrations than the group 3 soil at all soil depths except the 15 cm columns that received CWE and the 30 cm columns that received RSFE. Treatment of STE by either CW or RSF can be safely substituted for soil depth.

There was a 42% and 84% decrease in NH_4 concentrations after STE was treated by the CW and the RSF, respectively. In the group 2 soil columns there was a trend toward decreasing NH_4 concentrations with increasing soil depth were STE and CWE were applied to the soil columns. This trend does not exist in the soil columns dosed with RSFE because much of the NH_4 was nitrified in the RSF. The group 2 columns that received STE had decreased NH_4 concentrations in the leachate with increased soil depth. The NH_4 concentrations decreased from 24.9 to 17.6 mg L^{-1} from the 15 to 30 cm soil depths and to 8.7 mg L^{-1} at the 45 cm soil depth in the columns were STE was applied. Where CWE was applied there was a trend toward decreased NH_4 with increased soil depth. Concentrations of NH_4-N in all soil columns that received RSFE were below 7 mg L^{-1}. Column leachate NO_3-N concentrations increased by 98% where RSFE was applied as compared to STE. At both 15 cm and 45 cm deep soil columns that received RSFE averaged NO_3-N concentrations of 23.3 and 21.5 mg L^{-1} respectively. The 30 cm columns that received RSFE averaged below 27 mg L^{-1} NO_3-N. All columns that received CWE had an average NO_3-N concentration lower than 10 mg L^{-1}. The 15 cm columns that received STE averaged less than 12 mg L^{-1} NO_3-N and the 30 and 45 cm soil columns averaged lower than 1 mg L^{-1}.

The NH_4-N concentrations in the leachate from the 15, 30, and 45 cm deep group 3 columns that received CWE averaged below 7, 1 and 3 mg L^{-1}, respectively. The 15 and 45 cm columns that received STE averaged under 13 and 8 mg L^{-1} respectively, and the 30 cm deep soil columns averaged below 3 mg L^{-1}. All the columns that received RSFE averaged NH_4-N concentrations below 2 mg L^{-1}.

Year 2 leachate NO_3-N concentrations averaged less than 10 mg L^{-1} for all group 3 soil columns that received CWE as well as the 45 cm deep soil columns that received STE. All three soil depths that received RSFE as well as the 15 cm soil columns that received STE averaged below 12 mg L^{-1} NO_3-N, and the 30 cm deep soil columns that received STE averaged below 16 mg L^{-1} NO_3-N.

Regardless of treatment type or soil depth leachate PO_4 concentrations from the group 2 soil columns averaged below 3 mg L^{-1} resulting in a 41% reduction after soil filtration and reaction with the soil and soil microorganisms. There were differences in PO_4 concentrations in the group 3 column leachates from year 1 to year 2 of the study. Year 1 data showed that no PO_4 was being leached from the columns or that the concentrations were below detectable limits. However, year 2 data shows that PO_4 was being leached in detectable concentrations form all soil depths and treatment types. The group 2 soil leachate PO_4-P concentrations averaged over twice as high as those from the group 3 soil. This was expected because of the lower clay content and higher sand content in the group 2 soil. Coarser textured soils also have a greater porosity allowing for less filtration of an effluent as it percolates through the soil matrix.

The group 2 soil had lower pH, EC, and TDS, but higher Cl concentrations than the group 3 soil. For both texture group soils there was a parallel relationship between EC and TDS. The influent pH, EC, and TDS values averaged higher in the group 3 soil than the group 2 soil, and group 3 soil Cl levels averaged lower than the group 2 soil, and this may explain the differences in the leachates from the group 2 soils.

Infiltration rates in the group 2 soil columns were affected by effluent type and soil depth. When STE is treated by either CW or RSF infiltration rates will be higher than soils that received untreated STE. Soil infiltration rates decreased from year 1 to year 2 for the group 3 soil particularly with respect to the columns that received STE. This decrease may reflect the difference in the dosing regime or the effect of time and effluent type on infiltrative capacities.

The type of effluent had an impact on matric potentials in the group 2 soil. The columns that received STE and CWE averaged positive potentials and the columns that received RSFE averaged negative potentials. The average matric potentials in all the group 3 soil columns were negative for year 2. However, they were more positive than the year 1 results. This increase is attributed to the change in the dosing regime of these soil columns, resulting in more saturated conditions than in year 1 of this study.

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APPENDIX: 1
DATA

Appendix 1: Soil column number key group 2 soil.

#Column	description
111	15 cm STE replication 1
112	15 cm STE replication 2
113	15 cm STE replication 3
211	30 cm STE replication 1
212	30 cm STE replication 2
213	30 cm STE replication 3
311	45 cm STE replication 1
312	45 cm STE replication 2
313	45 cm STE replication 3
121	15 cm CWE replication 1
122	15 cm CWE replication 2
123	15 cm CWE replication 3
221	30 cm CWE replication 1
222	30 cm CWE replication 2
223	30 cm CWE replication 3
321	45 cm CWE replication 1
322	45 cm CWE replication 2
323	45 cm CWE replication 3
131	15 cm RSFE replication 1
132	15 cm RSFE replication 2
133	15 cm RSFE replication 3
231	30 cm RSFE replication 1
232	30 cm RSFE replication 2
233	30 cm RSFE replication 3
331	45 cm RSFE replication 1
332	45 cm RSFE replication 2
333	45 cm RSFE replication 3

Group 2 soil column leachate BOD(5) mg/L

Column #	Apr-95	May-95	Jun-95	Jul-95	Aug-95	Sep-95	Oct-95
111	13	16.425	NS	9.75	14.1	NS	11.6
112	12.98	8.775	14.85	5.9	13.425	15.9	14.3
113	13.05	20.85	NS	6.75	13.2	17.025	NS
211	7.04	16.95	5.55	8.1	14.85	13.725	13.1
212	8.45	4.275	4.43	12.75	14.25	14.55	13.3
213	8.1	9.865	4.88	8.025	14.475	13.275	12.4
311	7.1	4.615	9.9	7.95	14.55	14.85	16.1
312	9.2	6.08	6.04	13.35	15	14.1	7.2
313	20.5	5.74	9	2.025	14.625	14.025	9.3
121	5.4	7.765	5.96	9.9	6.075	6.263	7.4
122	8.5	10.13	6.68	15.225	6.825	6.975	8.2
123	5.1	12.49	5.93	11.475	5.8125	7.238	8
221	5.15	7.015	6.38	11.85	24.3	NS	NS
222	5.98	6.225	6.64	10.65	9.375	4.388	3.7
223	5.3	8.7	6.72	12	5.8875	7.05	5.7
231	9.7	7.465	5.52	9.675	10.0125	7.088	2.6
232	7.6	6.865	5.4	11.175	6.3	5.888	8.4
233	6.55	1.505	6.3	10.725	5.7375	6.15	4
131	3.6	9.19	9.19	8.55	6.9	8.625	5.9
132	4.6	7.5	6.56	6.6	7.6875	9.075	1
133	2.9	1.875	3.75	7.05	7.2	7.65	3.5
231	3.9	1.5	3.42	2.775	2.1	1.425	1.4
232	1.6	1.425	2.96	3.075	2.625	2.175	0.8
233	4.1	1.765	2.81	5.325	3.5625	3.525	NS
331	3.7	1.95	2.97	5.925	6.75	2.25	NS
332	3.5	4.615	3.9	9.3	7.425	8.025	NS
333	9.45	1.615	3.6	15.45	1.7625	2.475	2.4
STE	159	106.5	94.5	67.5	105.5	15.9	84
CWE	78	57	69	45	97	20.4	NS
RSFE	43.4	25.5	48	2.3	30.5	7.425	39

NS = No Sample obtained

Group 2 soil column leachate Cl ppm							
Column #	Apr-95	May-95	Jun-95	Jul-95	Aug-95	Sep-95	Oct-95
111	31.9	41.7	38.4	39.4	44.7	NS	37.2
112	31.9	41.8	29.7	50.4	47.2	45.2	35.6
113	33.6	35.4	34.4	46.5	47.6	60.5	NS
211	30.8	35.4	34.4	37.4	51.7	44.4	36.6
212	30.6	34.6	29.6	30.4	46.9	51.9	39.5
213	28.95	39.7	31.3	48.6	45.6	51.3	36.5
311	27.6	35.9	29.9	31.8	45.5	49.3	43.2
312	23.3	35.9	31.9	29.5	45.5	48.6	41.2
313	23.5	36.3	29.4	29.4	45.2	48.6	43.5
121	36.2	44.6	26.1	30.4	46.1	47.9	44.5
122	33.6	35.1	24.9	31.3	52	48.3	40.6
123	32.4	37.7	23.1	28.9	48.1	47.9	41.1
221	26.8	33.7	26.6	27.9	44.1	NS	NS
222	30.2	35.1	29.4	21.8	33.5	46.6	47.9
223	27.6	32.6	24.5	29.7	47.3	53.1	41.5
321	26.8	27.3	28.3	18.8	34.4	45.9	51.9
322	26.8	29.4	28.3	31	42.5	50.2	54.1
323	25.8	33.6	27.6	27.7	45.6	50	46.8
131	25.3	34.4	30.4	37.6	47.6	46.8	37.8
132	30.3	33.1	30.1	42.6	47.3	46.9	43.9
133	32.7	33.9	31.3	44.7	44.1	45.6	37.9
231	30.3	33.7	31.9	45.3	51.7	46.6	34.5
232	31.1	34.7	28.5	42.5	49.8	40.8	35.1
233	25.7	32.9	34.6	36.1	55.6	49.5	NS
331	28.8	33.6	27.9	46.7	39.4	44.1	NS
332	25.5	32.1	31.3	36.8	44.8	45.9	NS
333	25.3	33.4	34.1	23.1	38.8	50.5	46.3
STE	NS	37	33.7	45.9	41.3	56.4	50.9
CWE	NS	33.2	33.2	30.3	48.4	53.2	51
RSFE	NS	37.7	29	45.2	42.4	50.7	43.3
NS = No sample obtained							

Group 2 Soil Leachate Electrical Conductivity (uS/cm)							
Column#	**Apr-95**	**May-95**	**Jun-95**	**Jul-95**	**Aug-95**	**Sep-95**	**Oct-95**
111	881	739	NS	807	1135	NS	983
112	893	929	882	1191	1171	1114	955
113	933	984	NS	1267	1207	1253	565
211	372	443	684	1114	1097	1117	958
212	297	404	562	762	963	940	834
213	581	619	791	1191	1077	1104	911
311	451	861	710	857	877	968	900
312	339	502	590	689	1007	972	895
313	286	587	430	386	620	646	542
121	603	804	778	879	1108	1100	1007
122	589	757	699	785	1102	1126	929
123	769	818	705	921	1131	1137	958
221	744	822	788	832	NS	NS	NS
222	416	589	572	568	586	703	802
223	628	888	849	880	1107	1142	922
321	663	620	713	705	617	814	847
322	797	876	731	666	631	1025	829
323	534	688	699	655	783	827	833
131	833	784	587	980	1014	968	778
132	885	780	773	1003	1021	972	793
133	621	699	692	972	1000	967	800
231	754	721	646	717	888	865	704
232	726	710	674	832	930	890	398
233	807	759	572	545	741	514	NS
331	825	764	758	1006	846	968	NS
332	747	952	701	919	989	973	NS
333	498	338	398	382	328	539	542
STE	1049	1058	1123	1428	1284	1373	1115
CWE	1008	1026	1018	1053	1273	1262	1082
RSFE	1038	851	861	1132	1055	1025	860

NS = No sample obtained

Group 2 soil fecal coliform MPN/100ml

Column #	Apr-95	May-95	Jun-95	Jul-95	Aug-95	Sep-95	Oct-95
111	3500	100	0	10	560	0	1020
112	4200	8400	1700	630	500	10	10
113	5500	5800	NS	3500	310	340	NS
211	0	NS	0	1060	10	0	0
212	0	0	0	270	10	0	10
213	10900	450	0	1120	100	10	10
311	0	9200	0	10	0	0	10
312	0	10	0	10	10	0	10
313	0	2120	0	0	10	0	0
121	1750	2370	10	10	0	0	0
122	2080	600	0	10	0	0	0
123	1400	2000	10	230	0	0	0
221	2200	1550	10	10	0	0	NS
222	0	140	0	0	0	0	0
223	510	3000	10	120	0	0	0
321	660	0	0	0	0	0	0
322	300	370	0	10	0	0	0
323	240	10	0	0	0	0	0
131	10	10	0	0	0	0	10
132	140	10	0	10	0	0	300
133	120	0	0	0	0	0	480
231	0	10	10	0	0	0	0
232	0	0	0	0	0	0	0
233	150	10	0	0	0	0	NS
331	0	340	0	0	0	0	NS
332	10	2200	10	10	10	0	NS
333	0	0	0	0	0	0	0
STE	12000	23000	3600	5000	740	1860	34000
CWE	5000	4500	10	110	10	0	0
RSFE	110	10	10	10	10	0	10

NS = No sample obtained

Group 2 Soil Infiltration Rates min/cm

Column #	8/29/95	9/6/95	9/11/95
111	62.5	62.5	75
112P	300	600	200
113	5.56	5.56	3.7
211P	75	120	100
212P	100	150	400
213P	165	100	120
311P	150	57.14	400
312P	140	150	100
313P	60	133.33	400
121P	230	120	100
122	1.61	0.5	0.833
123	0.5	2.33	0.5
221P	150	133.33	100
222P	40	44.44	50
223	4.17	5.56	4.17
321P	50	50	57.14
322P	85.7	100	100
323P	150	120	150
131	0.5	0.5	0.5
132	25	16.67	0.5
133	26.67	20	33.33
231	25	25	6.67
232	33.33	25	37.5
233	75	25	25
331	5	37.5	10
332	6.25	5.88	3.75
333P	120	200	300

P = Ponded effluent on soil column

Group 2 soil column leachate NH4 (ppm)

Column #	Apr-95	May-95	Jun-95	Jul-95	Aug-95	Sep-95	Oct-95
111	40.95	3.2	0.9	5.07	25.2	NS	26.4
112	36.66	24.7	19.7	23.24	29.2	32.9	30.1
113	37.05	33.6	1.3	36.18	32.3	35.08	NS
211	3.07	8.9	12.6	26.78	29.9	25.79	28.4
212	2.68	11.5	0.7	9.07	15.7	11.05	14.9
213	12.84	16.6	24.9	29.4	29.2	26.34	28.4
311	6.59	20.8	7.5	10.61	10	6.67	14.6
312	1.9	3.8	2.6	5.07	18.7	8.86	15.8
313	1.9	12.9	5.7	3.53	8.9	4.49	5.7
121	5.42	9.4	11.8	14.31	19.5	9.95	19.1
122	6.98	6.4	4.6	3.83	9.6	4.49	8.1
123	19.47	13.6	12.4	17.39	17.1	6.67	13.5
221	16.74	11.9	12.3	12.77	NS	NS	NS
222	3.07	8.1	5.1	4.76	4.1	5.95	8.8
223	10.49	17.4	18.3	15.23	13.6	5.58	8.8
321	12.84	13.2	14.1	10.92	2.6	3.4	11.1
322	21.82	26.8	1.4	10.15	3.7	5.58	8.8
323	8.52	2.6	4.5	1.26	2.9	12.96	4.4
131	27.28	0.2	BDL	1.5	6.5	3.67	4.7
132	30.79	5.9	BDL	1.62	6.9	3.62	4.7
133	10.1	3.8	BDL	1.25	5.7	3.35	4.2
231	20.25	2.6	BDL	0.19	0.3	0.31	0.2
232	17.52	9.4	BDL	1.11	1.1	0.47	0.3
233	25.72	3.8	BDL	0.33	0.9	1.12	NS
331	24.16	3.8	BDL	0.56	2.8	1.18	NS
332	20.25	26.8	BDL	1.13	4.5	2	NS
333	10.88	3.8	1.4	0.61	0.5	0.53	0.7
STE	55.1	46.6	48	49.63	49.5	59.57	56.3
CWE	50.2	4.2	37.9	30.38	31.3	29.06	28.4
RSFE	20.6	2.08	2.8	14.55	6.9	5.32	7.1

BDL = Below detection limits

NS = No sample obtained

Group 2 soil column leachate NO3 (ppm)							
Column #	Apr-95	May-95	Jun-95	Jul-95	Aug-95	Sep-95	Oct-95
111	0.27	35.5	32.2	12.32	13.2	NS	17.1
112	0.24	20.4	10.9	BDL	BDL	0.55	0.3
113	0.28	4.7	11.4	0.46	BDL	18.11	NS
211	0.23	0.8	0.21	0.24	BDL	BDL	0.4
212	0.23	0.16	0.3	0.14	BDL	0.89	0.6
213	0.21	0.2	0.2	0.2	BDL	0.64	1
311	0.15	0.18	0.2	0.22	BDL	2.8	0.5
312	0.23	0.18	0.21	0.22	3.2	0.86	0.6
313	0.1	0.14	0.26	0.26	BDL	0.83	0.8
121	1.16	17.3	0.21	0.26	BDL	0.76	17.7
122	4.19	29.1	8.6	4.37	NS	13.16	13.9
123	7.56	21.2	5.2	3.87	12.9	12.26	14
221	5.87	24.9	13.9	8.68	10.5	NS	NS
222	0.32	BDL	0.46	BDL	BDL	5.05	18.2
223	0.47	20.2	5.9	1.72	8	13.49	0.02
321	0.23	BDL	0.44	0.57	7.1	6.63	0.8
322	0.24	2.9	0.4	0.4	20.8	1.23	0.5
323	3.01	36.8	21.2	0.43	5.3	1.04	22.2
131	5.03	33.3	21.2	15.47	BDL	31.58	20.4
132	4.61	32.7	29.4	17.46	20.2	34.63	22.9
133	8.06	35.6	27.3	18.12	28	35.35	23.8
231	4.61	36.4	31.6	16.13	24.1	35.35	23.8
232	25.42	40.9	36.9	14.47	35.7	34.45	23.8
233	3.68	33.9	28.6	BDL	36.9	10.6	NS
331	1.32	31.7	25.9	6.94	25	32.48	NS
332	5.37	17	32.6	18.12	33.5	37.14	NS
333	BDL	27.6	0.8	BDL	BDL	BDL	27.1
STE	BDL	0.08	BDL	BDL	BDL	BDL	0.14
CWE	7.22	BDL	BDL	BDL	BDL	BDL	2.5
RSFE	6.88	29.25	34.3	49.03	8.6	39.57	30.1
BDL = Below detection limits							
NS = No sample obtained							

Group 2 soil column leachate pH						
Column #	**Apr-95**	**May-95**	**Jun-95**	**Jul-95**	**Aug-95**	**Oct-95**
111	7.2	6.51	NS	7.41	7.39	7.13
112	7.22	7.03	6.79	6.77	7.2	7.28
113	7.15	7.24	NS	7.09	7.33	8.37
211	5.62	7.79	6.35	6.56	6.88	6.95
212	6.33	5.87	6.46	6.42	6.65	7.12
213	6.63	6.6	6.85	6.81	6.97	7.08
311	6.63	6.56	6.97	6.46	6.89	6.69
312	6.46	6.36	7.28	6.55	6.75	7.41
313	7.06	6.42	6.87	7.27	6.87	6.57
121	6.39	6.57	6.69	6.66	7.22	7.39
122	6.46	6.49	6.59	6.65	7.23	7.58
123	7.04	6.62	6.53	7	7.5	7.27
221	6.99	6.58	6.75	6.79	NS	NS
222	6.66	6.37	6.47	6.95	7.7	7.29
223	6.57	6.79	6.81	6.74	7.35	7.02
321	6.84	6.35	6.32	6.33	7.82	7.83
322	7.12	6.88	6.46	6.28	6.68	6.59
323	6.56	6.04	6.41	6.24	6.62	6.61
131	7.23	6.69	6.76	6.84	7.18	6.95
132	7.23	6.7	6.6	6.89	7.25	7.01
133	6.46	6.46	6.52	6.74	7.23	6.97
231	7.06	6.35	6.34	6.26	7.04	6.96
232	6.29	6.08	6.18	6.26	6.94	7.07
233	7.22	6.61	6.26	5.99	6.51	NS
331	7.01	6.47	6.64	6.85	7.33	NS
332	7.13	6.92	6.48	6.46	7.13	NS
333	7.9	5.87	6.42	5.7	7.17	6.7
STE	7.33	7.07	6.99	6.94	7.28	7.67
CWE	7.58	7.38	7.42	7.41	7.7	7.82
RSFE	7.33	6.73	6.67	6.86	6.95	7
NS = No sample obtained						

Group 2 soil column leachate PO4 (ppm)

Column #	Apr-95	May-95	Sep-95	Jul-95	Aug-95	Sep-95	Oct-95
111	3.56	2.43	0.48	0.93	2.46	NS	2.49
112	3.585	3.24	2.745	2.305	2.7	1.24	6.2
113	3.665	3.98	0.135	4.095	2.945	3.47	NS
211	0.03	0.045	0.015	0.985	0.15	0.15	0.05
212	0.015	0.05	0.015	0	0.05	0.005	0.05
213	0.7	0.075	0.12	3.445	3.97	3.285	1.72
311	0.02	0.89	0.06	0	0.035	0.045	0.06
312	0.02	0.025	0.02	0	0.27	0.03	0.06
313	0.005	0.045	0.015	0	0.025	0.035	0.05
121	0.02	0	0.04	0.235	0.53	0.205	0.23
122	0.04	0.029	0.75	1.125	2.03	2.395	2.3
123	2.175	2.205	1.95	3.225	3.17	3.06	2.08
221	1.585	2	2.17	2.39	0.095	NS	NS
222	0.02	0.025	0.015	0	0.04	0.02	0.17
223	0.185	2.75	2.99	2.82	2.805	2.925	1.31
321	0.55	0.13	0.25	0.255	0.03	0.22	0.13
322	1.56	2.47	2.71	0.705	0.055	0.98	0.12
323	0.6	0.045	0	0.205	0.1	0.025	0.82
131	2.81	3.69	0.125	4.3	3.525	3.26	2.74
132	3.05	3.65	4.33	4.575	3.545	3.69	2.33
133	0.32	0.105	0.725	3.345	3.275	3.5	3.5
231	1.995	2.28	1.315	0.13	0.13	0.095	0.14
232	0.015	0.035	0.045	0.23	0.135	0	0.41
233	2.455	2.86	0.24	0.07	0.06	NS	NS
331	1.51	2.595	3.325	3.93	4.175	3.485	NS
332	1.84	3.21	2.04	2.81	2.55	2.74	NS
333	0.63	0.02	0.025	0.01	0.03	0.045	0.35
STE	5.27	5.37	5.19	5.41	4.18	5.04	4.62
CWE	4.55	4.96	4.94	4.45	4.35	4.25	3.62
RSFE	4.54	5.58	5.67	6.21	4.73	5	4.15

NS = No sample obtained

Group 2 soil column leachate TDS ppm

Column #	Apr-95	May-95	Jun-95	Jul-95	Aug-95	Sep-95	Oct-95
111	438	368	NS	399	564	NS	491
112	444	462	439	595	583	556	477
113	464	490	NS	634	600	624	285
211	185	220	340	558	546	556	477
212	147	201	279	380	479	468	415
213	289	308	394	595	536	549	455
311	224	428	353	478	437	484	449
312	169	250	293	345	501	483	447
313	142	292	214	192	309	322	270
121	300	400	387	440	550	548	502
122	292	377	347	392	549	562	463
123	384	407	351	461	563	567	477
221	369	407	392	416	NS	NS	NS
222	208	292	285	285	297	351	400
223	312	441	422	440	551	569	460
321	330	308	355	353	307	407	422
322	395	436	364	333	314	510	413
323	266	342	347	328	390	412	415
131	414	390	292	490	505	482	386
132	440	388	383	502	509	485	395
133	308	348	344	486	498	481	398
231	376	359	321	359	441	431	352
232	361	353	336	415	463	443	200
233	402	378	284	273	369	257	NS
331	411	380	377	503	419	483	NS
332	372	474	348	460	493	485	NS
333	248	168	198	190	161	268	270
STE	522	526	559	714	639	685	555
CWE	501	511	506	527	634	629	539
RSFE	517	423	428	567	526	511	428

NS = No sample obtained

Group 2 soil temperature in degrees Celsius

Column #	Apr-95	May-95	Jun-95	Jul-95	Aug-95	Sep-95	Oct-95
111	ND	ND	ND	ND	ND	ND	ND
112	9.2	14.2	18.8	24.7	24.4	20.2	14.9
113	ND	ND	ND	ND	ND	ND	ND
211	ND	ND	ND	ND	ND	ND	ND
212	9.7	14.2	19.2	25	24.9	20.6	16
213	ND	ND	ND	ND	ND	ND	ND
311	ND	ND	ND	ND	ND	ND	ND
312	9.3	13.9	18.7	24.4	24.2	20.2	15.2
313	9.6	13.8	19.1	24.5	24.6	20.6	15.7
121	ND	ND	ND	ND	ND	ND	ND
122	ND	ND	ND	ND	ND	ND	ND
123	9.6	14.3	19.4	25.1	24.9	20.6	15.6
221	ND	ND	ND	ND	ND	ND	ND
222	ND	ND	ND	ND	ND	ND	ND
223	9.6	14.1	19.3	24.9	24.8	20.6	15.7
321	ND	ND	ND	ND	ND	ND	ND
322	ND	ND	ND	ND	ND	ND	ND
323	9.3	13.8	18.8	24.5	24.2	19.7	15.1
132	ND	ND	ND	ND	ND	ND	ND
133	ND	ND	ND	ND	ND	ND	ND
231	9.3	14	18.9	24.6	24.3	19.8	15
233	ND	ND	ND	ND	ND	ND	ND
331	9.7	14	19	24.8	24.9	20.7	16.1
332	ND	ND	ND	ND	ND	ND	ND
333	ND	ND	ND	ND	ND	ND	ND
REF 15	9.1	13.4		23.9	24.1	19.8	14.2
REF 30	9.2	13		23.6	23.9	20	14.8
REF 45	9.3	12.9		23.4	23.8	20	15

ND = No device

Group 2 soil column tensiometer Mbar							
Column #	Apr-95	May-95	Jun-95	Jul-95	Aug-95	Sep-95	Oct-95
111	-3	-17	5	0	0	-9	-9
112	-13	-3	-12	-12	-13	-15	-14
113	-19	-14	-7	-11	-12	-8	17
211	-2	-1	15	-2	3	6	4
212	7	19	23	0	12	4	17
213	12	25	4	10	7	12	23
311	-3	2	4	-4	-7	-2	8
312	18	22	10	-3	3	1	3
313	11	15	1	0	5	2	-1
121	-6	-6	-2	-15	-19	-14	-11
122	-4	2	1	7	2	-5	-8
123	0	-6	5	-6	-19	-12	-6
221	-9	-14	-13	-21	32	30	37
222	3	23	15	3	6	14	22
223	-1	-10	-2	-17	-15	-13	-11
321	-2	59	-21	0	-4	-2	-7
322	11	-5	7	20	20	14	24
323	-4	-10	-9	0	8	19	16
131	-2	6	-10	1	-8	-9	-8
132	-15	-11	-3	-15	-16	-12	0
133	-2	-4	-10	0	-4	-15	-19
231	1	-15	-29	-26	-21	-16	-17
232	-6	-23	-15	-1	-28	-8	-14
233	-30	-13	-13	-2	-8	-24	-13
331	-6	-12	-9	-5	-7	-8	-31
332	19	9	1	6	-11	-24	-39
333	3	41	25	18	14	19	12

Group 2	tis tkn %	wastewater tkn %	
111	2.11		21.11
112	2.39		21.78
113	2.11		4.13
211	2.12		22.41
212	2.12		7.91
213	2.4		21.36
311	1.84		11.9
312	1.83		10.64
313	2.11		6.44
121	2.68		11.69
122	2.94		6.23
123	2.39		9.8
221	2.67		2.87
222	1.82		7.28
223	2.68		6.23
321	2.11		6.65
322	2.38		6.65
323	3.23		2.45
131	2.39		2.03
132	2.52		3.92
133	2.95		4.55
231	2.66		4.76
232	2.68		2.03
233	2.68		9.96
331	2.79		7.81
332	2.39		9.42
333	1.84		9.18

Appendix 1: Soil column number key group 3 soil.

#	Column description
111	15 cm STE replication 1
112	15 cm STE replication 2
113	15 cm STE replication 3
211	30 cm STE replication 1
212	30 cm STE replication 2
213	30 cm STE replication 3
311	45 cm STE replication 1
312	45 cm STE replication 2
313	45 cm STE replication 3
121	15 cm CWE replication 1
122	15 cm CWE replication 2
123	15 cm CWE replication 3
221	30 cm CWE replication 1
222	30 cm CWE replication 2
223	30 cm CWE replication 3
321	45 cm CWE replication 1
322	45 cm CWE replication 2
323	45 cm CWE replication 3
131	15 cm RSFE replication 1
132	15 cm RSFE replication 2
133	15 cm RSFE replication 3
231	30 cm RSFE replication 1
232	30 cm RSFE replication 2
233	30 cm RSFE replication 3
331	45 cm RSFE replication 1
332	45 cm RSFE replication 2
333	45 cm RSFE replication 3

Group 3 soil column leachate BOD mg/L

Column #	Jul-94	Jan-95	Jun-95	Aug-95	Oct-95
111	3.86	8.25	9.61	10.8	10.4
112	4.27	9.15	6.83	6.64	9.3
113	5.89	25.2	10.01	6.23	9.4
211	0.46	3.9	8.21	7.65	10.4
212	NS	10.13	9.6	4.35	1.6
213	0.73	3.94	7.8	8.53	9.4
311	3.55	13.65	7.13	13.35	9.7
312	1.6	3.71	3.11	10.2	6
313	2.51	23.25	NS	NS	8.9
121	2.57	8.74	9.68	7.65	2.9
122	1.74	8.95	6.01	7.77	7.7
123	NS	21.23	13.45	14.6	8.5
221	0.61	4.09	5.36	4.43	2.2
222	1.41	3.78	3.04	6.04	3
223	0.35	3.49	7.13	8.1	2.8
321	0.39	3.63	1.24	1.99	1.5
322	0.45	2.93	1.24	2.89	0.2
323	3.58	3.49	9.56	6	2.5
131	1.01	4.13	3.04	8.36	2.4
132	0.77	4.13	3.3	8.4	2.4
133	0.32	3.9	2.33	6.56	1
231	0.74	3.38	3.94	4.91	1.8
232	0.52	3.64	1.5	4.05	1.7
233	0.47	3.75	1.46	5.55	1.9
331	0.34	3.33	0.94	1.88	1.1
332	1.1	3.11	1.35	1.73	0.4
333	0.67	2.88	0.79	1.8	0.3
STE	203.7	105	94.5	105.5	84
CWE	56	NS	69	97	NS
RSFE	1.83	NS	48	30.5	39

NS = No sample obtained

Group 3 soil column leachate Cl ppm					
Column #	Oct-94	Nov-94	Jun-95	Aug-95	Oct-95
111	7.1	32.4	31	47.5	34.6
112	6.2	32.9	35.4	45.7	37.5
113	6.2	32.4	29.4	47.3	36.1
211	2.3	26.1	33.3	59.2	39.6
212	4.7	25.9	27.9	50.1	36.4
213	8.6	29.1	32.4	39.9	42
311	12.6	13.7	26.8	46.6	33.1
312	6.8	14.3	30.4	46.4	35.1
313	6.2	10.4	NS	NS	34.9
121	7.7	23.5	27.1	48.2	34.2
122	15.1	21.8	28.6	46.6	31.7
123	12	22.1	31	NS	30.7
221	7.7	15.9	25.3	44.2	34.5
222	6.8	15.9	27.8	49	36.9
223	4.4	14.9	29.2	67.5	39.9
321	10.5	15.6	22.8	56.4	30
322	4.1	14.3	18.1	60.9	29.5
323	8.6	14	28.5	43.1	28.9
131	7.4	7.95	34.5	46.3	34.8
132	7.4	23.4	27.6	57.3	33.8
133	2.9	12.7	28.2	56.8	17.4
231	4.5	16.7	33.3	59.2	32.1
232	5.6	13.2	28.3	65.5	31.4
233	4.7	16.2	34.3	45.5	39.4
331	5.9	13.4	28	54.6	27.8
332	4.1	14	30.1	44.8	26
333	17.7	14.8	29.1	63	33.3
STE	14.7	47.3	33.7	41.3	50.9
CWE	18	19.2	31.6	48.4	51
RSFE	16.8	24.1	34.9	42.4	43.3
NS = No sample obtained					

Group 3 soil column leachate EC (uS/cm)

Column #	Jul-94	Oct-94	Nov-94	Jan-95	May-95	Jun-95	Jul-95	Aug-95	Sep-95
111	935	568	750	1030	1156	992	1181	1124	1120
112	778	562	734	1028	971	949	1203	1126	1074
113	884	688	774	1066	1023	1002	1251	1167	1106
211	676	574	694	963	874	877	1082	1135	1155
212	895	606	658	987	943	1033	1045	1131	1022
213	886	541	675	957	930	991	886	934	1114
311	906	576	617	955	1020	967	1009	1050	1006
312	1043	598	649	1065	953	950	891	1090	1071
313	1071	535	583	986	1026	NS	NS	NS	NS
121	959	612	654	1031	932	837	916	1139	1113
122	893	669	681	1022	1076	793	841	1072	1149
123	850	690	712	949	933	911	NS	976	1062
221	820	589	630	1043	873	781	814	1032	1062
222	819	575	627	1088	853	754	792	1061	1087
223	1002	725	734	972	933	802	907	1250	1036
321	992	608	611	1055	876	763	799	986	1074
322	1067	660	666	1003	793	879	893	1035	1196
323	1063	653	643	996	830	783	792	979	1197
131	872	585	625	926	815	850	1033	1067	993
132	791	543	643	923	891	868	1086	1227	1171
133	800	602	692	951	910	862	1111	1319	1125
231	781	561	640	962	785	797	928	1115	1028
232	878	618	653	928	899	775	943	1135	1079
233	783	545	609	925	844	801	954	1125	1020
331	930	561	578	978	857	794	874	1073	1076
332	875	557	575	958	899	806	890	998	953
333	825	523	556	988	861	777	872	1048	997
STE	1079	676	1019		1058	1160	1442	1284	1373
CWE	1066	711	757	1302	1026	956	1064	1273	1262
RSFE	900	595	786	950	851	961	1143	1055	1025

NS = No sample obtained

Group 3 Soil Infiltration Rates min/cm			
Column #	**9/6/95**	**9/11/95**	**9/12/95**
111P	600	300	200
112	3.32	3.64	3.51
113	0.48	1.39	0.45
211	2.5	1.14	2.5
212	6.25	5.26	5.88
213	4.55	5.56	7.14
311P	120	200	100
312P	150	600	200
313	3.57	4	0.77
121	0.45	0.27	0.5
122	5.56	5	5.88
123P	75	40	85.7
221	0.36	0.625	0.5
222P	200	300	200
223P	30	30	28.57
321	4.76	4.17	4.55
322	3.03	3.33	3.33
323P	300	600	300
131	8.33	0.61	0.625
132P	10.53	150	17.65
133	1.67	2.04	1.4
231	0.54	1.56	1.67
232	5	4.76	4.76
233	2.56	2.5	2.22
331	4.17	4	4
332	1.67	1.85	1.92
333	3.33	2.86	3.33
P = Ponded column			

Group 3 soil column leachate NH4 (ppm)

Column #	Jul-94	Oct-94	Nov-94	Jun-95	Aug-95	Oct-95
111	2	2.14	4.8	33.8	37.5	32.7
112	4.8	2.34	9.9	15.6	3.9	9.6
113	1.7	2.44	5.5	10.4	6.5	8.9
211	0.3	0.28	0.2	3.8	5.7	4.6
212	3.4	0.27	NS	12.3	0.4	0.4
213	0.3	0.24	0.3	0.9	1.6	4.6
311	0.3	0.29	0.2	3.5	27.1	10.6
312	0.3	0.29	0.3	NS	17.9	28.7
313	0.4	0.2	0.3	NS	NS	0.4
121	0.7	0.37	0.4	3.6	6.5	14.1
122	0.4	0.25	1	9.5	14.4	7.6
123	1.7	0.33	9.4	13.1	NS	18.7
221	0.5	0.24	0.3	0.2	1.8	1.9
222	0.3	0.25	0.2	0.2	1.3	3.6
223	0.2	0.26	0.2	0.01	0.2	1.9
321	0.3	0.21	0.3	0.01	0.27	0.5
322	0.2	0.29	0.3	0.2	0.13	0.4
323	0.3	0.26	0.3	NS	13.72	15.2
131	0.3	0.25	0.3	0.7	2.85	1.6
132	0.4	0.26	0.4	0.2	1.9	1.3
133	0.3	0.29	0.3	0.3	0.8	0.9
231	0.3	0.28	0.2	0.1	0.3	0.4
232	0.3	0.23	0.2	0.2	0.8	0.4
233	0.3	0.27	0.2	0.1	0.7	0.6
331	0.2	0.2	0.3	5.6	0.13	0.3
332	0.2	0.19	0.3	0.1	0.13	0.2
333	0.2	0.18	0.3	0.1	0.17	0.3
STE	43.2	14.3	26.8	48	49.5	56.3
CWE	34.2	11.47	11.88	37.9	31.3	28.4
RSFE	2.2	0.21	0.35	2.8	6.9	7.1

NS = No sample obtained

Group 3 soil column leachate NO3 (ppm)

Column #	Jul-94	Oct-94	Nov-94	Jun-95	Aug-95	Oct-95
111	0.1	0.34	0.26	0.25	41.5	0.3
112	0.3	0.46	0.77	0.2	41.5	24.1
113	0.2	0.28	0.18	0.2	37.8	20.6
211	2.5	0.68	7.18	5.7	25.1	23.3
212	0.8	0.39	0.26	16.6	41.5	25.3
213	8.4	6.94	18.5	7.4	27.1	22.3
311	0.2	0.19	0.11	31.7	BDL	24.3
312	1	3.77	6.74	13.4	BDL	18.8
313	0.2	1.61	3.03	NS	NS	0.5
121	0.4	1.93	0.96	2.5	23.4	19.3
122	0.1	0.23	0.11	0.2	6.9	20.3
123	1	0.25	0.19	0.2	NS	23.3
221	0.4	0.71	0.83	6.9	22.4	22.6
222	14.9	2.16	1.25	10.3	9.6	17.3
223	1.6	0.25	0.16	10.5	BDL	19.3
321	0.3	3.88	1.27	16.5	13.8	13.6
322	0.1	0.3	0.17	0.66	BDL	3.7
323	0.1	0.16	0.18	0.56	12.8	16
131	0.1	0.3	1.69	22.7	23.9	19.7
132	3.8	11.5	12.81	10.5	15.4	19.1
133	7.4	1.34	0.92	11.7	9.6	24.1
231	0.3	0.75	3.47	11.1	18.9	20.2
232	0.2	0.25	0.13	22.9	6.9	23.5
233	0.1	1.66	1.4	0.22	25.8	16.7
331	0.1	11.5	11.8	12.9	0.49	16.6
332	0.1	2.88	5.1	10.2	23.7	22.3
333	1	3.19	16.2	0.2	18.8	21.3
STE	0.17	0.019	0.19	0.79	BDL	0.14
CWE	0.08	0.04	4.51	BDL	BDL	2.48
RSFE	38.15	11.47	19.3	34.3	8.6	30.04

BDL = Below detection limits

NS = No sample obtained

Group 3 soil column leachate pH

Column #	Jul-94	Oct-94	Nov-94	Jan-95	May-95	6/7/95	6/21/95	Jul-95	Aug-95	Oct-95
111	7.05	7.18	7.2	7.6	7.3	8.43	7.28	7.25	7.9	7.25
112	7.08	7.34	7.19	7.36	7.42	NS	7.05	6.88	6.93	6.83
113	7.03	6.91	7.08	7.08	7.47	NS	7.21	6.88	7.12	6.9
211	7.48	6.88	6.8	6.88	7.13	7.09	6.93	6.92	7.4	7.13
212	7.12	7.08	7.14	7.44	7.53	NS	6.89	6.61	7.07	6.95
213	7.12	6.92	6.84	6.82	6.95	7.77	6.7	6.71	7.11	6.9
311	6.97	7.32	7.34	7.6	7.55	7.43	7.25	7.37	8.24	7.94
312	6.74	6.72	6.77	7.03	7.03	7.06	7	6.99	7.42	7.15
313	7.66	6.89	6.81	8.25	7.4	NS	NS	NS	NS	8.32
121	6.94	7.25	7.12	7.19	7.39	7.56	7.24	7.21	7.64	7.54
122	7.11	7.34	7.17	7.4	7.14	7.5	7.38	7.16	7.55	7.17
123	8.21	7.4	7.25	7.3	7.27	7.69	7.74	NS	8.32	7.96
221	7.11	6.97	6.93	7.07	7.32	7.24	7.06	7.11	7.36	7.35
222	7.21	7.03	6.91	7.02	7.29	7.05	7.04	6.91	7.32	7.34
223	7.36	7.13	6.81	7.12	6.71	7.01	7.29	7.43	7.8	7.62
321	7.43	6.93	6.86	7.17	7.31	7.02	7.09	6.91	7.4	7.43
322	7.41	6.96	6.87	7.23	7.46	NS	7.04	7.07	7.4	7.4
323	6.86	7.03	6.94	7.19	7.71	7.45	7.49	7.17	7.31	7.18
131	7	7.11	6.81	7.02	7.26	7.25	7.13	7.04	7.68	7.38
132	7.13	7.14	7.08	7.38	7.37	7.23	7.12	7.24	7.75	7.31
133	7.05	6.98	6.91	7.02	7.45	7.29	7.23	7.19	7.85	7.32
231	7.17	6.84	6.84	7.06	7.37	7.27	7.22	7.08	7.55	7.44
232	7.35	6.84	6.85	7.1	7.38	7.22	7.21	7.09	7.59	7.36
233	7.37	6.9	6.9	7.35	7.38	7.19	7.06	6.95	7.58	7.39
331	7.12	7	6.9	7.33	7.32	7.21	7.1	6.91	7.62	7.46
332	7.43	6.88	6.84	7.32	7.25	7.04	7.08	6.63	7.22	7.28
333	7.3	6.87	6.83	7.26	7.24	6.99	6.94	6.68	7.31	7.28
STE	6.98	7.17	7.26	7.5	7.07	6.99	7.25	6.94	7.28	7.67
CWE	7.6	7.55	7.5	7.92	7.38	7.42	7.44	7.41	7.7	7.82
RSFE	6.96	7.03	6.87	6.76	6.73	6.67	7.05	6.86	6.95	7

NS = No sample obtained

Group 3 soil column plant tissue weight (g)

Column #	Apr-95	May-95	6/9/95	6/27/95	Jul-95	Aug-95	Sep-95	Oct-95
111	16.9	8.2	11.7	5.4	2.2	2.2	3.5	2.2
112	10.2	6.1	12	7	4.9	1.3	1.7	1.4
113	29	10.1	17.3	11.5	6.1	3.5	5.3	3.9
211	20.2	7.2	12.2	8.4	6	8.3	8.8	3.8
212	20.6	11.8	18.4	11.4	5.5	6.2	10.3	5.3
213	NS	NS	NS	7.6	2.1	NS	NS	NS
311	11	5.5	8.8	4.4	2.6	2.3	2.9	2.7
312	20.7	7.3	10.5	5.3	2.9	3.3	3.5	1.9
313	38.5	11	20.4	9.3	3.5	1.8	4.7	2.8
121	20.5	8.2	18.6	11.2	6.1	4.1	3.3	2.9
122	18.7	7.6	13.3	8.8	5	1.8	1.9	2.3
123	15.2	6.2	11.1	5.7	3.8	3	3	1
221	16.8	8.8	16	8.8	5.4	3.9	5.2	3.1
222	23	9.4	18.5	11.7	9.3	12.5	11.8	4.8
223	33.3	11.3	27.1	14.8	10.4	9.1	6.4	2.4
321	23.3	10	20.7	12.2	8.4	7.5	9	3.9
322	26.5	10.5	20.2	12.2	9.6	13.2	13.9	5.7
323	27.4	7.4	16	7.8	3.5	0.9	0.8	0.6
131	15.3	8.6	16.1	9.6	5.7	4	5.8	3.1
132	21.4	8.6	17	10.7	8.7	9.6	9.1	4.4
133	43.6	9.2	22	12.1	8.8	11.5	13.2	5.1
231	24.8	9.4	18	12.1	8	9.6	7.4	2.9
232	40.9	10.7	24.3	13.7	9.7	12.9	12.7	4.6
233	20.9	9.6	18.4	10.6	7.7	7.8	6.4	3.2
331	26.8	9.2	21.4	13.4	9.4	14.3	13	5.4
332	26	10.7	18.5	12.8	7.3	6.5	6	3.1
333	20.9	7.8	21.6	14.5	9.3	8.8	5.8	4.1

NS = No sample obtained

Group 3 soil column leachate PO4 (ppm)						
Column #	Oct-94	Nov-94	Jan-95	Jun-95	Aug-95	Oct-95
111	0.02	0.06	0.05	0.11	0.035	0.2
112	0.02	0.06	0.02	0.04	0.665	1.91
113	0	0.03	0.02	0.03	0.835	1.27
211	0.015	0.06	0.025	0.82	0.68	0.64
212	0	0.03	0.035	0.02	0.004	0.15
213	0.005	0.03	0.04	0.28	0.255	0.62
311	0	0	0.025	0.04	0.035	0.075
312	0.015	0.05	0.045	0.05	0.035	0.105
313	0.005	0.04	0.025	NS	NS	0.1
121	0.05	0.14	1.045	1.76	1.56	1.51
122	0.005	0.03	0.025	0	0.3	1.71
123	0.125	0.13	1.815	0	NS	1.71
221	0.01	0.04	0.04	0.45	0.405	0.545
222	0.01	0.03	0.03	0.07	0.265	0.52
223	0.01	0.05	0.035	0.02	0.035	0.075
321	0.01	0.04	0.03	0	0.04	0.16
322	0.005	0.03	0.045	0.03	0.04	0.165
323	0.005	0.03	0.035	0.07	0.02	0.1
131	0.01	0.06	0.04	2.14	1.99	2.075
132	0.015	0.06	0.016	0.73	1.8	1.535
133	0.025	0.06	0.045	0.84	0.93	1.075
231	0.015	0.03	0.03	9.31	0.255	0.285
232	0.005	0.02	0.06	0.13	0.49	0.365
233	0.015	0.03	0.07	0.11	0.56	0.68
331	0.005	0.02	0.04	0.08	0.025	0.215
332	0.005	0	0.04	0.02	0.025	0.075
333	0.005	0.02	0.035	0.03	0.025	0.23
STE	1.49	2.41	5.56	5.43	4.18	4.62
CWE	0.87	1.29	3.87	4.66	4.35	3.62
RSFE	0.6	2.16	4.79	6.08	4.73	4.15
NS = No sample obtained						

Group 3 soil column leachate TDS ppm									
Column #	Jul-94	Oct-94	Nov-94	Jan-95	May-95	Jun-95	Jul-95	Aug-95	Sep-95
111	466	283	373	513	575	493	586	560	558
112	386	279	365	510	483	472	599	561	535
113	440	342	385	533	509	499	623	581	551
211	336	285	345	474	435	436	538	565	576
212	445	302	327	491	469	513	520	563	509
213	440	269	336	476	463	493	440	465	555
311	450	287	307	475	508	481	502	522	501
312	518	293	323	529	474	473	444	543	533
313	532	266	290	486	511	NS	NS	NS	NS
121	477	304	375	513	463	416	455	567	554
122	444	333	339	507	537	394	418	534	573
123	423	342	354	472	464	453	NS	488	529
221	408	291	313	519	435	388	404	514	528
222	407	286	312	542	424	375	394	528	542
223	498	361	365	481	464	399	451	622	516
321	493	302	304	525	436	379	397	491	536
322	530	329	331	500	394	437	446	516	596
323	529	325	320	494	413	783	393	487	598
131	434	291	310	460	406	423	514	531	494
132	393	270	320	462	444	432	540	611	583
133	398	301	344	470	453	429	553	657	559
231	389	279	318	479	391	396	462	555	513
232	437	307	325	459	447	385	469	565	538
233	389	272	303	458	421	400	475	561	509
331	462	277	287	487	426	394	435	534	536
332	435	278	286	471	447	401	443	497	475
333	410	260	276	491	428	386	434	521	498
STE	537	337	507	707	526	577	717	639	685
CWE	530	353	376	649	511	477	529	634	629
RSFE	447	296	391	470	423	478	569	526	511
NS = No sample obtained									

Group 3 soil column temperature degrees C							
Column #	**Apr-95**	**May-95**	**Jun-95**	**Jul-95**	**Aug-95**	**Sep-95**	**Oct-95**
111	10.9	14.4	18.7	24.2	24	19.8	14.9
112	10.8	14.3	18.5	24	24	20.2	15
113	11.3	14.4	19.1	24.2	24.5	20.5	15.4
211	11	14.7	18.7	23.9	23.8	20.2	14.9
212	11.1	14.3	18.9	24.1	24.4	20.5	15.5
213	MF	MF	MF	MF	MF	MF	MF
311	10.7	14.1	18.1	23.9	24	20.2	15.1
312	10.7	14.1	18.4	23.8	23.8	20.1	15.2
313	11.1	13.8	18.8	23.6	24	20.5	15.4
121	11.1	14.4	19	24.2	24.5	20.5	15.4
122	11.3	14.5	19	24.3	24.4	20.5	15.4
123	10.7	14.3	18.7	24.1	24	19.8	14.9
221	10.8	14.2	18.3	25.8	MF	MF	MF
222	10.8	14.2	18.6	24	24	20.2	15.1
223	11.2	14.3	19	24.1	24.3	20.5	15.5
321	11	13.9	18.8	23.7	24.1	20.5	15.5
322	11	14.2	18.7	23.9	24.3	20.5	15.5
323	10.8	14.1	18.6	24	24	19.7	15.2
131	10.8	14.3	18.4	24.1	24	20.2	15.1
132	11.1	14.3	19.1	24.1	24.3	20.5	15.8
133	11.2	14.1	19.1	24.1	24.3	20.5	15.2
231	11.5	14.6	18.7	24	23.7	19.7	14.9
232	11.2	14.2	19	24.2	24.4	20.5	15.5
233	10.8	14.2	18.2	24	24	20.2	15
331	11.2	13.9	18.9	23.7	24.1	20.5	15.2
332	10.7	14.1	18.7	23.9	23.9	19.7	14.9
333	10.9	13.7	19	23.6	24.1	20.5	15
STE	9.1	13.4	NS	23.9	24.1	19.8	14.2
CWE	9.2	13	NS	23.6	23.9	20	14.8
RSFE	9.3	12.9	NS	23.4	23.8	20	15

MF = Malfunctioning thermocouple

Group 3 soil tensimeter Mbar

Column #	Jul-94	Apr-95	May-95	Jun-95	Jul-95	Aug-95	Sep-95	Oct-95
111	-4	4	-4	7	-5	-3	-9	0
112	-8	2	-10	10	-4	-13	-10	-8
113	4	15	9	8	-3	-1	-4	-2
211	-3	-9	-6	-5	-10	-1	0	0
212	-7	12	1	9	5	5	0	1
213	31	8	-8	-5	-12	-8	-8	0
311	-8	21	7	5	2	-5	-3	0
312	-3	7	-6	-6	-5	-7	-2	0
313	-9	4	0	-4	-5	0	0	-9
121	-4	4	5	-1	-6	0	0	0
122	-3	8	-5	2	0	-2	-3	1
123	-3	39	32	20	18	29	36	32
221	-3	5	-6	-14	-6	-11	-10	9
222	-8	2	-12	-17	-18	-22	-12	-11
223	-7	3	-5	15	3	5	-4	15
321	-3	10	1	-5	1	-8	0	-2
322	-5	17	4	-15	0	16	-4	14
323	-15	3	-17	-10	-3	-10	-13	-5
131	12	-5	-9	-6	-8	-9	-3	4
132	-2	8	-2	2	-3	-4	7	0
133	-9	-5	-15	-10	-13	-1	-2	-3
231	-2	14	-13	-5	-12	-15	-13	-11
232	-2	2	-8	-7	-8	-17	-2	-2
233	-6	-6	-18	-6	-3	-12	-5	7
331	-2	14	-2	3	-5	-9	0	0
332	-8	-2	-23	-3	-18	-21	-21	-19
333	-5	5	-23	-5	-25	-14	-7	-2

Group 3	tis tkn %	wastewater tkn %		Jul-94	Oct-95
111	2.96			4.94	15.26
112	3.24			7.68	9.38
113	2.95			6.77	8.22
211	2.68			6.77	4.55
212	2.68			4.94	2.24
213	2.41			6.77	4.13
311	2.96			4.94	6.75
312	3.23			4.94	13.58
313	3.24			4.94	2.24
121	3.34			NS	4.55
122	3.24			4.94	6.65
123	2.67			5.86	9.17
221	3.51			4.94	3.29
222	3.38			6.77	3.5
223	2.81			4.03	14.85
321	2.96			5.86	2.24
322	3.37			4.94	2.03
323	3.25			4.94	10.64
131	3.25			4.94	4.97
132	2.95			4.94	7.7
133	2.95			4.94	2.34
231	3.53			4.94	2.24
232	3.38			4.94	2.66
233	3.25			4.94	2.45
331	3.51			4.03	2.45
332	3.52			4.94	2.13
333	3.23			4.94	2.24
NS = No sample obtained					

Group 3 soil column leachate fecal coliform MPN/100ml						
Column #	Apr-95	May-95	Jun-95	Jul-95	Aug-95	Sep-95
111	0	0	0	10	0	0
112	570	8400	0	1800	640	0
113	0	0	NS	200	610	10
211	1050	1330	620	8500	10	10
212	10	10	0	660	10	0
213	1001	2900	0	1680	10	10
311	0	0	0	0	0	0
312	0	0	0	0	0	0
313	0	0	NS	NS	NS	NS
121	960	1500	10	10	0	0
122	0	10	0	0	0	0
123	0	10	0	NS	0	0
221	360	1160	10	10	10	0
222	100	2430	0	10	0	0
223	0	0	0	10	0	0
321	0	0	0	0	0	0
322	0	10	NS	0	0	0
323	0	0	0	0	0	0
131	120	230	10	400	0	0
132	10	0	0	10	0	0
133	400	10	10	10	10	0
231	0	0	10	10	0	0
232	0	0	0	10	0	0
233	0	0	0	10	0	0
331	0	0	0	10	0	0
332	0	0	0	0	0	0
333	0	0	0	0	0	0
STE	12000	23000	3600	5000	740	1860
CWE	5000	4500	10	110	10	0
RSFE	110	10	10	10	10	0
NS = No sample obtained						

APPENDIX 2:
Group 2 Soil Location and Description

Soil Type: XXXXX loam, 0 to 2 percent slopes a fine-loamy, mixed, mesic family of Mollic Hapludalfs.

Location: About 2.14 kilometers (1.33 miles) southwest 230° of junction of Highways VA-655 and VA-652 at Longshop and 2.11 kilometers (1.31 miles) south southeast 160° of Wake Forest Cemetery on Whitethorne Farm, Montgomery County

Latitude: 37° 11' 49" N **Longitude:** 80° 35' 44" W

Physiographic Province: Valley and Ridge

Landscape position: River terrace

Natural vegetation: grass

Parent material: Alluvium

Slope gradient: 1 percent **Complexity:** Simple

Aspect: N/A

Relief: 9 meters (30 feet)

Elevation: 518 meters (1,700 feet)

Erosion class: Slight

Internal free water: None

Drainage class: Well drained

Flooding: Rare

Soil moisture: Moist (Colors are for moist soil samples.)

Root restricting depth: None

Rock fragments on the soil: None

Bedrock outcrops: None

Ap--0 to 23 cm; dark brown (10YR 3/3), broken, loam; moderate medium and coarse granular structure; friable, slightly sticky, slightly plastic; common fine and few coarse roots; many coarse tubular pores; few fine flakes of mica; 2 percent gravel; slightly acid; clear wavy boundary.

Bt1--23 to 56 cm; brown (7.5YR 4/4), broken, loam; moderate medium and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; few fine roots; many coarse tubular pores filled with dark brown (10YR 3/3), broken, materials from Ap; common faint brown(7.5YR 3/4), broken, clay films on faces of peds; few black (10YR 2/1), broken, manganese coatings on faces of peds; few fine flakes of mica; 10 percent gravel; moderately acid; diffuse smooth boundary.

Bt2--56 to 107 cm; brown (7.5YR 4/4), broken, loam; weak coarse subangular blocky structure; friable, slightly sticky, slightly plastic; very few fine roots in pores; common coarse tubular pores filled with dark brown (10YR 3/3), broken, materials from the Ap; common faint dark brown (7.5YR 3/4), broken, clay films on faces of peds; few black (10YR 2/1), broken, manganese coatings on faces of peds; common fine flakes of mica; 2 percent gravel; slightly acid; diffuse smooth boundary.

Bt3--107 to 142 cm; brown (7.5YR 4/4), broken, loam; weak very coarse subangular blocky structure; friable, slightly sticky, slightly plastic; very few very fine roots in pores; common coarse tubular pores; common faint dark brown (7.5YR 3/4), broken, clay films on faces of peds; common fine flakes of mica; 10 percent gravel; slightly acid; diffuse smooth boundary.

Bt4--142 to 203 cm; brown (7.5YR 4/4), broken, sandy loam; weak very coarse subangular blocky structure; friable, slightly sticky, slightly plastic; very few very fine roots in pores; common coarse tubular pores; common faint dark brown(7.5YR3/4), broken, clay films on faces of peds; few black (10YR 2/1), manganese coatings on faces of peds; common fine flakes of mica; 2 percent gravel; slightly acid.

VITA

William Gilbert Keeling was born to Eugene C. and Barbara S. Keeling in the town of Fredricksburg, Virginia in the year of our Lord nineteen hundred and sixty three on the twenty first day of the month of May. William G. Keeling being of reasonably sound mine and body received a B.S. degree in Horticulture from Virginia Polytechnic Institute and State University in the month of June nineteen hundred and eighty six. After an arduous effort he received a M.S. in Crop and Soil Environmental Sciences in the month of December nineteen hundred and ninety five.

William G. Keeling