Wastewater Renovation as a Function of Soil Depth and Effluent Quality

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Material in this report has been extracted from the 1996 report to the Virginia Department of Health. I would also like to acknowledge C. Duncan and W. Kelling since much of the information contained in this report was a direct result of research they conducted while at Virginia Tech.

MATERIALS AND METHODS

Soil columns were collected 35 cm below the mineral soil surface and physical and chemical properties are shown in Table 1. 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 (Fig. 1)are 15,30,and 45 cm. Influent types (wastwater applied to columns) consist of Constructed wetland effluent (CWE), recirculating sand filter effluent (RSFE), and septic tank effluent (STE). The influent distribution system 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. Tensiometers were installed in the center of the soil columns to monitor the energy status of water. Leachate from the soil columns was analyzed for BOD_5, fecal

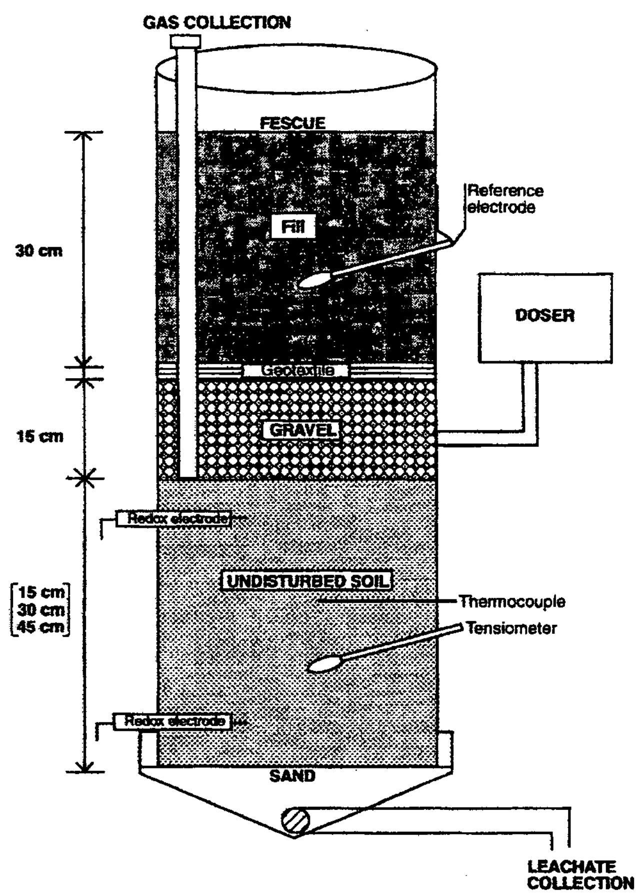

Figure 1. Columns containing varying lengths of undisturbed soil cores.

coliform (FC), nitrogen(NO_3-N, NH_4-N), phosphorus(P), chloride(Cl), pH, electrical conductivity(EC), and total dissolved solids (TDS).

Soil Columns

Undisturbed 20-cm-diameter soil columns (Fig.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 1. 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 beginning in May, 1994. 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 much of the remainder of the study.

Recirculating Media Filter

Table 2 shows the operating conditions for the recirculating sand filter used in this study.

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.

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-phosphate

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-}.

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 1. Soil physical and chemical properties.			
	---------- Depth (cm) -----------		
	0-15	15-30	30-45
Sand (%)	39.2	36.5	27.2
Silt (%)	46.7	45.4	39.2
Clay (%)	14.2	18.2	27.2
Texture[1]	Loam	Loam	Clay loam
Dbfm[2] (g cm^{-3})	1.63	1.61	1.74
ace[3] (%)	38.5	39.2	34.3
KSAT (cm h^{-1})	12.9	16.0	2.3
CEC[4] (cmole c/kg)	7.5	7.5	6.9
pH	5.2	6.2	5.7

[1]USDA textures
[2] = Bulk density (Db)at field moisture.
[3] = Pore space (%) = 1 - (Dbfm g cm^3/2.65 g cm^3 assumed particle density) times 100.
[4]Cation exchange capacity determined with ammonium acetate at pH 7.0.
KSAT = Saturated hydraulic conductivity

Table 2. 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

RESULTS AND DISCUSSION

Biological contaminants

Fecal coliform counts were divided into three study periods. The 1st study period consists of the first year (5-93 to 5-94) and represents the time that C. Duncan was conducting degree research (Duncan, 1994), the 2nd study period (5-94 to 9-95) was the time interval when W. Keeling was collecting data for his degree program (Keeling, 1995), and the 3rd study period (10-95 to 6-96) represents the time after Keeling completed his degree (Table 3).

counts/100 ml (99%) after additional treatment of the STE with a CW and a RSF, respectively, in the 1st study period. The FC counts for samples analyzed during the 2nd period (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 3). 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 FC counts returned to their original count range. In the 3rd study period, FC counts in the STE were reduced by 99% with additional treatment from either a CW or a RSF.

During the 1st study period, the FC counts were highest in leachate from the 15 and 30 cm column depths where STE was applied. The FC counts in leachate from the 15 cm deep soil columns receiving CWE were 40 counts/100 ml. Which is lower than the counts present in leachate from the 15 and 30 cm deep soil columns receiving STE. No FC counts were detected in any of the other columns.

During the 2nd study period FC counts in the column leachate remained higher where STE was applied to the 15 and 30 cm deep soil columns (Table 3). Low FC counts were present in the leachate from the 15 and 30 cm deep columns receiving CWE and the 15 cm deep soil column receiving RSFE for the first time during this study period. These values were 4 and 5 counts/100 ml. No FC counts were present in leachate from any of the other columns.

FC counts were present in leachate from one additional treatment (30 cm deep columns receiving RSFE) during the 3rd study period (Table 3). At this time, FC counts were present in the leachate from all the 15 and 30 cm deep soil columns. However, the counts tended to be lower where CWE and RSFE were applied to the soil columns. Again no FC counts were present in the leachate from the 45 cm deep soil columns.

Results from the 2nd and 3rd study periods indicates that the depth of coliform penetration into the soil has increased to 30 cm

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

Influent type	Soil depth (cm)	Fecal coliforms (counts /100 ml) 5/93 - 5/94	5/94 - 10/95	10/95 - 6/96
		Column influent		
STE	--	35800	11500	62000
CWE	--	3200	1400	85
RSFE	--	170	25	20
		Column leachate		
STE	15	910a*	23a	64a
STE	30	70b	24a	6abc
STE	45	0c	0b	0c
CWE	15	40bc	5b	10abc
CWE	30	0c	4b	5abc
CWE	45	0c	0b	0c
RSFE	15	0c	4b	25ab
RSFE	30	0c	0b	3bc
RSFE	45	0c	0b	0c

*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

where CWE and RSFE were applied to the soil columns. This does not agree with observations by Simon et al. (1986). They reported 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. In this study it is believed that the increased penetration of fecal coliforms is the result of changing the dosing regime from 6 times to 2 times daily (this change was initiated at the beginning of the 2nd study period). This observation implies 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.

Summary

These studies demonstrate the reduced FC counts derived from additional treatment of STE and the renovation capacity of the soil (both as a function of depth and texture). FC counts were lower at the 15 and 30 cm soil depths where additional treatment of STE was employed by either a CW or a RSF. The counts were normally lower in the leachate from columns that receive effluent (particularly RSFE) with lower FC counts. The FC counts decrease with increased soil depth.

The biological quality of the wastewater that had percolated through 30 cm of soil where STE had been treated with either a RSF or a CW and 45 cm of soil where STE was applied was very good.

The low FC counts present in the leachate from the soil columns may be related to the relatively low FC counts present in the STE. The low values present in the STE may result from enhanced dieoff in the septic tank because of increased residence time. The occupants of the residence were gone much of each day. Since there appears to be a strong relationship between FC counts in the wastewater applied to the soil and the biological quality of the wastewater after passing through various soil depths, wastewater with higher initial FC counts might result in higher FC counts at various depths.

We recommend that a minimum of 35 cm of unsaturated soil be present where additional treatment of STE is employed. In this study both CW and RSF adequately reduced the FC numbers. Where STE is applied to the soil we sould recommend that at least 45 cm of unsaturated soil be present.

Chemical Constituents

BOD_5

Treatment of STE by both CW and RSF systems lowered BOD_5 concentrations (Table 4). The BOD_5 concentrations in the STE, CWE, and RSFE tended to increase in the 2nd (10-94 to 10-95) and 3rd (10-95 to 6-96) study periods when compared with the 1st (5-93 to 5-94) study

Table 4. Effect of additional treatment on effluent concentrations of selected chemical constituents applied to each soil at varying time periods.

Effluent type	BOD_5	NH_4-N	NO_3-N	PO_4-P
	----------------mg L^{-1} --------------			
		(5-93 to 5-94)		
STE	116	38	0.3	3.36
CWE	46	27.7	0.3	2.29
RSFE	6.6	6.9	20.9	3.43
		(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
		(10-95 to 6-96)		
STE	110	58.1	0.37	4.53
CWE	25	33.2	1.23	4.58
RSFE	17	5.1	31.5	4.40

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

period (Table 4). The range in BOD_5 reduction when STE was treated by either a CW or a RSF was 38 to 75% and 75 to 94%, respectively.

The reduction in BOD_5 was not as high as some values stated in the literature. Gersbreg et al.(1984) reported 98% reductions in BOD_5 from municipal 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. The BOD_5 concentrations present in CWE and RSFE in this study are higher than those cited above. However, BOD_5 concentration in RSFE (15.8 mg L^{-1}) reported by EPA (1980) was similar to the concentrations measured in this study. Higher BOD_5 concentrations were expected in the CWE since the effluent was collected from the bottom of the CW. Gersberg et al. (1986) also noted BOD_5 reductions of 33% from selected CW systems. These reductions are comparable to the reductions observed in this study.

Soil

There was little difference in the BOD_5 concentrations between soil depth where different effluent types were applied (Table 5).

Table 5. The effect of soil depth and influent type on BOD_5 concentration in column leachate.				
Influent type	Soil depth (cm)	BOD_5 (mg L^{-1}) 5/93 - 5/94	5/94 - 10/95	10/95 - 6/96
STE	All	1.6a	8.9a*	9.0a
CWE	All	2.2a	5.2b	3.6b
RSFE	All	1.3a	3.3c	1.7b
All	15	2.6a	7.9a	6.7a
All	30	1.3b	4.8b	4.0b
All	45	1.1b	4.5b	3.6b
		Column leachate		
STE	15	2.3a*	10.1a	12.4a
STE	30	1.4a	7.0ab	7.5b
STE	45	1.1a	9.8a	6.9bc
CWE	15	3.9a	8.5a	5.5bcd
CWE	30	1.3a	4.4bcd	2.9cde
CWE	45	1.2a	3.1cd	2.8cde
RSFE	15	1.5a	5.4bc	2.0de
RSFE	30	1.2a	3.0cd	1.8de
RSFE	45	1.1a	1.4d	1.1e

All average among all soil depths
All 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
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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 5) from the 1st through the 3rd study period. 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.

These results demonstrate the ability of the soil system to substantially lower the BOD_5 after passage through a shallow soil depth when an unsaturated soil condition is maintained.

Nitrogen

There was an average decrease in NH_4-N concentrations of 37 and 87%, respectively, after STE was treated by the CW and the RSF (Table 4). The decrease in NH_4 -N concentration in the CW is primarily due to NH_3 volatilization (Huang, 1995). While the low NH_4 concentrations in the RSFE was a result of the conversion of NH_4 to NO_3.

The RSFE had the highest NO_3 concentration followed by CWE and STE. The NO_3 concentration in the column leachate in each of these systems is a reflection of the aerobic/anaerobic conditions present. STE is produced under the most anaerobic conditions and subsequently has little if any NO_3 present. RSFE, however, is produced under more aerobic conditions and much of the N present has been converted to NO_3. 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). Some reduction in N in the RSF would be expected as a result of denitrification.

Table 6. The effect of soil depth and influent type on NH_4-N concentration in column leachate.				
Influent type	Soil depth (cm)	-------------NH_4 (mg L^{-1})-----------		
		5/93-5/94	5/94-10/95	10/95-6/96
STE	All	0.7a	7.4a*	9.7a
CWE	All	0.7a	3.2b	6.0ab
RSFE	All	0.3a	0.8b	1.3b
All	15	1.3a	6.8a	9.8a
All	30	0.3b	1.2b	3.0b
All	45	0.2b	3.2b	4.4b
Column leachate				
STE	15	1.7a	12.4a	17.8a
STE	30	0.3b	2.4cd	4.1b
STE	45	0.2b	7.5b	7.4b
CWE	15	1.7a	6.9bc	9.3
CWE	30	0.3b	0.8d	3.8b
CWE	45	0.2b	2.3cd	5.4b
RSFE	15	0.5b	1.4d	2.1b
RSFE	30	0.2b	0.4d	1.2b
RSFE	45	0.2b	0.6d	0.4b

All average among all soil depths
All average among all influent types
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Concentrations of NH_4-N in the soil column leachates (Tables 6) increased with time from the 1st study period (5/93-5/94) through the 3rd study period (10/95-6/96). This is attributed to the change in dosing at the beginning of the 2nd study period (5/94-10/95). At this time the same volume of wastewater was applied to each soil column, but in 2 doses as compared to 6 doses during the 1st study period. Larger doses reduce the aeration status of the soil thereby reducing nitrification. Also more NH_4 may be present in the column leachate as a result of enhanced macropore flow with larger doses of wastewater.

The NH_4 concentration in the column leachate was related to the quality of the wastewater applied to the soil columns. The highest NH_4 concentrations were present in the column leachate where STE was applied to the soil columns followed by columns receiving CWE and the

Table 7. The effect of soil depth and influent type on NO_3-N concentration in column leachate.				
Influent type	Soil depth (cm)	------------NO_3-N (mg L^{-1})-----------		
		5/93-5/94	5/94-10/95	10/95-6/96
STE	All	19.2a	12.2a*	17.0b
CWE	All	10.3c	7.6a	17.6b
RSFE	All	14.4b	11.3a	25.4b
All	15	12.5b	10.3a	19.2a
All	30	15.4a	11.6a	20.8a
All	45	15.9a	9.3a	20.0a
		Column leachate		
STE	15	17.0abc	11.3a	12.4b
STE	30	19.1ab	15.2a	16.7ab
STE	45	21.3a	9.9a	22.0ab
CWE	15	6.6e	7.7a	19.4ab
CWE	30	13.1cd	8.9a	16.3ab
CWE	45	11.0de	6.2a	17.7ab
RSFE	15	13.9bcd	11.6a	25.7ab
RSFE	30	13.9bcd	10.5a	29.5a
RSFE	45	15.4abcd	11.9a	20.6ab

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lowest concentrations were present in columns receiving RSFE. This again indicates that the quality of the wastewater applied to the soil columns had an impact on the biochemical transformatios that occured in the soil columns. The columns receiving the wastewater with the lowest BOD_5 concentrations (RSFE) have the lowest NH_4 concentrations while the columns receiving wastewater with the highest BOD_5 concentrations have the highest NH_4 concentrations in the column leachate.

Soil depth also had a significant impact on the concentration of NH_4 in the soil column leachate. There was a decrease in NH_4 concentrations present in column leachate with increased soil depth over all three wastewaters. However, there were differences in NH_4 concentration in the column leachate depending of the type of astewater applied. Where STE was applied to the soil columns the NH_4-N concentrations were highest and where RSFE was applied the concentrations were lowest. These data show that the soil columns differed with respect to O_2 available for nitrification. Also, the

Table 8. Effects of soil depth and influent type on leachate TKN concentrations.			
Influent Type	Soil Depth (cm)	5/93-5/94	5/94-10/95
		---mg L^{-1}---	
STE	All	3.6a	6.6a
CWE	All	3.8a	5.2a
RSFE	All	3.0a	4.0a
All	15	4.3a	6.0a
All	30	3.0b	4.9a
All	45	3.1b	4.9a
STE	15	4.4ab	8.7a
STE	30	3.4bc	4.9a
STE	45	3.0c	6.2a
CWE	15	4.9a	4.3a
CWE	30	3.0c	6.2a
CWE	45	3.4bc	5.1a
RSFE	15	3.7abc	5.0a
RSFE	30	2.5c	3.7a
RSFE	45	2.9c	3.5a

All average among all soil depths
All 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

decrease in NH_4-N concentration with depth may reflect the increased exchange capacity present in the deeper soil columns.

The NO_3 concentrations in the column leachates varied with time (Tables 7). The NO_3 concentrations were similar in the 1st and 3rd study periods and lower in the 2nd study period. The low concentration present during the 2nd study periods may be related to the weak effluent that was present during the transition between occupants in the residence.

The NO_3 concentrations in the column leachate in the 1st study period were higher for column that received STE. However, in the 3rd study period, there was no difference in NO_3 concentrations with respect to type of wastewater applied and soil depth. However, columns receiving RSFE tended to have higher NO_3- N concentrations in the leachate than did columns that received either STE or SFE.

The decrease in inorganic N (NO_3 + NH_4) during the 1st study period was relatively large 61, 79, and 72%, respectively for columns receiving STE, CWE, and RSFE. However, in the 3rd study period the disappearance of inorganic N had decreased and ranged between 54 and

59%. This is probably a better estimate of the amount of N loss that can be expected when wastewater is applied to soil. During the 1st study period much of the NH_4 was apparently adsorbed on the exchange complex (in the deeper soil columns) and was not actually lost. However, after dosing these columns for three years, the values present in the 3rd study period are probably a good indicator of N loss that can be expected as a result of denitrification and NH_3 volatilization.

The TKN concentrations increased from year 1 to year 2 across all treatments except for the 30 cm columns that received STE (Table 8). 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 <10 mg L^{-1}.

Phosphorus

There was no change in the PO_4-P concentrations when STE was treated by a RSF (Table 9). The RSF utilized clean quartz sand which would not be expected to sorb or precipitate large quantities of P. However, these data suggest lower PO_4 (11%) concentrations when STE was treated by a CW. Phosphate uptake by the vegetation in the CW or possible precipitation with Ca^{2+} or Mg^{2+} explains the reduction of P in the CW (Huang, 1995).

There were differences in PO_4 concentrations in the column leachates for each study period (Table 4). During the 1st study period (5/93-5/94), no PO_4 was being leached from the columns and PO_4 concentrations were below detectable limits (Table 9). However, with time, PO_4 is being leached in detectable concentrations form all soil depths and from columns receiving different wastewater types. This

Table 9. The effect of soil depth and influent type on PO_4-P concentration in column leachate.				
Influent type	Soil depth (cm)	---------------------PO_4-P (mg L^{-1})---------------------		
		5/93 - 5/94	5/94 - 10/95	10/95 - 6/96
STE	All	BDL	12.2a*	0.43b
CWE	All	BDL	7.6a	0.56b
RSFE	All	BDL	11.3a	1.14a
All	15	BDL	10.3a	1.5a
All	30	BDL	11.6a	0.53b
All	45	BDL	9.3a	0.17c
		Column leachate		
STE	15	BDL	0.30b	0.78c
STE	30	BDL	0.21b	0.36d
STE	45	BDL	0.04b	0.08d
CWE	15	BDL	0.67a	1.46b
CWE	30	BDL	0.15b	0.41cd
CWE	45	BDL	0.05b	0.11d
RSFE	15	BDL	0.78a	2.25a
RSFE	30	BDL	0.19b	0.80c
RSFE	45	BDL	0.05b	0.30d

BDL - below detection limit
All - average among all soil depths
All - average among all influent types
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seems to indicate that the P fixation capacity has been exceeded or that the change in dosing, that occurred after the first study period, is responsible for the increased P concentration in the leachate collected from the columns. 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 leachate concentrations were being reduced with increasing soil depth regardless of the type of wastewater applied.

Increased P leaching may be much lower under field conditions because of the larger soil volume available for P sorption and the presence of more aerobic conditions. Studies have shown that P movement, under field conditions, is much less than predicted from laboratory studies. This is attributed, in part, to regeneration of P sorption sites under field conditions.

Soil Infiltration Rates

Soil infiltration rates decreased from year 1 to year 2 particularly with respect to 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. When STE is treated by CW or RSF, infiltration rates were higher. However, infiltration rates were higher in columns dosed with RSFE as compared to columns dosed with CWE (Table 10).

Table 10. Infiltration rates.

Influent Type	Soil Depth cm	6/94 $(cm/min)x10^{-3}$	10/95 $(cm/min)x10^{-3}$
STE	All	53.0a	11.0a
CWE	All	76.0a	12.0a
RSFE	All	164.0b	244.0b
All	15	112.0a	19.0a
All	30	70.0a	32.0a
All	45	66.0a	10.0a
		Column leachate	
STE	15	53.0ab	8.0ab
STE	30	64.0abc	221.0b
STE	45	45.0a	7.0a
CWE	15	167.0bc	41.0ab
CWE	30	48.0a	11.0ab
CWE	45	80.0abc	8.0ab
RSFE	15	588.0c	156.0b
RSFE	30	161.0bc	352.0b
RSFE	45	97.0bc	332.0b

All average among all soil depths
All 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

Soil Water Potential

The average matric potentials in all the soil columns were negative for both sampling periods (Table 11). However, the values were higher during the 10/94-10/95 period compared to the 5/93-5/94 period. This is attributed to the change in the dosing regime of these soil columns, resulting in more saturated conditions during the second year of this study. There was no difference based on soil depth.

Table 11.	**Soil matric potentials.**		
Influent type	Soil depth	Matric potential	
		5/93-5/94	10/94-10/95
	cm	kPa	
STE	All	-0.91a	-0.09a
CWE	All	-0.78a	-0.24a
RSFE	All	-0.92a	-0.59a
All	15	-0.72a	-0.16a
All	30	-0.89a	-0.38a
All	45	-1.02a	-0.38a
STE	15	-0.68a	-0.12a
STE	30	-0.91a	-0.04a
STE	45	-1.15a	-0.11a
CWE	15	-0.59a	-0.03a
CWE	30	-0.77a	-0.47a
CWE	45	-0.96a	-0.21a
RSFE	15	-0.89a	-0.32a
RSFE	30	-0.93a	-0.63a
RSFE	45	-0.95a	-0.82a

All - average among all soil depths
All - 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

CONCLUSIONS

These data suggest that the CW and the RSF treatment systems are effective in the renovation of domestic wastewaters. This should enable the use of marginally suited soils where highly treated wastewater is applied. Soils provided 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.

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 in renovation 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 should 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. This aerobic condition should 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 soil hydraulic infiltration capacity. Since 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.

Even though there were generally small differences in the biological and chemical quality of highly treated effluent after passing through 15 cm of soil as compared to passage through 30 and 45 cm, subsurface flow of the wastewater from the application site needs to be carefully evaluated if 15 cm of separation distances are to be considered.