NUTRIENT REMOVAL FROM SECONDARY EFFLUENT BY SOIL

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Soil columns were used to study the effects of effluent application rate and application frequency on wastewater renovation through soil media. Attempts were made to determine the feasibile wastewater loading rate. Chemical analyses were performed on soil, wastewater and filtrate samples. Bench tests were conducted to determine the nutrient adsorptive properties of a selected soil. Under equilibrium batch conditions, ammonia adsorption on Ninigrit sandy loam can be expressed by the Freundlich adsorption isotherm. In the *p*H ranges for usual wastewaters, around 7.0, nitrate adsorption on soil was insignificant. Column test results showed that all soil columns achieved 99% or greater phosphate removal. At the end of the 12-wk test period, nitrogen concentrations in all the filtrates were below the Canadian drinking water standard of 10 ppm NO_3-N. Test results also showed that denitrification could have been a significant factor in nitrogen removal.

INTRODUCTION

Although land application of wastewater is an old practice, it is only recently that it has received widespread interest of a scientific nature (Parizek et al. 1967; Pound and Crites 1973). In land application of wastewater, large quantities of suspended and dissolved materials are applied to a soil surface. Part of these materials may be temporarily or permanently retained in the root zone; the remainder will be carried underground by the flowing water. In order to develop optimum management schemes for environmental control, particularly the prevention of soil and water pollution, it is important to investigate the processes that control wastewater movement from the soil surface through the root zone and on down to the groundwater table. There is clearly a lack of basic information on the effluent application rate, the maximum loading, the frequency of application for various types of soil, and the effects of wastewater effluent on soil properties, groundwater qualities, crops, animals and human beings.

In this study, experiments were conducted with the following objectives:

1. To measure the nutrient adsorptive properties of a selected soil;
2. To study the effects of effluent application rate and application frequency on wastewater renovation through soil media;
3. To determine the feasible wastewater application rates on the soil-water system.

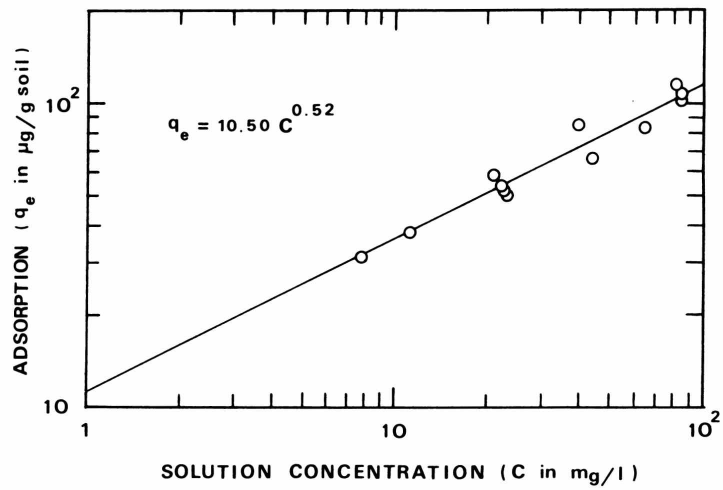

Figure 1. Adsorption isotherm for NH_3-N.

EXPERIMENTAL PROCEDURE

Bench Tests

Bench tests were conducted to determine the nutrient adsorptive properties of Ninigrit sandy loam. The procedure used was adapted from Preul and Schroepfer (1968). Three series of tests were conducted in which fixed weights of soil were allowed to equilibrate with solutions of graded concentrations of NH_3-N, NO_3-N, and phosphate, respectively, for periods of 3-5 days. The nutrient adsorptive capacities were then determined based on the original concentrations in the soil and the final concentrations in the solutions. In the case of nitrate nitrogen adsorption, two series of tests were run to observe the effect of *p*H on NO_3-N adsorption. In the first series, the *p*H was not adjusted. In the second series, the *p*H was adjusted to 7.0.

Column Tests

Column tests can provide information closely related to practical conditions. At the same time, complicated conditions can be simplified.

A two-way classification experiment was designed to investigate the effects of interactions between wastewater application rate and application frequency on effluent renovation. After a thorough review of current literature, three wastewater application rates (5, 10 and 20 cm/wk), and two application frequencies (daily and weekly) were chosen. Three testing periods (4, 8 and 12 wk) were selected. With these variables considered, 18 soil columns were constructed and tested.

The columns were made of plexiglass, 1.27 cm thick. The cross-sectional dimensions of each column were 15 X 15 cm. Both Ninigrit sandy loam and Hinckley sand were air-dried and then passed through a standard No. 10 sieve before being placed in the columns. In order to achieve relatively homogeneous and repeatable soil conditions, empty columns were placed on a shaker, and the soils were poured through a funnel into the columns. For each column, the bottom 15 cm was filled with Hinckley sand and then Ninigrit sandy loam was compacted to a depth of 45 cm. This was to simulate a field condition, with a sand layer lying 45 cm below the soil surface.

Secondary effluent from the Westfield Wastewater Treatment Plant, Westfield, Massachusetts, was used for this experiment. The secondary effluent feed application rate was controlled by a regulating valve. For each application, the valve was frequently adjusted so that the soil surface was saturated, but not flooded, since under field conditions surface runoff should be prevented. Polyethylene covers were used on all soil columns to prevent evaporation.

All tests were conducted at a temperature of 15°C in order to more closely simulate subsoil conditions and to eliminate the effect

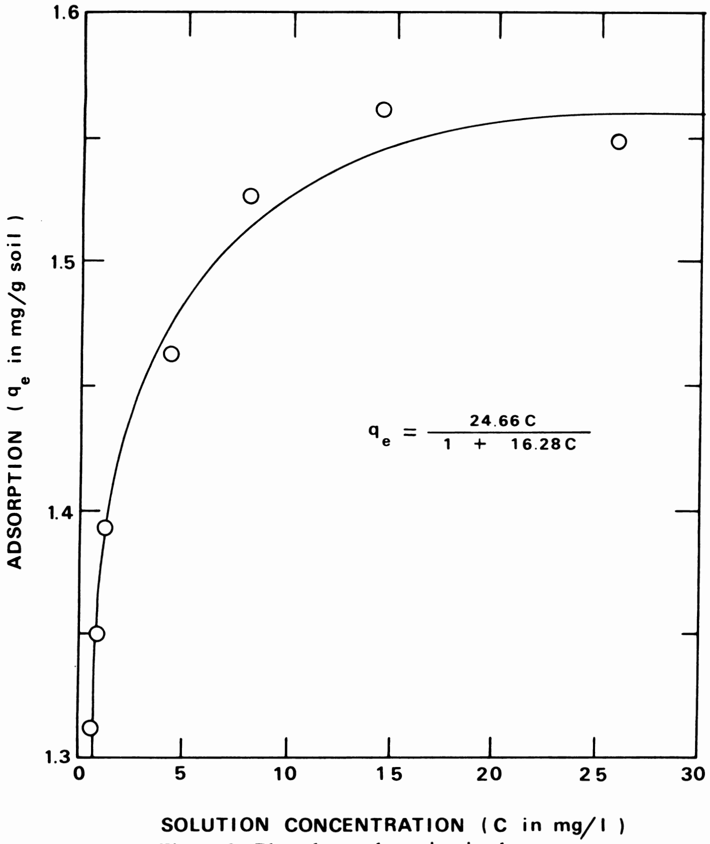

Figure 2. Phosphate adsorption isotherm.

of temperature variations. During the testing period, effluent was collected daily from the bottom of each column. This effluent was then analyzed for total organic carbon (TOC), total N, NH_3-N, NO_3-N, organic N and total P (Taras et al. 1971).

In order to find out the vertical distribution profile of nitrogen and phosphate in the soil, the soil columns were sectioned into 2.5-cm increments and analyzed for N (all forms) and P after each testing period.

RESULTS AND DISCUSSION

Bench Tests

Ammonia nitrogen adsorption

Ammonia nitrogren adsorption data are presented in Fig. 1. They follow the Freundlich isotherm (Weber 1972)

$$q_e = KC^{1/n} \qquad (1)$$

where q_e is the adsoprtion of NH_3-N in micrograms per gram of dry soil, C is the concentration of NH_3-N in the solution when equilibrium is reached, and, K and n are empirical constants. When log q_e is plotted against log C, a straight line with slope $1/n$ is obtained. For this case, $n = 1.94$ and $K = 10.50$.

TABLE I. NITRATE ADSORPTION ON SOIL

Initial NO_3-N (mg/l)	*pH*	Final NO_3-N (mg/l)	Adsorption of NO_3-N (μg/g)
100	5.5	86	56
50	5.8	44.5	22
25	5.6	21.75	13
10	5.6	8.75	3
5	5.7	4.5	2
0	5.7	0.1	0
100	7.0	100	0
50	7.1	50	0
25	7.0	25.5	0
10	7.2	10.2	0
5	7.0	5.1	0
0	7.1	0.2	0

TABLE II. AVERAGE CHARACTERISTICS OF SECONDARY EFFLUENT

pH		7.1
Nitrogen	Total N	24.34 mg/l
	NH_3-N	0.41 mg/l (as N)
	Organic-N	1.00 mg/l (as N)
	NO_3-N	22.92 mg/l (as N)
	NO_2-N	0.01 mg/l (as N)
Phosphorus	Total P	10.84 mg/l
Total organic carbon		5.18 mg/l

TABLE III. AVERAGED EFFLUENT QUALITY FROM COLUMNS HAVING 5 cm/wk APPLICATION RATE

Testing period	Daily or weekly	Total N (mg/l)	NH_3-N (mg/l)	Organic N (mg/l)	NO_3-N (mg/l)	NO_2-N (mg/l)	Total P (mg/l)	Total organic carbon (mg/l)
1	D	N/A†						
	W	N/A						
2	D	N/A						
	W	N/A						
3	D	N/A						
	W	N/A						
4	D	N/A						
	W	325.03	.63	.34	324.00	.062	.20	71.7
5	D	N/A						
	W	130.42	.52	.36	129.50	.043	.12	27.7
6	D	178.17	.31	.36	177.50	.009	.14	34.0
	W	19.45	.64	.51	18.30	.008	.07	19.7
7	D	52.51	1.18	1.33	50.00	.009	.09	7.0
	W	3.41	.83	.86	1.70	.025	.06	14.0
8	D	20.57	2.30	2.17	16.10	.004	.09	6.1
	W	4.35	2.28	.87	1.20	.001	.11	9.0
9	D	3.31	1.70	.42	1.19	.003	.12	16.5
	W	4.71	2.60	1.15	.96	.001	.14	9.0
10	D	4.42	3.40	.02	1.00	.002	.08	16.0
	W	3.69	2.10	.22	1.37	.002	.08	21.0
11	D	5.11	4.00	.01	1.10	.001	.07	15.5
	W	4.75	3.25	.30	1.20	.001	.14	17.0
12	D	5.43	4.30	.13	1.00	.005	.08	15.0
	W	4.30	2.00	1.25	1.05	.008	.09	16.0

†N/A means not applicable, since there was no effluent.

TABLE IV. AVERAGED EFFLUENT QUALITY FROM COLUMNS HAVING 10 cm/wk APPLICATION RATE

Testing period	Daily or weekly	Total N (mg/l)	NH_3-N (mg/l)	Organic N (mg/l)	NO_3-N (mg/l)	NO_2-N (mg/l)	Total P (mg/l)	Total organic carbon (mg/l)
1	D	N/A†						
	W	N/A						
2	D	N/A						
	W	N/A						
3	D	164.97	.66	.37	163.67	.271	.10	75.5
	W	122.73	.62	.34	121.67	.107	.17	72.5
4	D	26.70	1.15	1.18	24.33	.046	.04	27.9
	W	17.06	1.50	.65	14.90	.012	.11	21.1
5	D	5.95	2.20	.95	2.90	.009	.09	21.5
	W	5.37	1.68	.38	3.30	.011	.01	20.5
6	D	4.04	1.75	1.00	1.29	.001	.07	18.5
	W	5.59	2.27	.64	2.68	.007	.06	16.7
7	D	4.11	1.60	1.23	1.28	.002	.07	14.2
	W	5.15	2.40	.55	2.20	.001	.05	12.2
8	D	4.71	2.40	.87	1.44	.003	.06	22.0
	W	6.88	3.55	.58	2.75	.002	.09	8.2
9	D	4.72	2.90	.42	1.40	.006	.07	31.4
	W	5.63	4.30	.05	1.28	.003	.10	10.1
10	D	4.46	3.10	.45	.91	.007	.13	32.9
	W	6.31	3.80	.31	2.20	.007	.06	18.7
11	D	7.47	4.60	1.90	.95	.022	.13	25.0
	W	7.22	5.00	.42	1.80	.001	.12	20.3
12	D	6.37	3.30	2.10	.95	.029	.15	21.0
	W	8.99	5.80	1.90	1.28	.010	.11	20.0

†N/A means not applicable, since there was no effluent.

Nitrate nitrogen adsorption

Nitrate nitrogen adsorption data are shown in Table I. The results indicate that the adsorption of NO_3-N is strongly dependent on pH. In the first series of tests, the final pH was about 5.7 and significant adsorption of NO_3-N occurred. In the second series of tests, the final pH was about 7.0 and no significant adsorption of NO_3-N resulted. It can be seen that the adsorption of NO_3-N under conditions commonly found in groundwater or secondary effluent with a pH around 7.0 should not be significant. However, it can be significant if pH is below 6.0.

Phosphate adsorption

Phosphate adsorption data are presented in Fig. 2. The data can be fitted into the Langmuir isotherm (Weber 1972):

$$q_e = \frac{Q^{\circ} bc}{1 + bc} \qquad (2)$$

where

q_e = the amount of phosphate adsorbed per unit weight of dry soil,
Q° = the amount of phosphate adsorbed per unit weight of soil in forming a complete monolayer on the surface,
b = constant,
c = concentration in solution at equilibrium.

For this case, b = 16.28 and Q° = 1.52 mg/g.

Column Tests

Wastewater characteristics

At the beginning of the tests, about 300 *l* of secondary effluent were taken from the Westfield Wastewater Treatment Plant, Westfield, Massachusetts and then stored at a temperature of 4°C. Total phosphate, nitrogen and total organic carbon (TOC) analyses were done weekly. Test data showed very little variation in total P, N and TOC throughout the storage period. The average values are given in Table II.

Soil column effluent quality

The effluent from soil columns was collected daily and stored at 4°C. Chemical analyses were done weekly. The results are given in Tables III, IV and V. Generally, the pH values were around 7.0.

From these data, it can be seen that TOC in the effluent decreased with time. However, the values were higher than those of the secondary effluent. It is believed that organic carbon was gradually leached out of the soil columns.

Total P in the effluent was in the range of 0 - 0.22 mg/*l*. The average value for all the samples was 0.10 mg/*l*. Therefore, the phosphate removal efficiency of all the soil columns was at least 99%.

Nitrate contents were very high during the first 2 wk after effluents started draining from the columns. There are two possible explanations:

(1) Since the soils were air-dried, the micro-organism population should have been very low when the test was started. Therefore, a period of about 2 wk might have been required for microbial growth to reach maturity. The high nitrate concentration might have been due to leaching of nitrate originally in the soil.

(2) It is very possible that nitrification occurred and was a dominant factor for the first 1 or 2 wk.

Nitrate concentration in the effluent from all the columns showed a decreasing trend with time. However, the columns having the 20 cm/wk application rate showed a slight increase in the last 4 wk. The rapid decrease in nitrate concentration and the slight variation in organic-N concentration were interpreted as evidence of denitrification. As far as nitrate concentration is concerned, this suggests that denitrification may be an important factor in wastewater renovation.

It is obvious that NH_3-N concentration in the effluent increased with time. The possible chemical reactions involved may be hypothesized, e.g. mineralization of organic nitrogen, and nitrate reduction, but cannot be verified by the results of this study.

In Fig. 3, the variations of the total nitrogen concentration in the weekly collected effluents are presented. The average total nitrogen concentrations are plotted against time. It is clear that during the first 3 wk after drainage started, the nitrogen concentration in the effluent from all the columns showed a decreasing trend with time. This was followed by fluctuations and a later slow increase with time. By the end of the 12-wk testing period, effluent from the columns with 5 cm/wk application rate had the lowest total nitrogen concentrations. Effluent from the columns with 10 and 20 cm/wk rates had slightly higher total nitrogen concentrations, ranging from 6.4 to 9.0 mg/*l*. This trend of nitrogen contents increasing with time may well have been due to a nitrate application rate that was higher than the rates of denitrification and nitrate reduction. It could also have been due to a slowdown in denitrification as organic carbon was gradually leached out of the column. Further studies are needed to confirm or deny this.

When drainage first started, the nitrogen content (mostly nitrate) was high. However, it can be seen that the lower the wastewater loadings, the higher were the nitrogen contents in the effluents collected. It is obvious that there was a dilution effect. For the 5 cm/wk application, less wastewater was applied. Therefore, nitrate leaching resulted in the highest nitrogen concentration in these effluents as compared with the 10 and 20 cm/wk applications.

For the 10 cm/wk application, it is noted that on the 3rd wk of the testing period, the effluent nitrogen concentrations were already below those of the input wastewater. This means that micro-organisms in the soil became active within 2-3 wk.

Under field conditions, this kind of leaching may or may not happen. Soils are usually moist and the soil microbial population will always exceed that of an air-dried soil. Therefore, it may be expected that nitrate leaching will not occur at the beginning of wastewater application. However, this can only be confirmed by doing field plot tests.

Based on the effluent nitrogen concentrations, nitrogen removal efficiencies of columns with different application rates and application frequencies are given in Table VI. It can be seen that the nitrogen removal efficiency decreased with increasing loading rate. At the end of a 12-wk period, the columns with the 5 cm/wk application rate had the best nitrogen removal efficiency.

In both the 5 cm/wk and the 20 cm/wk series, effluent applied weekly had a better renovation effect than that applied daily. This may have been due to a longer resting period for weekly application. For the 10 cm/wk series, the fact that daily application achieved better nitrogen removal than that of weekly application cannot be explained. It might have resulted from sample variation. However, this could not be verified as no replicates were available for the last 4 wk.

For the 10 cm/wk and 20 cm/wk application rates, the removal efficiency increased in the first few weeks and then decreased to around 63-74%. The increase of removal efficiency might have been due to soil microbes that were gradually reaching maturity. The decrease could have been due to a slowdown in denitrification and nitrate reduction as organic carbon was gradually leached out of the columns, or it may simply have been due to nitrate loading rates that were higher than the rates of denitrification and nitrate reduction.

TABLE V. AVERAGED EFFLUENT QUALITY FROM COLUMNS HAVING 20 cm/wk APPLICATION RATE

Testing period	Daily or weekly	Total N (mg/l)	NH_3-N (mg/l)	Organic N (mg/l)	NO_3-N (mg/l)	NO_2-N (mg/l)	Total P (mg/l)	Total organic carbon (mg/l)
1	D	N/A†						
	W	N/A						
2	D	57.80	.90	.33	56.50	.099	.22	74.3
	W	48.18	1.03	.84	46.30	.014	.15	43.1
3	D	11.45	1.82	1.12	8.51	.009	.10	29.4
	W	18.24	2.37	.64	15.23	.009	.00	23.3
4	D	4.48	1.85	.70	1.93	.005	.09	25.5
	W	5.97	2.63	.61	2.73	.009	.09	19.3
5	D	5.06	2.00	.65	2.40	.010	.11	32.2
	W	5.31	2.25	.30	2.75	.011	.07	23.0
6	D	3.45	1.90	.38	1.17	.006	.11	25.7
	W	5.89	1.70	.38	3.80	.012	.07	18.8
7	D	5.60	3.13	1.16	1.30	.012	.21	20.4
	W	4.47	1.73	.68	2.05	.011	.11	18.5
8	D	4.76	2.70	.48	1.55	.029	.08	23.4
	W	5.85	2.65	1.21	1.98	.016	.13	18.7
9	D	6.31	3.15	.03	3.10	.039	.13	21.0
	W	5.42	2.10	.31	3.00	.018	.08	20.0
10	D	8.20	3.90	.02	4.20	.088	.10	19.0
	W	6.83	3.20	.42	3.20	.017	.10	18.5
11	D	9.43	2.90	1.41	4.05	.075	.10	20.0
	W	7.33	2.40	.02	4.90	.018	.10	20.5
12	D	8.53	4.00	.41	4.10	.029	.12	20.0
	W	6.81	2.50	1.00	3.30	.019	.14	20.0

†N/A means not applicable, since there was no effluent.

TABLE VI. NITROGEN REMOVAL EFFICIENCY

Time (week)	Application rate					
	5 cm/wk		10 cm/wk		20 cm/wk	
	Daily	Weekly	Daily	Weekly	Daily	Weekly
1	N/A†	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	-137.59%(40)	-98.07%(40)
3	N/A	N/A	-577.49%(30)	-404.11%(30)	52.92%(60)	25.02%(60)
4	N/A	-1,235.25%	-9.75%(40)	29.90 , (40)	81.57%(80)	75.39%(80)
5	N/A	-435.70%	75.54%(50)	77.96%(50)	79.21%(100)	78.18%(100)
6	-632.21%(30)‡	20.08%(30)	83.40%(60)	77.05%(60)	85.82%(120)	75.82%(120)
7	-115.69%	85.98%	83.16%	78.64%	76.99%	81.64%
8	15.60%(40)	82.37%(40)	80.66%(80)	71.75%(80)	80.45%	75.86%
9	86.39%	80.65%	80.58%	76.86%	74.02%	77.70%
10	81.83%(50)	84.83%(50)	81.65%(100)	74.05%(100)	66.26%	71.91%
11	78.99%	80.48%	69.30%	70.33%	61.22%	69.82%
12	77.67%(60)	82.30%(60)	73.79%(120)	63.07%(120)	64.92%	71.98%

†N/A means not applicable.
‡Number in parentheses stands for equivalent total wastewater loading; i.e. 5 cm/wk for 10 wk is equivalent to 10 cm/wk for 5 wk.

The removal efficiency might have been reduced if the tests were allowed to continue. However, the data showed that even without crop uptake, removal efficiencies of 63-82% can be maintained for different application rates. It is expected that if suitable crops were incorporated into the system, the removal efficiency would increase.

As shown in the last line of Table VI, the nitrogen removal efficiency with different wastewater application rates varied by about 10-20%, while the amount of wastewater applied varied two to four times. Therefore, a compromise between the nitrogen removal efficiency and the rate of loading will have to be considered. The final decision probably will be one based on economics.

In this study, the influential factors were controlled under laboratory conditions; therefore the results may not be directly applicable to the field application of waste effluent. However, these results can be expected to reflect general trends. The variation of temperature was not considered. The columns were packed with 45 cm of top soil. In the field, the top soil may not be as deep and the microbial population would probably be different. More studies are needed to establish correlation between results from column studies and field conditions.

The loading of 20 cm/wk for 9 wk is equivalent to that of 5 cm/wk for 36 wk. In the New England area and the Maritime Provinces, 36 wk should cover the spring, summer and autumn seasons, which are suitable for spray irrigation. Assuming that the results obtained in this study are valid for field conditions, one may expect that with an application rate of 5 cm/wk for 36 wk, the nitrogen removal efficiency would be around 70%. If suitable crops were planted, this removal efficiency would be higher (Sopper 1973).

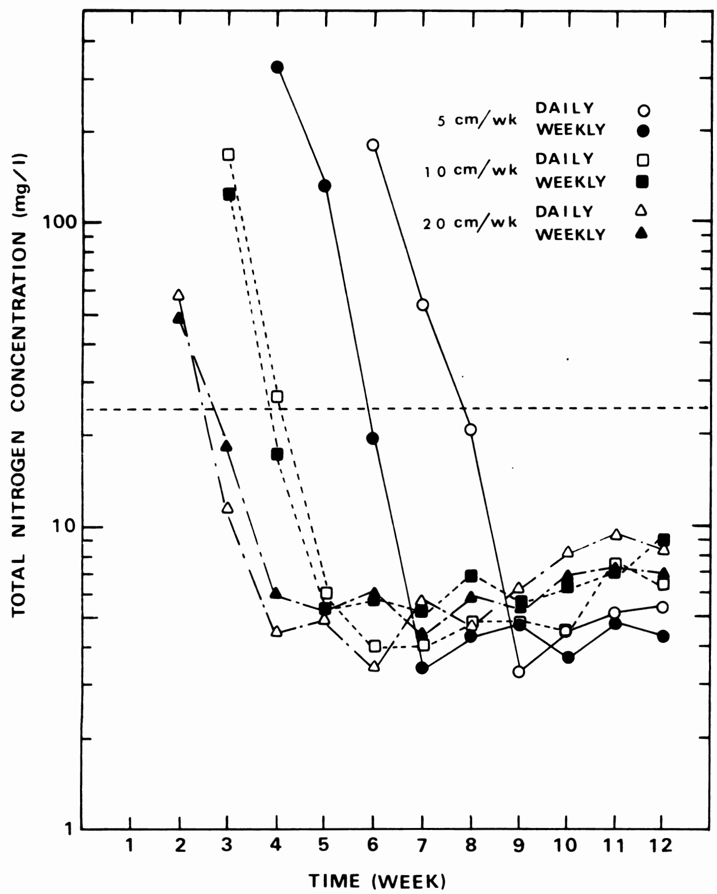

Figure 3. Total nitrogen concentration vs. time.

Nutrient distribution in soil columns

At the end of each testing period, columns were sectioned into 2.5-cm increments and analyzed for nitrogen and phosphate. Phosphate profiles at the end of a 12-wk period are given in Table VII. Since it was observed, however, that phosphate accumulated in the top 2.5-5 cm of the column, only the profiles of the top 15 cm are presented. The averaged value of phosphate originally present in the Ninigrit sandy loam was 1.31 mg P/g dry soil. It may be seen that the phosphate accumulation in soil decreased with depth. For the case of the 5 cm/wk application rate, phosphate accumulated in the top 2.5 cm of the soil; it decreased from 1.60 to 1.40 and 1.66 to 1.3 mg P/g dry soil for daily and weekly applications, respectively. For the 10 cm/wk and 20 cm/wk cases, the accumulation reached a depth of 5 cm; however, the P content in the soil for columns with 20 cm/wk application rate were higher than those of columns with 10 cm/wk application rate.

TABLE VII. PHOSPHATE PROFILES AT THE END OF THE 12-wk PERIOD (IN mg P/g DRY SOIL)

	Application rate					
	5 cm/wk		10 cm/wk		20 cm/wk	
Depth (cm)	Daily	Weekly	Daily	Weekly	Daily	Weekly
0	1.60	1.66	1.69	2.03	2.07	1.83
1.25	1.50	1.49	1.61	1.69	1.85	1.79
2.5	1.40	1.31	1.51	1.35	1.89	1.74
3.75	- †	-	1.40	-	1.69	1.59
5.0	1.31	1.32	1.41	1.38	1.45	1.35
7.5	-	-	1.31	1.36	-	1.24
10	1.36	1.29	1.28	1.28	1.28	1.22
15	1.35	1.28	1.25	1.37	1.30	1.23

†Sample was not taken at this depth.

The total nitrogen in all the columns appeared quite uniformly distributed with depth. However, NH_3-N and NO_3-N were distributed increasingly and decreasingly with depth, respectively. Data for columns 17 and 18, at the end of the 12-wk period, are given in Table VIII. The interface between sand and sandy loam was at a depth of approximately 45 cm. It can be seen that both NH_3-N and NO_3-N contents in the Hinckley sand were considerably lower than those of the Ninigrit sand loam. Data for all the columns were reported elsewhere (Lo 1975). Mass balances were performed for soil columns on a weekly basis.

Since the total nitrogen in the soil columns remained fairly constant both before and after wastewater application, the nitrogen removal efficiency given in Table

TABLE VIII. NH_3-N AND NO_3-N + NO_2-N OF THE COLUMNS 17 AND 18 AT THE END OF THE 12-wk PERIOD (IIN mg N/DRY SOIL)

Depth (cm)	NH_3-N (mg/g)	NO_3-NO_2-N (mg/g)	NH_3-N (mg/g)	NO_3-NO_2-N (mg/g)
2.5	.0200	.0599	.0191	.0446
7.5	.0189	.0389	.0185	.0326
12.5	.0171	.0171	.0173	.0194
18	.0237	.0259	.0280	.0161
23	.0303	.0347	.0386	.0129
28	.0353	.0232	.0399	.0129
33	.0392	.0109	.0408	.0129
38	.0426	.0153	.0432	.0130
43	.0462	.0198	.0459	.0131
48	.0050	.0032	.0020	.0015
53	.0049	.0032	.0015	.0015

VI also gave a rough estimate of the percentage of nitrogen loss that occurred each week. The results of bench tests indicated that with a pH around 7.0, the adsorption of nitrate nitrogen on soil would have been insignificant. Therefore, it was suspected that a large portion of this nitrogen loss could have been due to denitrification.

SUMMARY AND CONCLUSIONS

Under equilibrium batch conditions, ammonia adsorption on Ninigrit very fine sandy loam can be expressed by the Freundlich adsorption isotherm

$$q_e = KC^{1/n} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

with K = 10.5 and n = 1.94.

In the pH ranges for usual wastewaters, no significant nitrate adsorption on soil will occur.

Phosphate adsorption on Ninigrit sandy loam can be expressed by the Langmuir isotherm

$$q_e = \frac{Q^\circ bc}{1 + bc} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

with Q° = 1.52 mg/g and b = 16.28.

Column test results showed that all soil columns achieved 99% or greater phosphate removal.

Phosphate from the applied secondary effluent accumulated in the top 2.5-5.0 cm of the soil columns, depending on loading.

At the end of the 12-wk test period, columns with 5 cm/wk application rate had the best nitrogen removal, about 80%. Columns with 10 and 20 cm/wks application rates had nitrogen removal ranging from 63 to 74%. Nitrogen concentrations in all the effluents were below the recommended limit of 10 mg/l NO_3-N for drinking water. It is expected that if crops were incorporated into the systems, nitrogen removal efficiency would have been higher.

Although there are no detailed quantitative data, it is believed that denitrification can be an important factor in land disposal of waste effluent. Total nitrogen loss in the soil columns amounted to about 65-80% of the nitrogen input through wastewater application. A portion of this must be due to denitrification. More research on denitrification in soils is recommended.

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