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LA THÈSE A ÉTÉ
MICROFILMÉE TELLE QUE
NOUS L'AVONS REÇUE

USE OF KITCHEN WASTE FOR DENITRIFICATION AND REDUCTION
OF ASSOCIATED PARAMETERS BY SOIL FILTRATION

by

N. Biswas

Submitted in partial fulfillment of
the requirements for the degree of
Doctor of Philosophy

Department of Civil Engineering
School of Graduate Studies
University of Ottawa

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ABSTRACT

This study was carried out to investigate the feasibility of using kitchen wastewater as a source of organic carbon for denitrifying bacteria in a subsurface disposal system under laboratory conditions. Synthetic feed solutions comprised of potassium nitrate and kitchen wastewater represented nitrified septic tank effluent. Preliminary experiments were carried out using a soil column system and more advanced trials in a model tile installation.

During the first part of the study, twenty soil columns representing four different soil depths were used. Five different carbon (expressed as methanol) to nitrogen ratios ranging from 2:1 to 6:1, were applied to these soil columns for seven months. Results of this study indicated a minimum carbon to nitrogen ratio for successful denitrification, which was subsequently used during the final part of the study using a model tile installation in the laboratory.

A C:N ratio of 4:1 was found to be the minimum ratio for successful (over 90 percent) denitrification in the soil columns for all the soil depths ranging from 150 mm to 450 mm. The C:N ratios ranged from 2:1 to 6:1. Less than 15 percent of nitrate removal was obtained when the C:N ratio was only 2:1. For the first 20 weeks the rate of application was 200 mm/wk. During the last 8 weeks of the study the soil columns were dosed

with a rate of 420 mm/wk. The results show negligible variation in the nitrate removal efficiencies for C:N ratios equal to or greater than 4:1. The average nitrate removal efficiency in the tile bed which was dosed with C:N ratio of 4:1 at a rate of 80 L/m²/d for six months, was 79 percent at a depth of 1000 mm.

A nitrate removal efficiency of only 21 percent was observed in the tile bed at a depth of 400 mm and for a rate higher than 60 percent a minimum required depth was 600 mm. Nitrite was not detected in column effluents where the C:N ratio was higher than 3:1. The levels of TKN (total kjeldahl nitrogen) reductions in soil columns for a feed solution of 4:1 varied from 24 to 48 percent. In the tile field these levels ranged from 25 to 52 percent. COD (chemical oxygen demand) removal rate in the tile field ranged from 51 to 73 percent. In soil columns for a C:N ratio of 4:1 a depth of 450 mm reduced the influent COD by over 90 percent. Presence of high dissolved oxygen concentration in the feed solution did not inhibit denitrification. The minimum levels of DO in the column and tile bed effluents ranged from 1.0 to 2.5 mg/L respectively. The ratio of change in total alkalinity to corresponding levels of nitrate removal ranged from 2.44 to 3.03 in the soil columns and from 2.27 to 3.01 in the tile bed. The residual SOC (soluble organic carbon) levels in the soil columns as well as in the tile field were found to be lower than expected even for high C:N ratios and the recovery rate never exceeded 20 percent of the excess applied SOC. Reduction of TSS (total suspended solids)

was low for both the soil columns and the tile field on a regular basis. The maximum level of reduction for the soil column was 31 percent. In the tile bed this level was always lower than 27 percent and occasionally produced negative results. The levels of pH in the treated effluents ranged from 6.8 to 7.6 and were found to be suitable to denitrification.

Due to insufficient number of samples obtained from the unsaturated zone in the tile bed for the nitrate test, a conclusion on nitrate removal in an unsaturated zone cannot be made. However, over 60 percent removal of nitrate with an average of 64 percent was recorded at a depth of 700 mm where the moisture content was above 20 percent by volume even after 3 hours after the loading operation was completed.

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CHAPTER 1

INTRODUCTION

1.1. Nature of the Problem

Disposal into the soil of various wastes has been a common practice for many years; the use of individual on-site methods for domestic wastewater disposal is one of the most important cases. The most commonly accepted method used for such on-site disposal is by means of a septic tank followed by some type of subsurface disposal system.

It has been reported that soils are capable of removing most of the biodegradable matter and fecal organisms from wastewater (52,89,92). The nutrients in the effluent, excepting nitrogen, can also be removed effectively. For example, field studies show that the removal of phosphorus through soil can be as high as 90 percent (10).

Nitrogen compounds in secondary effluent or in septic tank effluent are mostly in the form of ammonium ion (2,77,89). Along their paths in the soil these ammonium ions are oxidized into more stable nitrate ions. The NO_3 ions are highly mobile especially if the disposal field is located in well-drained, aerated soil (72,91). These nitrate ions may reach the groundwater and become a very undesirable contaminant causing serious environmental problems (27,32,33). The main problems caused

by nitrate are the association of methemoglobinemia with high nitrate levels and eutrophication of receiving waters because of excess nitrates. Other problems such as increase in oxygen and chlorine demand and toxicity to fish can also occur if subsurface disposal systems are improperly designed and placed very close to receiving streams and lakes.

In Iowa, well waters containing an appreciable amount of nitrate were found as early as 1945, to cause methemoglobinemia in infants (69). The Yearbook of 1950 (98) of the American Public Health Association reported some 262 cases and 29 deaths. This disease, which is called "Blue-baby" disease, stems from depletion of oxygen in the blood and the baby becomes cyanotic (32). Since no cases of methemoglobinemia have been reported from water containing less than 45 mg/L of nitrate as NO_3 , the U.S. Public Health Service drinking water standards, published in 1962, recommended 45 mg/L as NO_3 (or 10 mg/L as N) as the maximum acceptable limit for drinking water (86). A major contributor of nitrate to groundwater is the effluent from conventional subsurface wastewater disposal systems (19,27,33,75). Andreoli et al (4) reported serious groundwater contamination problems in Nassau County on Long Island, N.Y., where 40 percent of the population (total population - 1,460,000) is dependent on individual on-site sewage disposal system. Data available through 1976 indicate 19 highly productive wells exceeded the public health limit for nitrate concentration and had to be

shut down or their water had to be blended with higher quality water. A trend of increasing nitrate levels was also detected in 35 percent of 447 public water supplies, private and monitoring wells (4). High potential for nitrate pollution from septic tanks is also reported by Goehring (33) in New Castle County, Delaware. Once the nitrogen concentration exceeds the recommended limit of 45 mg/l as NO_3 , the sources of water supply, which are usually shallow wells, have to be deepened or their water must be treated or blended with higher quality water. If these alternatives are found to be impractical, the well is taken out of service in favour of a new uncontaminated source. For instance, in Kingston, Jamaica, half of the 28 drinking water wells have been abandoned due to high nitrate level (66).

1.2. Purpose of this Study

Successful denitrification of wastewater using methanol and other sources of organic carbon has been reported by many researchers (4,31,54,81,95). Most of these sources are not readily available at the site and more often than not involve the additional cost of chemicals. Therefore, this study was undertaken to investigate the feasibility of using kitchen wastewater, which is readily available in a household at no additional cost, as a source of organic carbon for denitrifying bacteria in a subsurface disposal system under laboratory conditions.

1.3. Summary of Work

During the first part of the study several soil columns were used to represent the vertical sections of a tile field disposal system. Five different soil depths were used. Synthetic feed solutions containing five different carbon to nitrogen ratios were applied to these soil columns for seven months. The kitchen wastewater was used to provide the necessary amounts of soluble organic carbon for denitrification. Potassium nitrate was used to represent nitrified septic tank effluent. Both the feed solutions and the column effluents were analyzed with respect to the following parameters: reductions in nitrate, chemical oxygen demand (COD), soluble organic carbon (SOC), dissolved oxygen (DO), total suspended solids (TSS) and variations in ammonia, nitrite, total kjeldahl nitrogen (TKN), pH and Alkalinity. Removal efficiency was determined by comparing the reduction achieved between the point at which the feed solution was applied to the soil columns and the respective treated column effluents. An analysis of the data obtained during this study provided the optimum value of the required carbon to nitrogen ratio for successful denitrification along with the removal efficiencies of other parameters with respect to various soil depths and time.

During the second part of the study, a single test tile was loaded with synthetic feed solution under laboratory conditions. This feed solution contained only the optimum

carbon to nitrogen ratio found in the study using soil columns. Sampling devices were installed at various depths. Percolates collected in the seepage bed were analyzed for various parameters as mentioned before including nitrate. The test tile was placed in a tank to achieve a balance between the amounts of feed solution and the effluent. An attempt was made to observe the level of denitrification at both the saturated and unsaturated zone in the tile field. A water table was maintained in the tank all the time and the level was varied 3 times during the study. This part of the study lasted for about six months.

CHAPTER 2

THEORETICAL BACKGROUND

2.1. Scope

There are many ways by which nitrogen can be removed from wastewater. Since this study is to be carried out in soils, only the pertinent theoretical considerations regarding the biological actions on nitrogen in soils are considered here. Also, the theory of the movement of water transporting nitrate is presented.

2.2. Biological Actions on Nitrogen in Soils

Nitrogen added to soils in organic and inorganic forms is subject to various changes brought about by microorganisms present in the soils. The actions and interactions are many and of a complex nature. However, the most feasible approaches for nitrogen control in soils appear to lie in the use of nitrification and denitrification processes (20,44,48).

The main advantage of biological denitrification is that it returns nitrogen to the atmosphere as inert N_2 , thus reducing the threat of groundwater contamination.

There are three conditions which must be met in order to remove nitrogen from sewage water by biological denitrification (21,44,48,86). These conditions are:

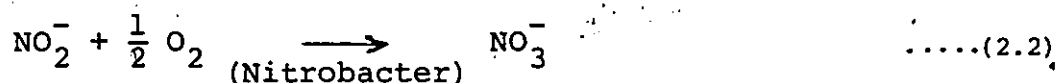
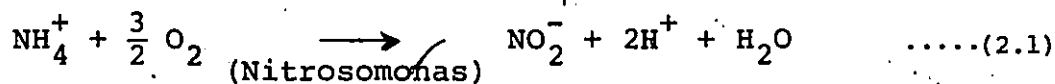
- a) the $\text{NH}_4\text{-N}$ which makes up most of the nitrogen content of secondary or septic tank effluent must be oxidized to nitrate;
- b) nitrate must move through a zone where oxygen is absent;
- c) organic carbon must be provided in that zone as an energy source for the denitrifying bacteria.

2.2.1. Nitrification

This process can be defined as the biological conversion of nitrogen in inorganic or organic compounds from a reduced to a more oxidized state. For wastewater applied to soil, the bacterial populations sequentially oxidize ammonia to nitrate with intermediate formation of nitrite. Several of these bacterial populations have been identified (17,69,86). Nitrosomonas, Nitrosospira, Nitrosocoecus and Nitrosocystis oxidize ammonia to nitrite whereas Nitrobacter, Nitrosogloca, Nitrocystis oxidize nitrite to nitrate. Of these genera the most commonly found autotrophs in the soil water systems are Nitrosomonas and Nitrobacter (75,86).

The nitrification process is dependent mostly on autotrophic organisms, however other heterotrophic bacteria, actinomycetes and fungi are also found to accomplish nitrification. This genera include Mycobacterium, Nocardia, Streptomyces, Agrobacterium, Bacillus and Pseudomonas (3).

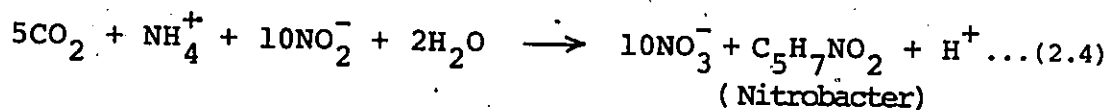
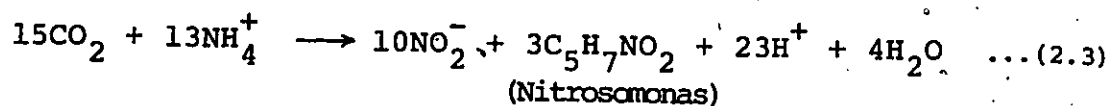
Oxidation of ammonium and nitrite can be expressed by the following stoichiometric equation:



During these reactions, Nitrosomonas is reported to obtain more energy per mole of nitrogen oxidized than Nitrobacter (34,86).

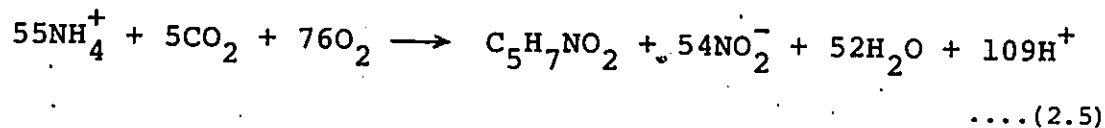
Nitrosomonas obtain 58. to 84 k cal per mole of ammonia, whereas Nitrobacter obtain between 15.4 to 20.9 k cal per mole of nitrite (63). Assuming that the cell synthesis per unit energy obtained is equal, an oxidation reaction for the same amount of nitrogen will produce more Nitrosomonas than Nitrobacter. In other words, Nitrobacter bacteria must process 3 times as much substrate as the Nitrosomonas bacteria to obtain the same energy. This probably explains the rapid conversion of nitrite to nitrate and is also the reason for not having large build-ups of nitrites in the ecosystem.

Assuming that the empirical formula for bacterial cells is $\text{C}_5\text{H}_7\text{NO}_2$, the following reactions show the growth of the organisms (34,86):

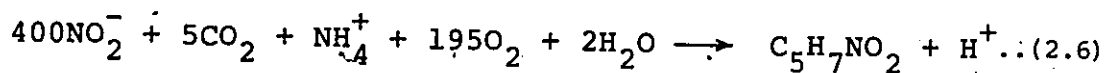


Ignoring the complexity of actual biochemical reactions the cellular yields reported for the nitrifying bacteria (34):

Nitrosomonas



Nitrobacter



These are only empirical formulas and are not balanced.

2.2.2. Denitrification

The biochemical pathways followed during the oxidation of organic matter are many. This is because of the presence of various compounds, e.g., sugar, amino acids, fats in the wastewater. In carbon metabolism, coenzymes such as NAD are reduced (by accepting two electrons) from the organic matter and CO₂ may be produced. The reduced NADH then transfers electrons to oxygen by the electron transport system (Fig. 2.1). This redox process is used by bacteria for the production of ATP at 3 coupling sites, which is the energy storing molecule subsequently used in their

biosynthesis and movement.

However, under anoxic condition denitrifying bacteria use nitrate etc. to replace oxygen as the oxidant. The genera includes Pseudomonas, Achromobacter, Bacillus and Micrococcus (3,69). These organisms can use either oxygen or nitrates as the terminal electron acceptor. Figure 2.1 shows these alternate pathways clearly where nitrate is reduced to nitrites etc. and then to nitrogen gas. Note the enzymes involved. As can be seen that the proposed coupling sites for ATP production are only one when nitrate is used as the electron acceptor. This means that the available energy for the bacteria is less when nitrate is used in their respiratory process as compared to oxygen.

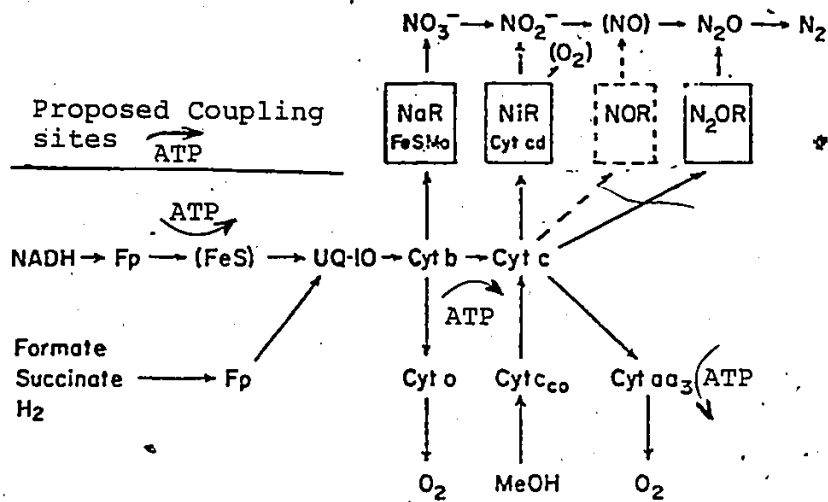


Fig. 2:1. Possible Pathways of Electron Transport System in Denitrification (99).

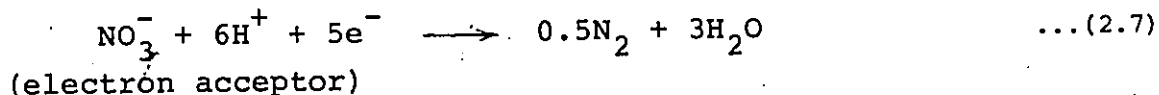
Abbreviations: NaR - nitrate reductase; NiR - nitrite reductase; NOR - nitric oxide reductase; N₂OR - nitrous oxide reductase; Fp - flavoprotein; FeS - iron-sulfur center; UQ-10 - ubiquinone-10; Cyt - cytochrome; Mo - molybdenum; MeOH - methanol; ATP - adenosine triphosphate; NAD - nicotinamide adenine dinucleotide.

This is nitrate dissimilation where nitrate is reduced to nitrogen gas. In contrast nitrate assimilation is also possible by denitrifiers, where nitrate is reduced to ammonia level and is used for the synthesis of cell protein (44, 69).

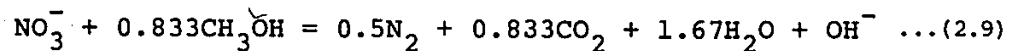
Once the ammonium nitrogen is oxidized to nitrate and enters an anoxic zone in the soil, the denitrification process starts immediately and continues as long as the organic carbon available to the denitrifiers remains. However, the quantity of available organic carbon in the soil is limited and without this electron donor, denitrifiers cease their operation and as a result NO_3 escapes to groundwater.

Fresh organic matter, sugars, protein and wastewater have been used as suppliers of organic carbon in various studies (45,47,48,58,81,86). Methanol has been one of the most common and widely used organic carbon sources in the denitrifying process (29,54,79).

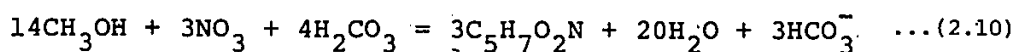
The oxidation reduction half reactions using methanol are as follows:



By combining the above equations, we obtain:

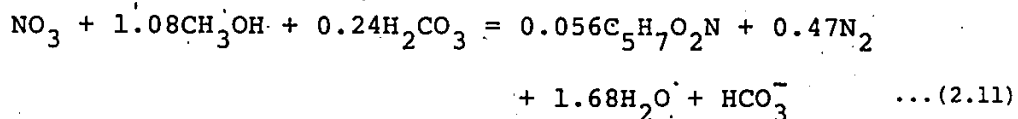


When we consider the assimilation of NO_3^- , the synthesis reaction becomes (54,86):

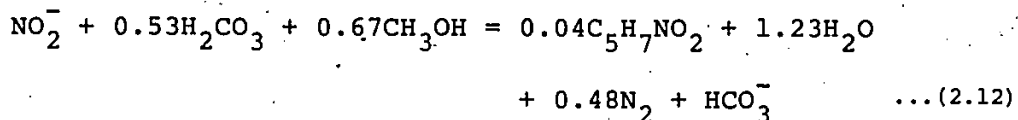


For overall reactions McCarty et al (54) developed the following reactions:

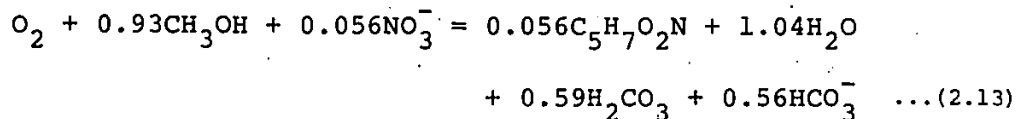
Overall Nitrate Removal



Overall Nitrite Removal



Over all Deoxygenation



Therefore, the overall methanol requirements can be expressed

as (54):

$$C_m = 2.47\text{NO}_3^- -\text{N} + 1.53\text{NO}_2^- -\text{N} + 0.87\text{DO} \quad \dots(2.14)$$

where

C_m = required methanol concentration, mg/L

$\text{NO}_3^- -\text{N}$ = nitrate concentration removed, mg/L

$\text{NO}_2^- -\text{N}$ = nitrite concentration removed, mg/L

and DO = dissolved oxygen removed, mg/L

Biomass production can be calculated according to the following relationship:

$$C_b = 0.53\text{NO}_3^- -\text{N} + 0.32\text{NO}_2^- -\text{N} + 0.19\text{DO} \quad \dots(2.15)$$

where

C_b = biomass production, mg/L

If there is no nitrite present, wastewater containing 20 mg/L of nitrate and 10 mg/L of dissolved oxygen will require $20(2.47) + 10(0.87)$ or 33.4 mg/L of methanol for complete denitrification. The quantity of bacterial cells expected is $20(0.53) + 10(0.19)$ or 12.5 mg/L.

During the reduction of nitrate and nitrite, bicarbonate is produced and thus there is an overall increase in the alkalinity of the system. However, results in the literature show that

in most of the cases this condition was not inhibitory to the denitrification process (41,86). Production of alkalinity as reported by Horstkotte et al (36) for a suspended growth system was 2.89 mg as CaCO_3 per mg of nitrogen reduced. This value is, however, less than the theoretical value of 3.57 mg/L as CaCO_3 by approximately 20 percent and can be attributed to the complexity of overall biological transformations which take place during the process of denitrification (36). A recommended value for alkalinity in practical engineering applications is found to be 3.0 mg/L as CaCO_3 (86).

CHAPTER 3

LITERATURE REVIEW

3.1. Scope

There is a considerable amount of published material on removal of nitrogen from wastewater through biological, physical and chemical interactions of nitrogen compounds moving through soils. An attempt has been made to review those works which are considered relevant to this study.

3.2. Biological Denitrification

3.2.1. Attached Growth System

Once the soil profile reaches the reduced state, biological reduction of nitrates starts immediately. However, researchers (41,44,77) found that the denitrification process was often inhibited due to the lack of any available carbon source for the denitrifiers. Field and laboratory studies showed that less than 30 percent nitrogen removal was obtained when a loamy sand was flooded with secondary effluent at infiltration rates of 30 to 40 cm/d (13,46). In these cases the only limiting factor was found to be the available organic carbon.

Andreoli et al (4) used methanol as an external source of organic carbon in a field study and reported nearly

complete reduction of nitrates within one month of commencement of methanol addition. In this study an impermeable pan was used at the bottom of the leaching bed and almost all the samples collected from this saturated zone depicted very high (over 90 percent) nitrate removal.

Although methanol is a popular choice as a source of carbon in the process of denitrification, other alternate sources were also investigated. Wilson et al (86) used brewery waste as a source of carbon in columnar denitrification and found it to be an effective substitute to supplement for methanol. No significant difference in degree of denitrification was observed when sufficient dosage of methanol and brewery wastes were used separately.

Bremner and Shaw (18) found that 800 mg of wheat straw added to a soil sample gave the same rate of denitrification after twelve days as 5 mg of sucrose.

Dextrose was also used successfully in columnar denitrification (47). This carbon source was added to secondary wastewater effluent to increase the level of organic carbon to 75 mg/L, and consequently nitrogen removal was increased by more than 30 percent.

Horizontal sand columns were used by Davenport et al (26) in a denitrification study where CH_3OH as well as saw dust were used as separate energy source. A synthetic feed solution

containing 2500 mg of NO_3^- was used. The maximum level of nitrate removal was reported to be 87 percent. Although the supplied level of organic carbon methanol was higher than the theoretical requirement, complete denitrification was never achieved and it was attributed to the lack of other necessary nutrients such as phosphorus in the feed solution. In the same study, use of saw dust alone was found to have little effect on nitrate removal.

A recent study was carried out by Lance et al (45), where primary as well as secondary effluents were used as carbon sources. Soil columns were mainly divided into two groups - vegetated columns and non-vegetated columns. For both the carbon sources the same columns, flooding schedules and measuring techniques were used. For primary effluent the nitrogen removal was 45.6 and 81.8 percent for non-vegetated and vegetated columns, respectively, as compared to 28.5 and 48.1 percent nitrogen removal from secondary effluent by non-vegetated and vegetated columns. Primary effluent produced better nitrogen removal than the other source because of its higher concentration of organic carbon. However, nitrogen removal was much higher in the vegetated columns than in the non-vegetated ones for both the sources and can be attributed to nitrogen uptake by plants. Common Bermuda grass was used in the study. Surprisingly, the infiltration rate in the columns was not significantly affected, although

the primary effluent sometimes contained as high as 181 mg/L of suspended solids. One of the problems which is associated with the use of primary effluent as a source of organic carbon is that it also contains additional nitrogen in the form of ammonium ion. Another practical problem of achieving nitrification followed by denitrification in the same soil profile is that the supplied organic carbon for the denitrifying bacteria may be depleted by other heterotrophic bacteria, not involved in nitrate reduction, before it reaches the denitrification zone. For this reason Andreoli et al (4) used feeder pipes to supply the organic carbon source (methanol) to the denitrification zone instead of to the nitrification zone with the wastewater.

A study has been reported by Laak (42) in which greywater from a household was used in successful denitrification in an attached growth system. A system called the 'RUCK' system was developed for an average household where greywater has been separated from the blackwater and has been used as a source of organic carbon (Figure 3.1). The effluent from the blackwater septic tank is nitrified through a subsurface sand bed. This nitrified effluent stream is then mixed with the effluent from the greywater septic tank and the combined waste stream is brought into an anaerobic upflow rock-filled tank where denitrification takes place. The rock filter effluent is then disposed of by means of a conventional seepage system.

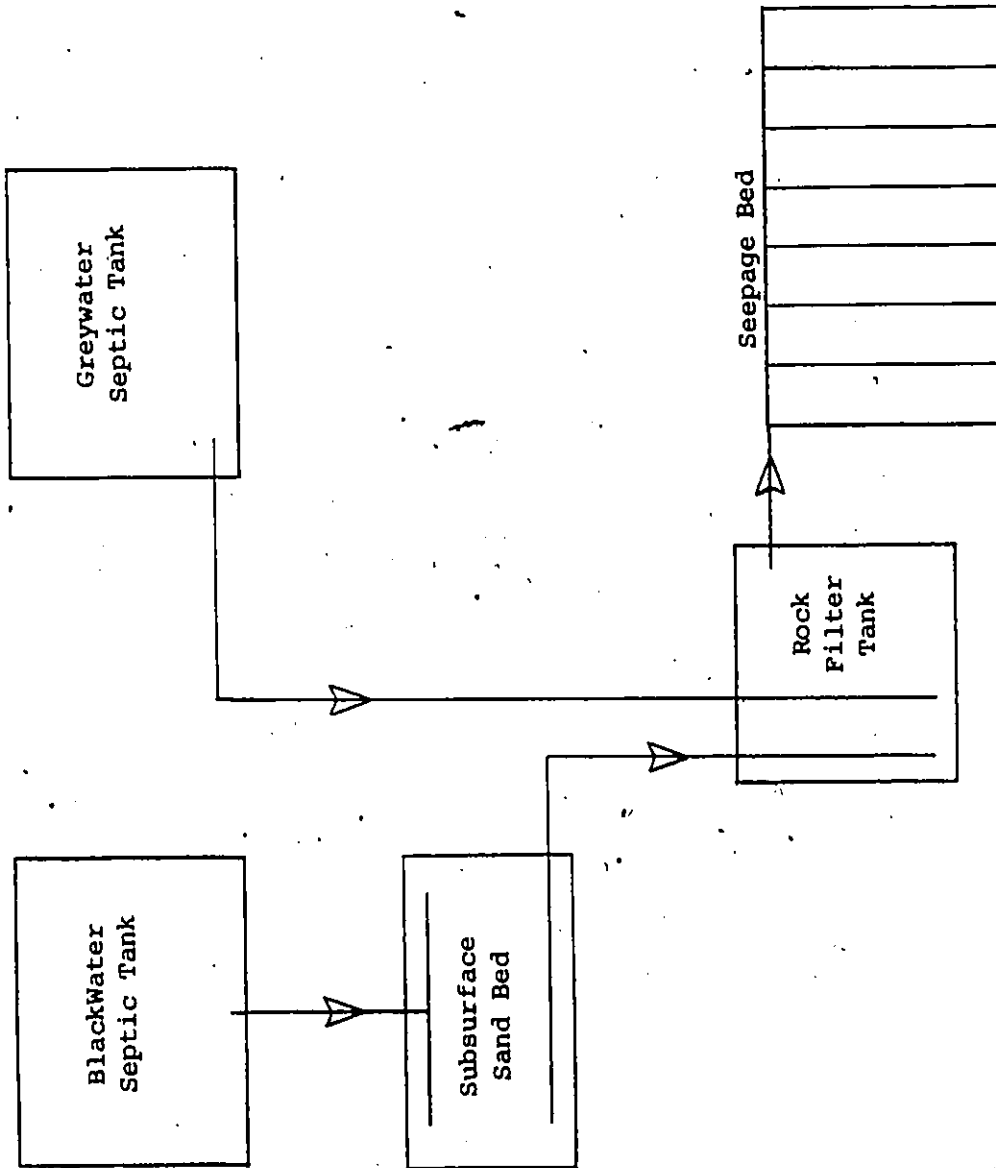


Fig. 3.1. RUCK System (42)

This method of treatment has been in operation for a household system for two years and for eight condominium systems for six months. Over 70 percent efficiency in nitrogen removal has been achieved. The final effluent before infiltration into the soil is reported to have less than 10 mg/L of total nitrogen and a nitrate content of 0.2 - 5 mg/L. Favourable comparisons were obtained when these efficiencies were compared with the results produced by the use of methanol as a carbon source.

3.2.2. Suspended Growth System

The most successful and widely-used suspended growth treatment system in removing nitrogen comprises nitrification followed by biological denitrification (67,86).

A single-stage, activated sludge system designed for denitrification was suggested by Wuhrmann (67) in the early sixties without any external source of organic carbon.

Ludzach and Ettinger (51) first proposed the use of organic carbon present in the untreated influent for denitrification. They also used alternate aerobic and anaerobic zones for nitrogen removal in the activated sludge process achieving over 60 percent efficiency.

Barnard (6) used two anaerobic and two aerobic chambers in an alternating sequence and obtained 93 percent

reduction of nitrogen without the addition of any organic chemical under laboratory conditions. Within an operating temperature range of 20 to 23°C the total retention time for the nitrification and denitrification facilities were in the order of 16 hours. To reduce this long retention time Barnard suggested the addition of methanol or other carbon sources to boost the activity in the denitrification chamber.

McCarty et al (54) first compared various sources of organic carbon in the denitrification process. The sources included ethanol, methanol, acetone, acetic acid and sugar. After comparing their unit costs and other properties, for the same amount of nitrate reduction, it was concluded that methanol was the most economical and effective source of organic carbon.

Francis and Mankin (31) used methanol as an external carbon source in denitrifying high nitrate effluent from a UO_2 fuel fabrication plant successfully in continuous flow-stirred reactors. In this study two important observations were made: a) at nitrate concentrations $>6 \text{ kg NO}_3/\text{m}^3$, denitrification rates were inhibited; and b) methanol concentration as high as $11.6 \text{ kg CH}_3\text{OH}/\text{m}^3$, while maintaining the NO_3 concentration $<5 \text{ kg NO}_3/\text{m}^3$, did not inhibit denitrification. However, Picard and Faup (67) found excess methanol to be toxic to the denitrifiers; a sudden appearance of high nitrate concentration in the effluent from the denitrification chamber was attributed to the excess methanol

itself or to hydrogen sulfide formed by the reduction of the sulphates in the water during the anaerobic fermentation of the remaining methanol.

3.3. Other Methods of Nitrogen Removal in Soils

3.3.1. Removal of Nitrogen by Irrigation of Crops

Wastewaters, when applied as irrigation water for crops, serve dual purposes; they meet the water requirement for the crop and also supply the necessary nutrients (1,15,25). These nutrients including nitrogen are incorporated into the plant tissue and are completely removed from the system when the crop is harvested.

The literature shows that selection of the proper crop is very important when effective removal of nitrogen is desired by land irrigation. A long growing season, tolerance for floods and high requirements for nitrogen are the desired qualities. Sopper (78) reported that reed canary grass irrigated with 50 mm² (2 in.) of secondary effluent per week removed 0.045 kg/m² (408 lb/acre) of nitrogen during 1 year, whereas corn silage irrigated at the same rate removed only 0.018 kg/m² (140 lb/acre) of nitrogen per year (89). However, there are three main drawbacks of this method of nitrogen removal:

- 1) It is impractical for individual wastewater disposal system because of associated public health problems.

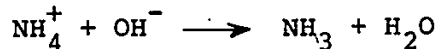
- 2) There are chances of excess nitrogen reaching groundwater.
- 3) There are high requirements of land area and a high cost associated with it.

3.3.2. Removal of Nitrogen by Adsorption in Soils

Soil particles possess a negative charge in general, which means that they have a greater electrokinetic capacity to attract the positively-charged cations out of solution (8). Wastewaters coming out of septic tanks contain NH_4^+ ions which are adsorbed by the negatively-charged soil particles (clay) and organic colloids. However, review of the literature establishes the fact that the adsorption of NH_4^+ by the soil when flooded with wastewater is very limited and once the soil is saturated with ammonium ions this capacity is even reduced (44,70). Furthermore, these immobilized ions can be oxidized in the course of time to the highly mobile nitrate ion and would eventually find its way into the groundwater. Studies carried out by Nommick (60) also indicated that this method had the above-mentioned shortcomings.

3.3.3. Removal of Nitrogen by Volatilization of Ammonia

Nitrogen present in the wastewater can be removed in the form of NH_3 provided certain conditions are met. Ammonia exists in equilibrium with ammonium ion in solution.



Below pH 7, most of the nitrogen is present as ammonium ion. At a higher pH level, the percentage of gaseous ammonia increases. For a pH of 7.5 to 8.0, which is a typical pH value for wastewater, less than 10 percent of the nitrogen would be in the gaseous form (43). In other words, without the addition of alkaline chemicals, volatilization of ammonia is not sufficient to remove any significant amount of nitrogen from the wastewater and therefore is not practical in an individual wastewater disposal system.

Non-biological reactions called chemodenitrification can also produce gaseous ammonia. Again, this process requires a pH value below or around 5.0 and high nitrite concentrations which are not the characteristics of the average domestic wastewater (20).

3.4. Factors Affecting Nitrification and Denitrification

3.4.1. Factors Affecting Nitrification

pH

The optimum pH for the growth of the nitrifiers is not sharply defined but in pure cultures it has been reported to be in the alkaline range (3). During nitrification the pH drops because of the destruction of alkalinity and production of hydrogen ions. Theoretically a decrease of 7.1 gm of

alkalinity as CaCO_3 should occur for every gram of nitrate nitrogen produced. Wild et al (95) found that if the value of pH in the nitrification system is outside the range of 7.0 to 9.8, less than 50 percent of the optimum rate occurred. During nitrification with submerged filters, Haug and McCarty (34) found that, where excess alkalinity was available, oxidation was 95 percent complete. In a test where alkalinity was approximately equal to the amount required for neutralization, the effluent from the submerged filter had a pH of nearly 5.5, while the efficiency of oxidation dropped to 90 percent, and in a test with substantially less alkalinity than theoretically required, nitrification ceased completely when a residual alkalinity of 10 mg/L as CaCO_3 was reached.

For blackwater flows from a household, Brandes (16) reported that enough alkalinity (i.e. alkalinity/nitrogen requirement of 7/1) was present for successful nitrification. This has been recently confirmed by Laak (42) in a field study where the nitrification was complete and the pH was in the range of 3.5 to 4.0. The nitrification was achieved in a sand filter and the effluent did not have any alkalinity left.

Temperature

The nitrification process is found to be affected by the temperature of the environment. For optimum growth of nitrifiers, the temperature needs to be between 30° and 36°C (3). Laboratory studies have indicated that the rate of nitrification increases throughout the range of 5° - 35°C in reasonable agree-

ment with the general concept of doubling for each 10°C increase (85). However, information on the rate of nitrification at low temperatures indicates conflicting results. Rimere et al (71) reported negligible nitrification below 10°C , whereas Haug and McCarty (34) used a submerged filter and found nitrification to be reasonably rapid and stable at temperatures as low as 1°C . They also found that with a detention time between 90 and 120 minutes at 5°C , the submerged filter was able to nitrify 90 percent of the incoming ammonia nitrogen.

Dissolved Oxygen

Oxygen must be available for the successful nitrification of wastewater. A level of $4.6 \text{ mg O}_2/\text{mg NH}_4^+\text{-N}$ is found to be sufficient for the aeration requirement in a nitrification process (86). Successful nitrification of septic tank effluent in soil has been well documented (41,59,70,89). The presence of a low concentration of oxygen in the septic tank effluent did not pose any significant problem. For a subsurface sand filter, used for nitrification of blackwater, Laak (42) found that it was the loading rate which was particularly important for successful denitrification. The other factor was the type of filter cover; both silt and clay covers produced low nitrification rates. This may be attributed to the possible reduced oxygen penetration from the atmosphere.

3.4.2. Factors Affecting Denitrification

pH

Clayfield (21) reported the optimum pH for denitrifiers to be around 7.5. Less than 80 percent nitrate removal efficiency was obtained below a pH level of 7.0. For a pH of 6.0, the removal rate dropped to less than 40 percent. Similar results are also reported by other researchers (86). However, Dawson and Murphy (24) found an optimum level of 7.0 for maximum denitrification. They reported an efficiency of 75 percent around the pH level of 6.0. This is also supported by Laak (42) in a recent field study where 70 percent denitrification was obtained at a pH level of around 6.8. Contrasts in the efficiency of denitrification process for higher pH were less pronounced. However, a pH level of more than 8.0 seems to depress the denitrification process (86).

Temperature

For isolated denitrifying bacteria, the optimum temperature for denitrification is found to vary from 30°C to 65°C (12). This is a wide range and in a natural soil system temperatures this high would not often be reached with the exception of tropical countries. Furthermore, isolation of bacteria in a subsurface disposal system is also not possible.

In the literature, the effects of temperature below

30°C on denitrification rates have been found to be varied. Stensel (82) reported very little change in the rate between 20 and 30°C. Dawson and Murphy (24) found that denitrification rates doubled for each 10°C increase in temperature between 5 and 20°C in a laboratory study. Some researchers (12,19,43) reported little or no denitrification below 10°C in soil systems. Terry and Nelson (85) found significant denitrification rates below 5°C. Merrow (56) also observed a significant rate of denitrification at temperature around 10°C. Devenport et al (26) also reported a decrease in nitrate removal efficiency with the drop of temperature. They found 87 percent NO_3^- removal in 24 days at 24°C, 75 percent at 18°C in 28 days and 62 percent at 13°C in 27 days respectively.

Moisture Content and Characteristics of Soil

Moisture content of the soil where denitrification is taking place is also found to be very important in achieving a high degree of denitrification (44). Bremner and Shaw (19) found that below 60 percent of field capacity, removal of nitrogen through denitrification was negligible although other conditions for denitrification were favourable. Meek et al (55) found that production of nitrogen gas in incubated soil samples did not change when the water contents were between 34 to 41 percent but increased sharply when the moisture content reached 44.5 percent. The typical moisture characteristic of the soil used was 48 percent moisture at saturation and

32 percent at field capacity. The literature shows that the rate of denitrification in some soils can be doubled by a change of 2 to 6 percent in water content above the field capacity level for those soils (81). Patrick et al (64) found that after a week of flooding, the soil profile exhibited characteristics of a reduced state.

Soil characteristics have also been found to affect denitrification in some studies. For fine sediments Vankessel (88) found that denitrification took place in the top 7 to 14 cm of the soil profile. Test results involving sandy loam soil show that denitrification was not significant until a depth of 16 cm is reached in the soil profile (91). This may be due to the fact that oxygen present in sandy soil in the top layers prohibit denitrification. In a subsurface disposal field the soil depth is not expected to be a limiting factor.

Dissolved Oxygen

Inhibition of denitrification due to the presence of dissolved oxygen is not well documented. In a column study Smith et al (77) observed no significant effect of high dissolved oxygen levels on successful denitrification. The lowest values of oxygen in the effluents were between 1 and 1.5 mg/L. Horstkotte et al (36) also reported significant denitrification in the presence of low levels of oxygen.

In a subsurface disposal system biological

denitrification will be preceded by biological nitrification where the low level of oxygen concentration coming out of the septic tank will be further reduced; therefore, the oxygen level should not hamper successful denitrification.

Nitrate Concentration

A study of the literature shows that there are discrepancies in the results regarding the effect of nitrate concentration on the rate of denitrification. Some researchers (22,65) have reported that nitrate concentration has no effect on the rate of denitrification; i.e., zero order kinetics have been indicated when the initial concentration of nitrate is around 1000 mg/L. At a low level some dependence of the denitrification rate on the nitrate concentration was observed by Voltz (91); however, at higher levels the rate of denitrification was independent. Sikora and Keeney (75) carried out some laboratory studies with initial concentration of nitrate of 40 mg/L and found that the denitrification rates followed first order reactions. This was true at three levels of temperature varying from 5°C to 20°C.

Vankessel (88) observed another interesting phenomenon where he found that the rate of denitrification was also dependent on the type of the soil. For one soil he reported first order kinetics below 300 mg/L of nitrate concentration and zero order above. For another soil the dividing concentration of nitrate was around 500 to 600 mg/L. There are other

studies in which similar variations for the dividing points have been reported (38,56).

CHAPTER 4

PURPOSE OF STUDY AND EXPERIMENTAL PROCEDURE

4.1. Purpose of the Study

After reviewing previous work on denitrification, it can be concluded that, under favourable environmental conditions, denitrifying bacteria present in the soil are capable of removing most of the nitrogen from wastewater. However, to create this favourable environment, a sufficient amount of organic carbon must be made available to the denitrifying bacteria. Although methanol and a few other sources have been used successfully in some studies, they are far from being practical for solving excess nitrate problems which are associated with small scale on-site sewage disposal systems. The RUCK system (42) is the only exception and has thus far been reported to be quite successful in removing nitrogen from septic tank effluent. This study investigated a practical means of achieving denitrification in a septic tank-tile field system by using greywater as the carbon source for the denitrifying bacteria in a separate denitrification reactor.

After carrying out a detailed survey Laak (41) reported that greywater flow from a household makes up 40 - 60 percent of the total wastewater flow (Table 4.1). In domestic households, kitchen wastewaters form part of the greywater.

Table 4.1 Greywater Flow - 40 to 70 Percent of Total Flow (41)

Item	Greywater range	Combined sewage
S.S	85 - 300 mg/L or 18 g/c/d	100 - 400 mg/L
BOD ₅	100 - 300 mg/L	150 - 350 mg/L
PO ₄	8 - 95 mg/L	10 - 100 mg/L
TN	3 - 25 mg/L	20 - 80 mg/l
Temperature	40 - 60 °C	36 - 40 °C
Grease	60 - 150 mg/l	50 - 150 mg/L
Flow	0.13 - 0.17 m ³ /c/d	0.15 - 0.21 m ³ /c/d

Note: g/c/d - gram per capita per day
 m³/c/d - cubic meter per capita per day

It contains wastewater from garbage disposal, from food preparation and from dishwashing. Table 4.2 shows water-use volumes in households as found by various researchers. Water usage consumption as a percentage is shown in Table 4.3. It can be seen that, on the average, the volume of water used in a kitchen makes up over 10 percent of the total volume. Characteristics of kitchen waste which contributes most of the organic carbon in greywater have been analyzed by a few researchers and are presented in Table 4.4 along with the results obtained by the author during the study. It can be seen that kitchen wastewater is very rich in soluble organic carbon and comparatively low in nitrogen; thus it would be a good source of organic carbon for denitrification. Thus, in this study kitchen waste consisting of effluent from a domestic garbage grinder was used to provide the source of necessary organic carbon for denitrification.

The ammonia present in the septic tank effluent has to be oxidized to nitrate before undergoing denitrification. In this study, synthetic feed solution containing a known amount of KNO_3 was used to represent nitrified septic tank effluent. The other constituent of the feed solution was a predetermined amount of kitchen waste (details are given in the latter part of this chapter). Application of this feed solution to the soil columns can be compared with a conventional septic tank-disposal system in which the kitchen waste is mixed

Table 4.2. Water Use Volumes

Usage	Witt, 1974 (97)	Laak, 1974 (40)	Bennett & Linstedt, 1975 (11)	Wiegand et al, 1976 (76)	Ligman et al, 1974 (50)
Laundry	127.3	28.0	45.4	39.8	38.0
Bath	81.3	40.1	41.6	37.9	47.5
Dishes	47.5	13.6	26.5	18.6	13.3
Other	-	-	-	30.3	-
Total	256.1	81.7	113.5	126.6	98.8

Note: All items are expressed in liter per capita per day

Table 4.3. Household Water Usage (Percentage of Total)

Usage	Ligman 1972 (49)	Wallman 1972 (93)	Bennett et al 1975 (11)	Siegrist et al 1976 (74)	Laak 1974 (40)
Toilet	41	27 - 45	33	22	47
Laundry	19	18	27	25	18
Bath	26	18 - 36	24	23	21
Kitchen	10	13	16	11	9
Drinking	3	-	-	-	-
Cleaning	1	-	-	-	-
Other	0	6	-	19	5

Total Flow (L/c/d) 171 114 - 190 169.1 163.4 155.8

Note: L/c/d - liter per capita per day

Table 4.4. Characteristics of Kitchen Waste

Item	Siegrist et al. (1976) (mg/L)	Witt et al (1974) (mg/c/d)**	Author*
Total PO ₄	74	419	-
Ortho PO ₄	31	177	-
SS	720.	4111	75 - 170
TOC (Filtered)	880	4111	1180 - 4800
NH ₃ -N	6	32.3	<3.2
NO ₂ -N	-	-	0.0
NO ₃ -N	0.3	1.8	0.0
TKN	74	424	51.7 - 145.2
TOC (Not filtered)	-	5000	1300 - 5600

* Garbage grinder was used and the waste was allowed to settle for two hours before the supernatant was taken for analysis.

** milligram per capita per day

with the nitrified (through a sand filter) septic tank effluent prior to the final subsurface disposal. The system proposed here is very similar to the RUCK system. The differences are the absence of a separate denitrification reactor and the substitution of kitchen waste for greywater. This treatment facility would be a low-cost one and is expected to reduce the nitrogen in the final effluent considerably without any addition of chemicals.

In summary, the objective of this study was to investigate the removal of nitrate by denitrification through soil using only kitchen wastewater as the source of organic carbon for the denitrifiers. In the first part of the study soil columns were used to obtain information about the optimum carbon to nitrogen ratio for complete denitrification, and in the subsequent study this ratio was used for denitrification in a small scale tile field representing field conditions. Both the studies were carried out under laboratory conditions. Variations of parameters other than nitrate with soil depth and time were also of major concern. These parameters included pH, alkalinity, nitrite, nitrate, ammonia, organic nitrogen, suspended solids, chemical oxygen demand, dissolved oxygen and soluble organic carbon.

4.2. Experimental Procedure

4.2.1. Scope

To assess the operation and efficiency of a subsurface disposal system with denitrifying capabilities, it is necessary to collect representative samples regularly for laboratory analysis. This collection of samples is difficult in the field situation and may become impossible in the winter or during periods of high groundwater. Furthermore, some control of the environmental conditions is needed beyond that which is possible in a field installation. With these limitations in mind, it was proposed to carry out this research work in the laboratory at the University of Ottawa under controlled conditions.

4.2.2. Studies with Soil Columns

A septic-tile field system usually consists of a baffled septic tank followed by a gravel-filled subsurface seepage bed where the effluent from the septic tank flows through a perforated or open joint pipe and is dispersed through the gravel into the soil. It was felt that it would be useful to conduct a soil column study before attempting to model a subsurface seepage bed.

Soil columns have been widely used to represent the vertical dimension of disposal fields and the results have been found to be representative of the actual field conditions (29,45,52,77). During the first part of the study, tests were

carried out with soil columns of various sizes. These preliminary tests aided in the planning of the tests of the model tile field system, described below, and provided a comparison between column tests and the laboratory model of an actual tile field system.

The main variables involved in the soil column studies were:

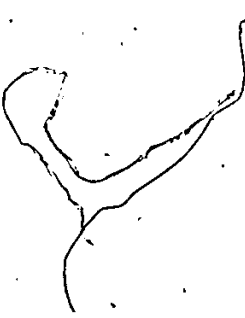
- 1) concentration of organic carbon in the kitchen waste;
- 2) depth of soil in soil column;
- 3) rate of application.

4.2.2.1. Test Materials

Basic materials used in the soil columnar study are individually described in the following paragraphs. These materials include the soil sample, the columnar tubes and the feed solution composed of nitrate solution and kitchen wastewater.

Soil Sample

The soil sample was obtained from the Rideau River basin, Municipality of Ottawa-Carleton, Province of Ontario, about 10 km south of Ottawa (Figure 4.1). There is an existing sand pit in this area; the soil was trucked to the laboratory.



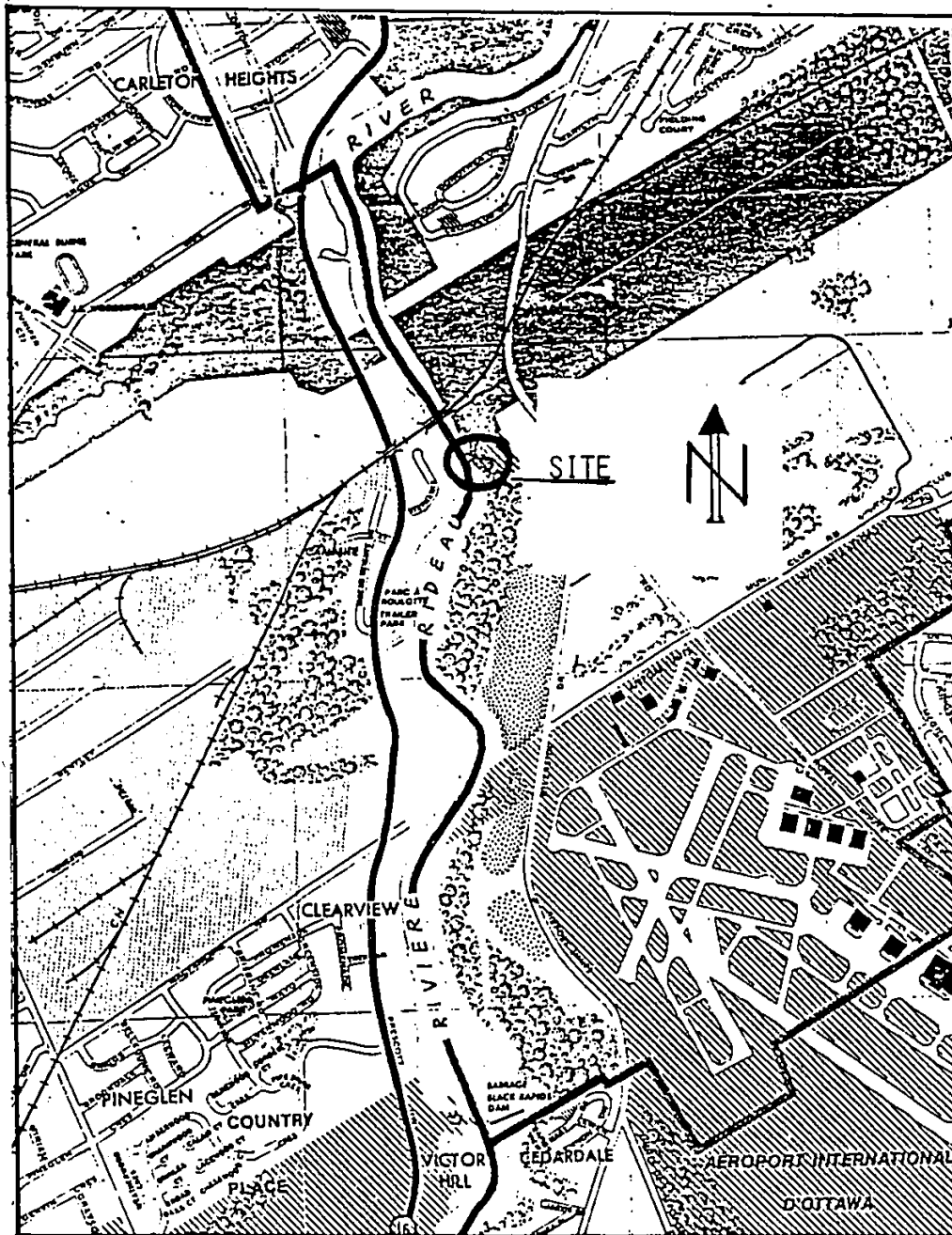


Fig. 4.1 Location Map for the Soil Sample at the Municipality of Ottawa Carleton

The soil of this region is predominantly of a coarse sand type with very little clay content. Sieve analysis was done to obtain a grain size distribution for this soil and is shown in Figure A1, Appendix A, p.170 (5). Tests for other parameters were carried out as described by Bowles (14) and the results are shown in Table A1, Appendix A, p.172. The uniformity coefficient and the effective size were 3.36 and 0.14 mm respectively.

Soil samples were cleared of vegetation, leaves, large-size gravel and other foreign matter before being used in the study.

Soil Columns

Fifty millimeter internal diameter clear acrylic tubes were filled with soil materials to represent part of the disposal bed; a schematic diagram is shown in Figure 4.2. Rubber stoppers were used as caps. These soil columns were fitted with a gravel filter at the bottom. The filters were used so that there would be no interference with the infiltration capacity or the treatment efficiencies of the soil. To reduce any carry over of soil grains in the effluent, a metal screen (mesh No. 100) was placed at the top of the effluent collector in each column. All the soil columns were covered with aluminium foil on the top to reduce oxygenation of the soil profile. However, there were always small openings through which a limited amount of air may have entered the

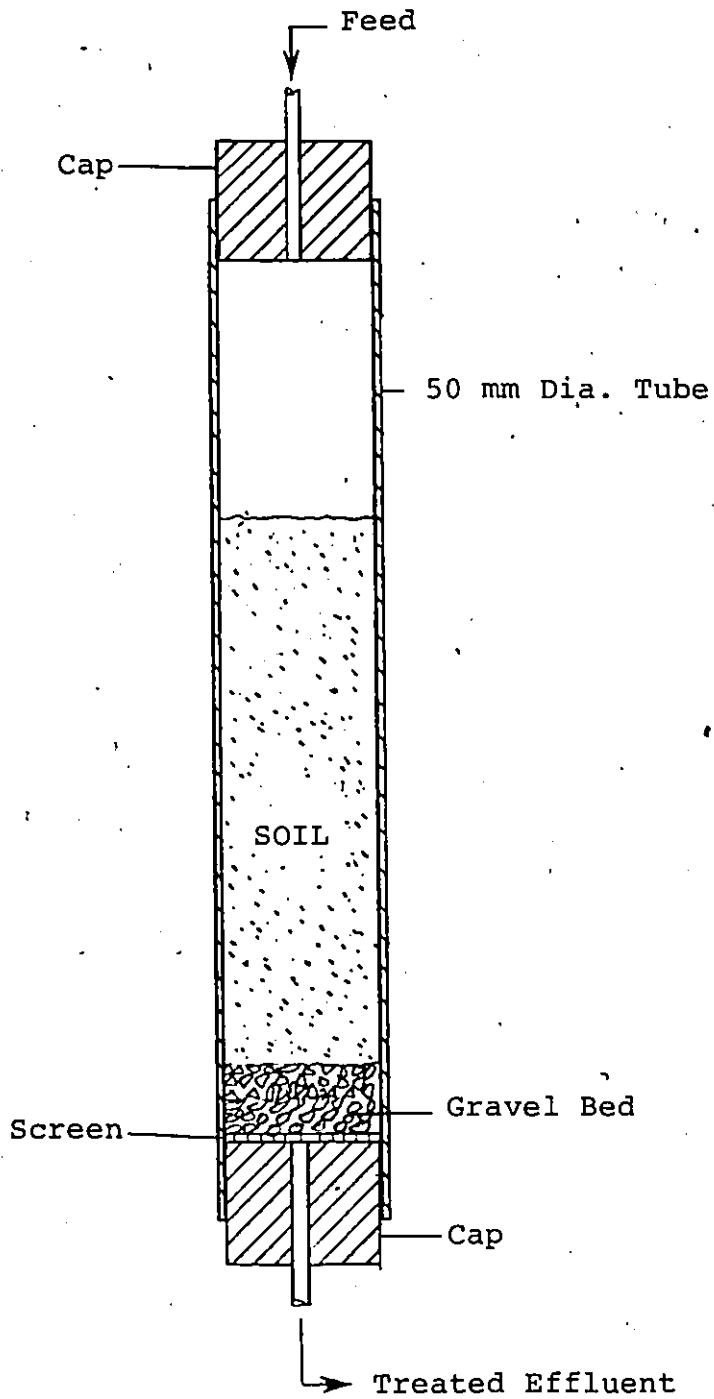


Fig. 4.2 Soil Column

columns.

Twenty soil columns were used in the study (Figure 4.3). To evaluate the effects of soil depth on nitrate and other parameters, four different depths of soil and five different carbon to nitrogen ratios were used (Table 4.5).

Nitrate Solution

To represent nitrified septic tank effluent, a known amount of KNO_3 crystals (J.T. Baker Chemical Co.) was dissolved into ammonia-free distilled water. A stock solution of 10,000 mg/L of nitrogen as nitrate was prepared by dissolving 72.2 gm of KNO_3 into 1 L of ammonia-free distilled water. Daily stocks were prepared from this stock solution by appropriate dilution. Old stock solution were replaced with fresh ones whenever there was a change in the nitrate concentration.

In septic tank effluents a typical concentration of $\text{NH}_4\text{-N}$ is found to be around 25 mg/L as shown in Table 4.6. This nitrogen is oxidized in an aerobic environment while going through the soil profile and is transformed into nitrate. Since it is a reasonable assumption to have 25 mg/L of nitrate nitrogen in the nitrified septic tank effluents, the concentration of nitrogen as nitrate in the feed solutions was reduced to 25 mg/L in all the experiments by proper dilution.

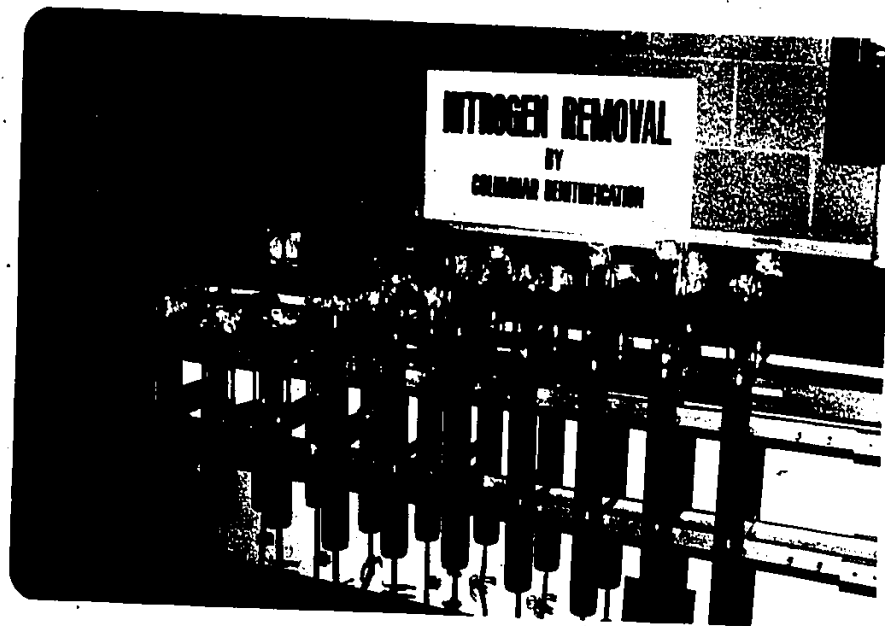


Fig. 4.3. Arrangement of Soil Columns

Table 4.5. Soil Depths and Carbon to Nitrogen Ratios Used for Various Columns

Column number	Soil depth (mm)	Carbon (as methanol) to nitrogen ratio
1	150	2:1
2	150	3:1
3	150	4:1
4	150	5:1
5	150	6:1
6	250	2:1
7	250	3:1
8	250	4:1
9	250	5:1
10	250	6:1
11	350	2:1
12	350	3:1
13	350	4:1
14	350	5:1
15	350	6:1
16	450	2:1
17	450	3:1
18	450	4:1
19	450	5:1
20	450	6:1

Table 4.6. Characteristics of Septic Tank Effluent (69)

Characteristics	Concentrations
Org. nitrogen	10 mg/L
NO ₂ -N	0.003 mg/L
NO ₃ -N	0.15 mg/L
NH ₄ -N	25 mg/L
K	10 - 15 mg/L
Na	up to 100 mg/L
Phosphate	20 mg/L
Sulphate	50 mg/L
Chloride	70 mg/L
ABS	5 mg/L
Alkalinity	300 mg/L
pH	7.0 - 7.5
BOD ₅ (20°C)	130 mg/L
Dissolved Oxygen	0 mg/L
Temperature	75° F
Total SS	40 mg/L

Kitchen Wastewater

Wastewater from a domestic kitchen was obtained regularly. The use of a domestic garbage grinder provided a kitchen waste which was high in soluble organic carbon as shown in Table 4.4.

Feed Solution

Synthetic feed solutions were used throughout the study. Nitrate solutions were mixed with kitchen wastewater to produce the desired carbon to nitrogen ratios. They were mixed in predetermined quantities to produce five levels of C:N ratios ranging from 2:1 to 6:1 (Table 4.1). The characteristics of each feed solution were determined prior to the loading. Organic carbon is calculated and expressed as methanol throughout this study.

4.2.2.2 Dosing of Soil Columns

Each soil column was dosed independently through the opening on top with the specific feed solution. It was done daily with the help of a buret which was filled to the required level (predetermined application rate) and allowed to discharge the influent on top of the soil. This was done carefully using a long tube so that the top of the soil was not disturbed. The time required to load all the columns was around one hour. The top covers of the columns were replaced

immediately. No attempt was made to reduce the oxygen concentration in the influent. Sufficient free board on top of the soil was provided to facilitate the dosing operation. Each soil column was saturated with the respective feed solution at the beginning of the first loading and thereafter the columns were dosed according to the appropriate application rate.

The application rate for all the columns was 200 mm per week for the first 20 weeks. Thereafter, the rate was increased to 420 mm per week and continued for 8 weeks. The volumes of effluents which were collected at the bottom were adjusted by using screw clamps to control the outflow so that it was equal to the inflow. Volumetric cylinders were used to measure the effluent volumes before transferring them to the respective sampling bottles. This process was carried out immediately after the dosing operation and the effluent line was clamped back tightly. All the operations were carried out manually.

4.2.2.3 Collection of Samples and Analysis

Every week samples were collected at the bottom of each column for 28 weeks. Attempts were made to analyze the samples within 48 hours, and all analyses were completed within 72 hours of sample collection. The samples were stored in a refrigerator ($<4^{\circ}\text{C}$) before analysis.

Characterization of this wastewater and of the treated effluents was made based on the following parameters: 1) pH, 2) suspended solids, 3) soluble organic carbon, 4) nitrogen compounds, 5) alkalinity, 6) chemical oxygen demand and 7) dissolved oxygen.

In general, methods outlined in "Standard Methods" (80) were followed for the chemical analyses. The methods used in the determination of each parameter are indicated below.

pH

pH was determined electrometrically using a digital pH meter (Section 424 of "Standard Methods").

Suspended Solids

Total suspended solids were determined by the glass fiber filter method (Section 208D of "Standard Methods").

Volatile Suspended Solids

The glass fiber filter with the suspended solids was ignited in a muffle furnace at 600°C for 15 minutes and the weight loss was reported as volatile suspended solids (Section 208E of "Standard Methods").

Dissolved Oxygen

Dissolved oxygen was measured by the membrane electrode method (Section 422F of "Standard Methods").

Total Soluble Organic Carbon

TSOC was measured using Beckman Model 915, TSOC Analyzer (57,73) (Section 505 of "Standard Methods").

Organic Nitrogen

Organic Nitrogen was determined in a KJELTEC III system (83). This is a further development of the conventional Kjeldahl method. The analytical principle is the same although the technique has been altered resulting in a much more rapid test procedure and higher capacity.

Ammonia Nitrogen

Ammonia Nitrogen was determined by Kjeldahl method at the beginning (Section 418 of "Standard Methods"): Distillation, followed by titration was used in the estimation. Gas electrode method was also found to be fairly accurate and was adopted for its rapidity during the later stages of the study.

Nitrate Nitrogen

Brucine method (Section 419D of "Standard Methods") was used for nitrate measurement.

Ancillary tests were also carried out in the determination of nitrate nitrogen using the Orion Model 95-10, Nitrate Electrode (62) as described in Section 419B of "Standard Methods".

The results compared favourably with the Standard⁴ Brucine Method for accuracy and reliability. Thereafter the Nitrate Electrode Method was adopted as a regular analytical method for the study. Calibration curves used in various tests are furnished in Appendix B, pp. 176-183.

Nitrite Nitrogen

Nitrite Nitrogen was determined by Diazotization method (Section 420 of "Standard Methods").

Alkalinity

Titration methods (Section 402 and 403 of "Standard Methods") were used to determine total alkalinity (pH 4.6) and the results are reported as CaCO_3 .

Chemical Oxygen Demand

The dichromate reflux method (Section 508 of "Standard Methods") was adopted for measuring COD.

4.2.3. Study with the Tile Field

4.2.3.1. The Setup

A small scale tile bed was constructed in the laboratory to simulate field conditions. The experimental setup used in the study is described below.

Design and Installation

A tank was built in the laboratory from aluminium

sheet metal. The size was 2400x1200x1200 mm high (Figure 4.4). This was used as the physical boundary of the test bed and had one side made of transparent plexiglass. Once the tank was built, it was checked for water leakage. After the joints were sealed properly, the tank was filled with the soil material (the same) soil as used in the soil columns). Gases (mainly nitrogen) are produced during denitrification. To facilitate the escape of these gases, eight 12-mm diameter plastic pipes were laid along the width of the tank as shown in Figure 4.5. The lower limb of each of these gas collectors was perforated and was covered with fibre glass tapes to prevent clogging from soil. The vertical section was not perforated and was raised beyond the ground level into the atmosphere. To increase the contact area, the lower limbs of the gas collectors were placed at approximately 10° with the bottom of the tank. A longitudinal section of the tile field is shown in Figure 4.6 where, for sampling ports, the tank was divided into 4 sections along the length. Twenty sampling points were selected, including four at the bottom of the tank, and these sampling points were evenly distributed in all the four sections at various depths. Figures 4.7 and 4.8 show the exact locations of these sampling points. To collect samples from these points simple gravity samplers were installed. The gravity samplers were made of plastic funnels 200 mm in diameter and 150 mm high, packed with a depth of 50 mm of gravel (Figure 4.9 and 4.10). Nylon tubing of 6 mm diameter was

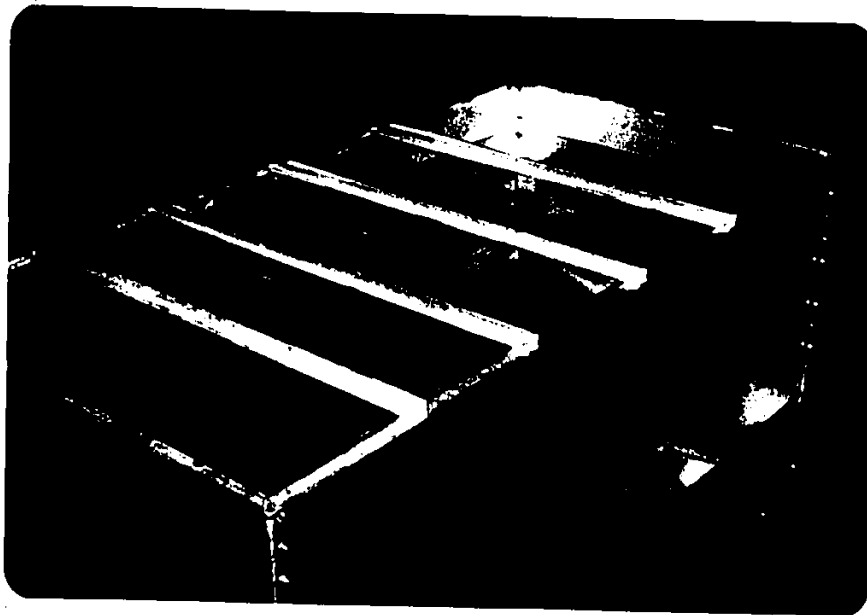


Fig. 4.4. Aluminium Tank Being Tested for Water Leakage

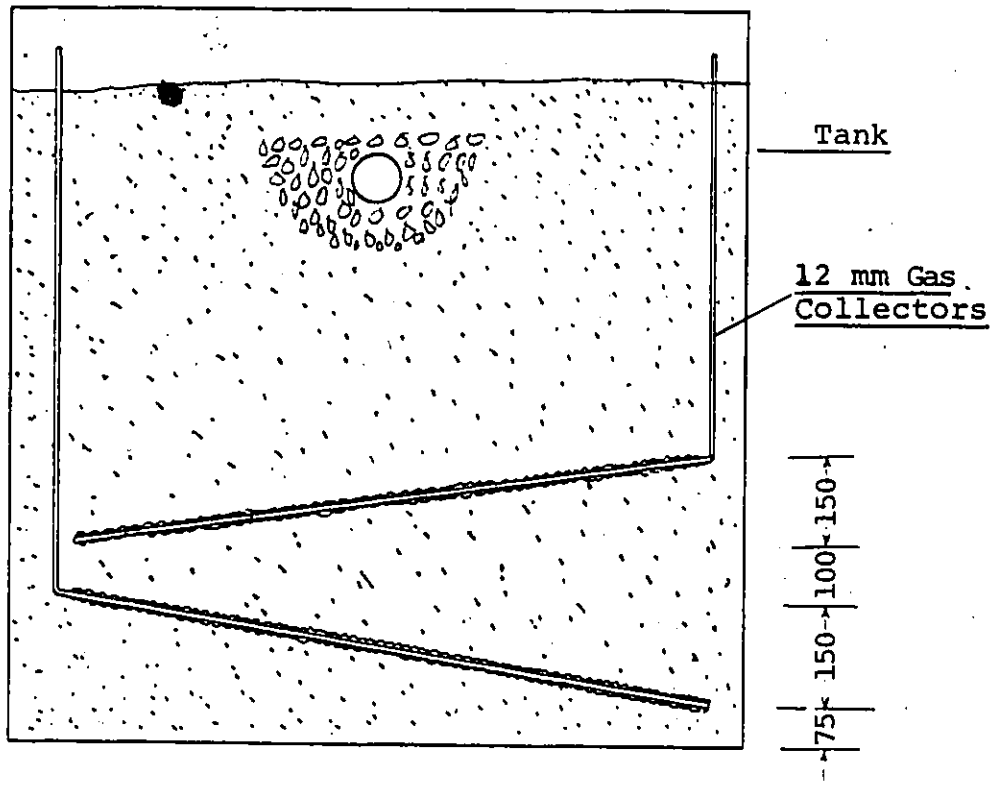


Fig. 4.5. Arrangements of the Perforated Gas Collector Pipes (Covered with Fiber Glass Tapes to Prevent Clogging)

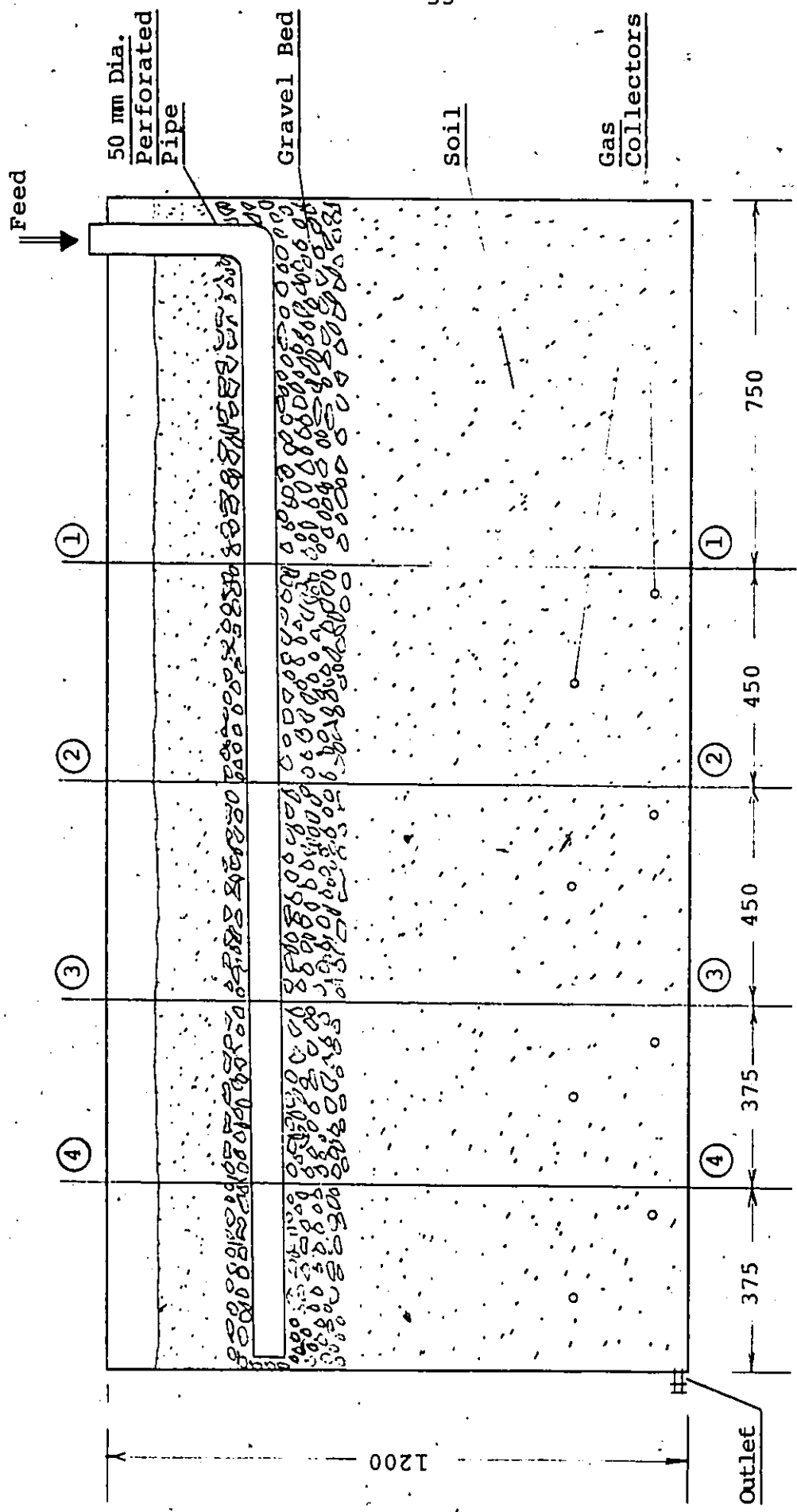


Fig. 4.6. Longitudinal Section of the Tile Field

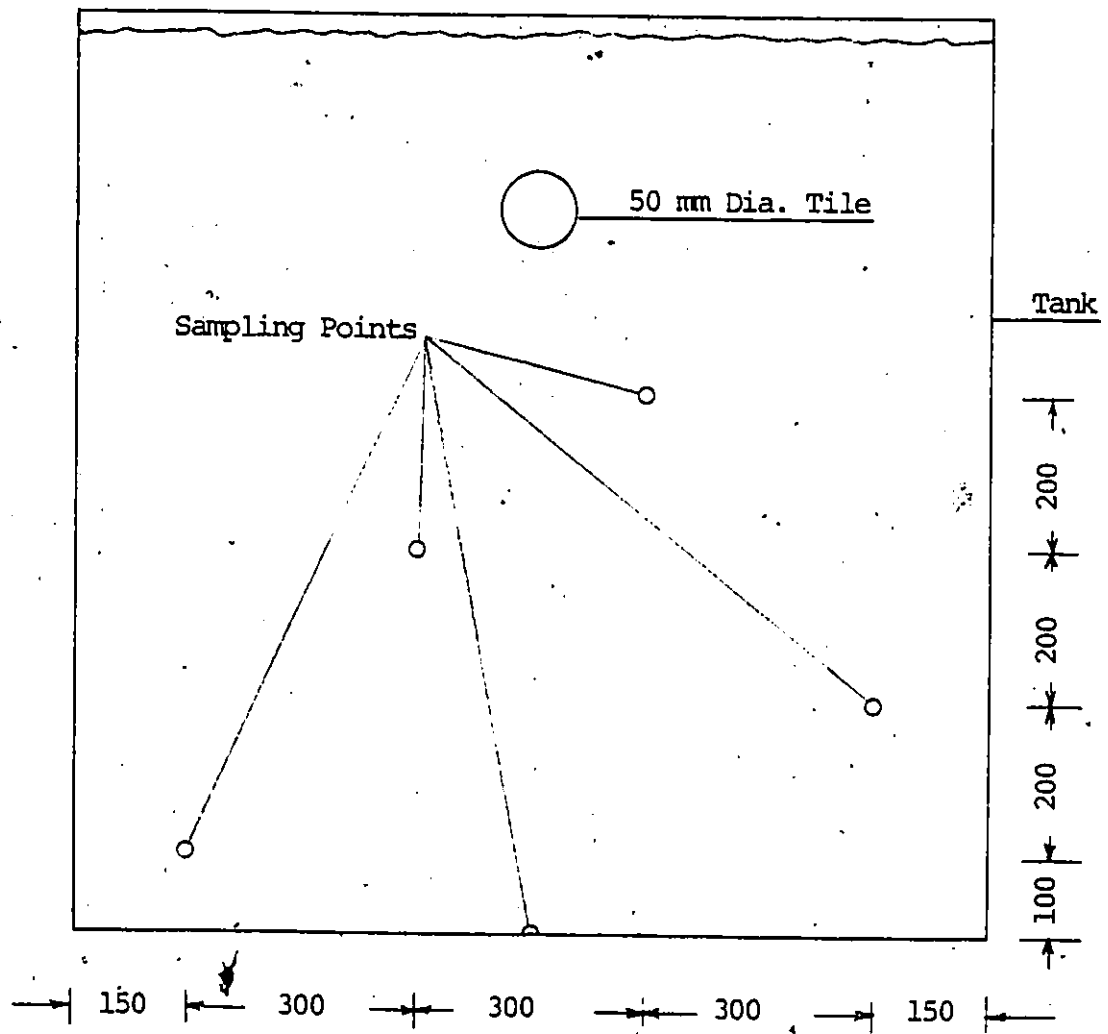


Fig. 4.7 Location of Sampling Points at Sections 1 & 3

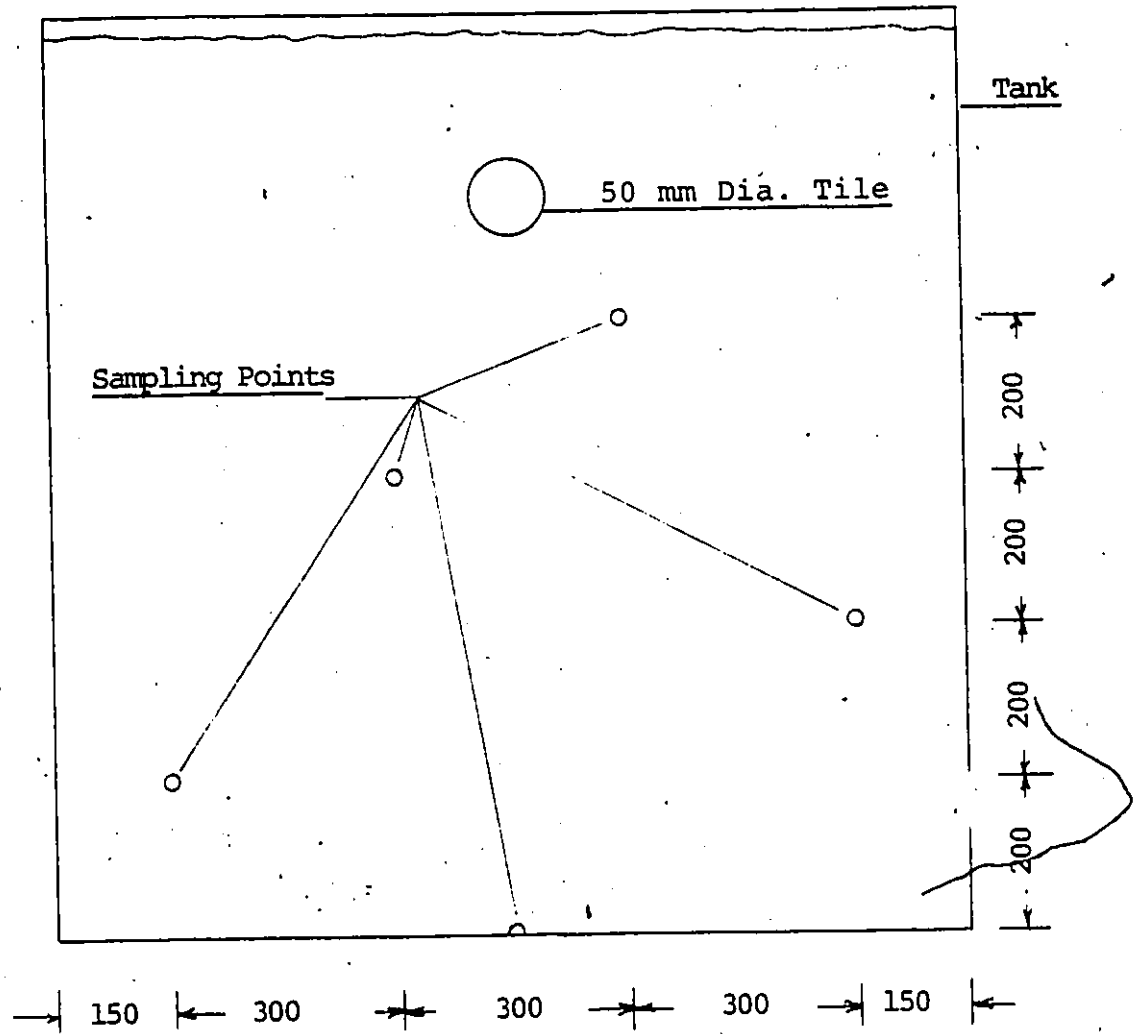


Fig. 4.8. Location of Sampling Points at Sections 2 & 4



Fig. 4.9. Gravity Samplers (Plastic Funnels).

2

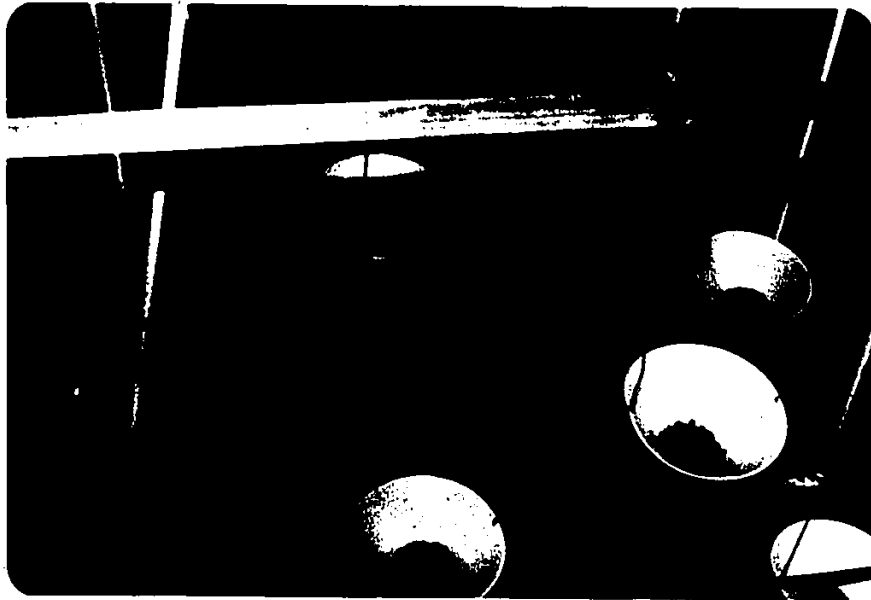


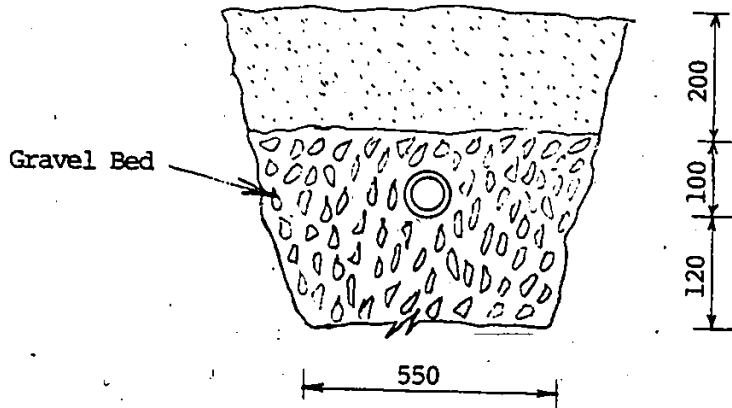
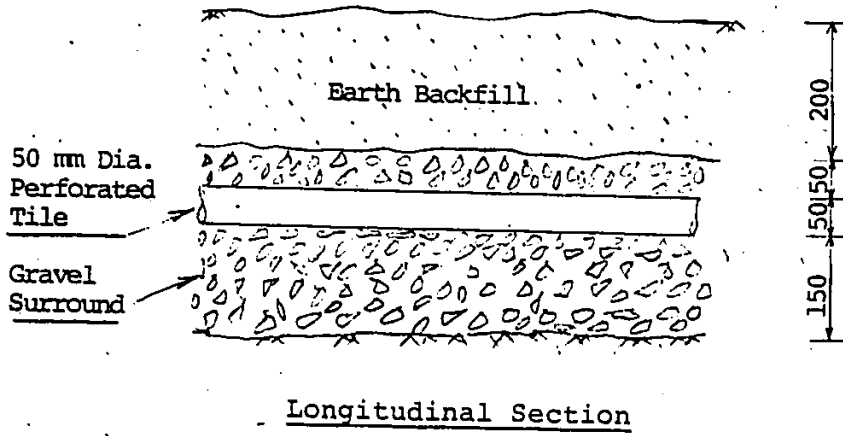
Fig. 4.10. Top View of the Samplers

connected to the bottom of each funnel to carry the samples to the outlet. These tubes were passed through the bottom of the tank and tagged with a number identifying the location of the sampler. After the gas collectors and the sampling devices were installed the tank was filled with the soil. To ensure that the funnels remained at the proper locations during the filling operation, they were tied to the top cross-members with wires. The gas collectors were manually held in the proper positions during the filling operation.

The experimental tile was perforated pipe 50 mm in diameter and 2400 mm long. The installation followed closely the specification given in "Manual of Septic Tank Practices" (53). The details of the test tile arrangement are shown in Figure 4.11. The slope of the tile was 1 in 50.

After the tile was laid the trench was properly backfilled to ground level. A small piece of the same PVC pipe was joined to the tile at 90° and was brought above the ground level. This was used to dose the tile with the help of a funnel and feeding tank as shown in Figure 4.12.

The application rate was $80 \text{ L/m}^2/\text{d}$. The feed solution containing C:N ratio of 4:1 was prepared daily in large polyethylene containers before transferring it into the feeding tank. Through a gate valve situated at the outlet in the feed tank this feed solution was discharged into the tile. The whole loading operation took about an hour.



Cross Section

Fig. 4.11. Details of Test Tile

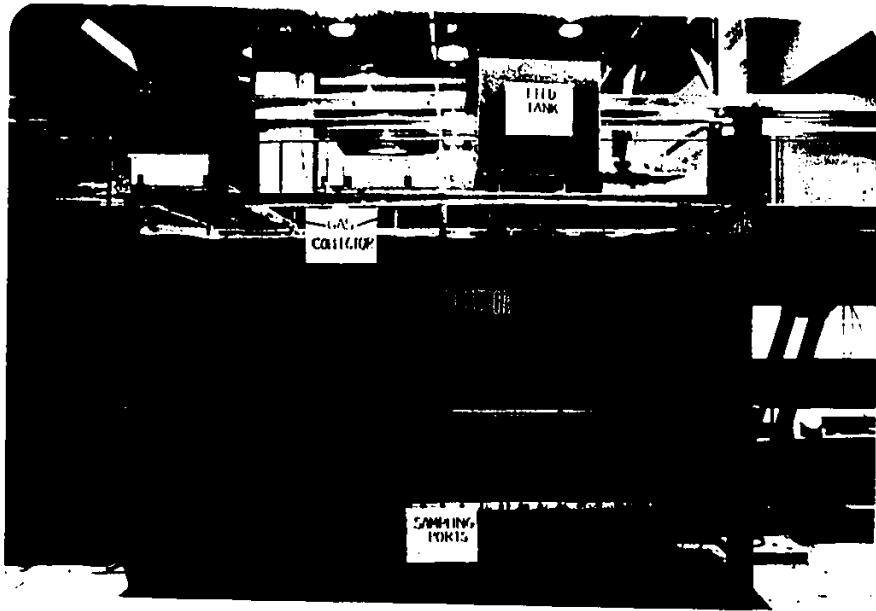


Fig. 4.12. View of the Tank Showing Sampling Ports,
Gas Collector Outlets and the Feed Tank

A conventional tap was installed at the bottom of the tank (below the lower end of the tile) and was used as an outlet. After the loading operation the outlet tap was used to discharge effluents from the tank. A graduated cylinder and a stop watch were used to calculate the discharge through the outlet; the required time for discharge was calculated so that the effluent flow was equal to the influent flow on a daily basis.

4.2.3.2. Details of Sample Collection and Variation of the Water Table in the Tile Field

Since the tile was enclosed in a tank, it was possible to vary the depth of the water table. Three levels of water table were chosen and are shown in Table 4.7. These levels were such that some of the sampling points were expected to be in the unsaturated zone at all times. However, in most cases, collection of samples at these points was not possible even when external suction was applied. Once the water table reached a predetermined depth, it was maintained for two months by adjusting the outflow to be equal to the inflow. A measuring stick was lowered through one of the gas collector pipes to monitor the depth of the water table. Sample collection details are shown in Table 4.7. Sampling ports 17, 18, 19 and 20 did not collect any sample during the entire period of investigation. During February and March 1981, the water table was 450 mm below the ground level and all the sampling ports from 1 to

Table 4.7. Sample Collection Details

Date of collection	Depth to water table (mm)	Sampling port numbers													
		1,2,3,4 at 1000 mm	5&6 at 900 mm	7&8 at 800 mm	9&10 at 700 mm	11&12 at 600 mm	13&14 at 500 mm	15&16 at 400 mm	17&18 at 300 mm	19&20 at 200 mm					
5/2/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
12/2/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
19/2/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
26/2/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
5/3/81	450	x	x	x	x	x	x	x	x	x	x	x	x	x	
12/3/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
19/3/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
26/3/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
2/4/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
9/4/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
16/4/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
23/4/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
30/4/81	650	x	x	x	x	x	x	x	x	x	x	x	x	x	
7/5/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
14/5/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
21/5/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
4/6/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
11/6/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
18/6/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
25/6/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
2/7/81	800	x	x	x	x	x	x	x	x	x	x	x	x	x	
9/7/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
16/7/81		x	x	x	x	x	x	x	x	x	x	x	x	x	
23/7/81		x	x	x	x	x	x	x	x	x	x	x	x	x	

Note: 'x' indicates successful collection of sample

16 collected samples regularly. The water table was subsequently lowered to the depth of 650 mm and percolates were collected only in ports 1 to 12. For water table at 800 mm below ground level it was only possible to collect enough samples from ports 1 to 8 on a regular basis. Only on 4 occasions did ports 9 and 10, situated at 10 cm above the water table, yield large enough samples for nitrate analyses.

Each week samples were collected from the various sampling ports. Each tube was allowed to drain for a brief period before the collection of the sample. The samples were stored in a refrigerator ($<4^{\circ}\text{C}$) before analysis.

The analytical determination of the concentrations of all the parameters and the respective analytical methods were the same as those outlined previously.

CHAPTER 5

RESULTS AND ANALYSIS

The entire experimental work has been divided into two sections according to specific objectives. These sections are:

- 1) a study with soil columns;
- 2) a study with a laboratory model of a tile installation.

The first part of the study was carried out with soil columns under controlled laboratory conditions using kitchen wastewater as the source of organic carbon and to determine criteria for the subsequent study using a model tile installation.

5.1. Study with Soil Columns

Specific objectives of this study were:

- to obtain the percent removal of nitrate, nitrite, ammonia, TKN, chemical oxygen demand, dissolved oxygen, soluble organic carbon, suspended solids in various soil columns using kitchen waste as the source of organic carbon;
- to obtain an optimum ratio of carbon to nitrogen for successful denitrification for subsequent use in the model tile study;
- to find the relationship between the soil depths

and percent removal of nitrate, TKN, chemical oxygen demand, dissolved oxygen, alkalinity, soluble organic carbon and suspended solids.

Physical characteristics of the soil columns and the various C:N ratios used in this study have been shown in Table 4.1 (Chapter 4). The kitchen wastes were analyzed for nitrogen compounds and organic carbon content before being added to the respective feed solutions to produce final C:N ratios as shown in Table 4.1. The soil column experiment was carried out for 28 weeks. The raw kitchen wastewater characteristics are shown in Table 5.1. For the first 5 weeks the characteristics were determined on a weekly basis with the exception of SOC which was done everyday before preparing the feed solutions. For the rest of the period the analyses were done once a month. Levels of pH in the kitchen waste ranged from 5.3 to 7.2. Tests for acidity were not done. Results for alkalinity for the kitchen waste show that the total alkalinity (methyl orange end point 4.6) varied from 120 to 200 mg/L as CaCO₃. COD values were fairly high and so were the concentrations of soluble organic carbon. Nitrite and nitrate were not detected during this study. Small amounts of NH₃ were found in five samples. Most of the nitrogen was in the form of organic nitrogen. Dissolved oxygen levels were a little below saturation in all the samples. Total suspended solids varied from 60 to 175 mg/L. Prior to the tests, the kitchen waste was allowed to settle for at least two hours and the floating scum was removed before collecting the

Table 5.1. Raw Kitchen Wastewater Characteristics

Date	Characteristics*									
	pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	COD (mg/L)	SOC (mg/L)	DO
30/6/80	6.0	0.0	0.0	0.0	106.6	170	-	5500	1180	8.4
7/7/80	5.9	0.0	0.0	1.1	62.0	190	105	3500	2060	8.3
14/7/80	6.7	0.0	0.0	2.1	132.2	120	135	5750	1760	7.9
21/7/80	7.2	-	0.0	0.0	51.7	200	75	2750	1940	8.1
28/7/80	7.1	-	0.0	0.0	63.0	150	100	3250	1800	8.2
19/8/80	5.3	-	0.0	0.0	84.2	140	-	3750	1680	8.2
16/9/80	5.8	-	0.0	0.0	145.2	190	130	8000	1720	8.3
20/10/80	5.9	-	0.0	2.1	112.6	145	60	7250	2240	8.1
18/11/80	7.8	-	0.0	3.2	117.2	190	170	8500	2260	8.2
11/12/80	6.2	-	0.0	0.0	98.8	160	115	6500	2140	8.3
12/1/81	6.7	-	0.0	0.0	122.5	150	-	8250	1980	8.1

* Samples were allowed to settle for two hours before carrying out the tests on the supernatant.

supernatant for analyses.

Five different feed solutions were prepared each time for loading purposes. They were prepared to produce various carbon to nitrogen ratios. Since the determination of the treatment efficiency of a soil column was based on the characteristics of the feed solutions and the corresponding treated effluents, all the feed solutions were analyzed for the various parameters. These characteristics are given in Table C1 in Appendix C (p. 185).

The treated effluents from the soil columns were analyzed every week and are shown in Tables C2 and C3 in Appendix C (pp. 199-219).

5.1.1 Variation of Parameters in Soil Columns

Analyses were made to determine the variation in the efficiency for various parameters in the soil columns with respect to time, organic carbon applied and soil depth. These results are discussed in the following paragraphs.

Nitrate

Percent removals of nitrate are shown in Tables 5.2 to 5.5; these have been calculated from the effluent nitrate levels given in Tables C2 and C3, Appendix C, and the constant influent nitrate level of 25 mg/L, used for all soil columns. As mentioned before, the application rate was increased after 20 weeks

Table 5.2. Removal of Nitrate in 150 mm Soil Columns

Applica- tion Rate (mm/wk)	Time (week)	Percentage removal of nitrate (%)				
		C:N=2:1	C:N=3:1	C:N=4:1	C:N=5:1	C:N=6:1
200	1	0	24	32	40	40
	2	0	36	36	60	72
	3	30	80	94	93	95
	4	26	74	88	91	90
	5	24	64	92	92	93
	6	24	80	90	92	95
	7	12	76	90	94	96
	8	24	70	88	92	92
	9	12	76	91	94	94
	10	24	70	89	91	94
	11	20	68	88	92	90
	12	20	74	92	94	90
	13	24	68	92	90	93
	14	20	72	96	94	92
	15	12	67	88	92	92
	16	25	77	88	88	94
	17	20	72	90	90	96
	18	20	68	91	92	96
	19	20	68	91	92	93
	20	22	64	88	92	89
420	21	20	76	91	92	94
	22	-	71	92	93	93
	23	4	74	90	92	93
	24	12	71	87	90	92
	25	4	72	86	93	94
	26	4	76	88	87	94
	27	8	68	92	92	94
	28	8	67	90	88	95

Table 5.3. Removal of Nitrate in 250 mm Soil Columns

Applica- tion rate (mm/wk)	Time (week)	Percentage removal of nitrate (%)				
		C:N=2:1	C:N=3:1	C:N=4:1	C:N=5:1	C:N=6:1
200	1	0	32	32	24	52
	2	0	64	56	72	68
	3	30	79	91	90	92
	4	23	73	90	93	94
	5	24	72	93	96	92
	6	20	72	92	95	94
	7	21	74	94	92	93
	8	23	71	90	92	96
	9	18	75	91	92	95
	10	20	73	93	93	92
	11	22	74	93	94	95
	12	23	72	90	91	95
	13	23	76	92	92	91
	14	20	76	92	94	93
	15	19	73	90	93	94
	16	21	75	93	94	95
	17	22	74	93	94	94
	18	24	76	92	94	94
	19	21	68	92	92	95
	20	21	69	91	93	96
420	21	22	73	92	93	94
	22	22	75	93	90	95
	23	23	76	93	95	93
	24	25	72	92	93	95
	25	24	71	90	92	94
	26	20	76	94	94	91
	27	18	74	93	93	94
	28	23	76	93	92	93

Table 5.4. Removal of Nitrate in 350 mm Soil Columns

Applica- tion rate (mm/wk)	Time (week)	Percentage removal of nitrate (%)				
		C:N=2:1	C:N=3:1	C:N=4:1	C:N=5:1	C:N=6:1
	1	0	48	36	52	52
	2	4	48	72	64	80
	3	27	82	92	95	94
	4	24	77	95	93	94
	5	21	83	95	97	98
	6	22	81	94	97	97
	7	23	72	93	92	97
	8	26	79	94	95	95
	9	22	77	94	96	96
200	10	21	77	92	96	92
	11	23	82	95	95	96
	12	22	80	94	96	97
	13	22	83	95	95	96
	14	23	81	90	93	95
	15	25	79	96	96	96
	16	25	80	95	94	97
	17	20	81	94	95	95
	18	21	78	93	95	97
	19	23	78	95	95	97
	20	25	81	94	96	96
	21	22	80	93	95	96
	22	23	79	93	94	97
	23	22	80	95	92	97
420	24	24	83	95	96	96
	25	22	81	94	96	95
	26	26	79	94	95	95
	27	22	81	95	95	97
	28	21	83	95	95	97

Table 5.5 Removal of Nitrate in 450 mm Soil Columns

Applica- tion rate (mg/wk)	Time (week)	Percentage removal of nitrate (%)				
		C:N=2:1	C:N=3:1	C:N=4:1	C:N=5:1	C:N=6:1
	1	8	48	44	52	52
	2	4	32	76	60	80
	3	32	86	96	96	96
	4	25	79	95	96	98
	5	26	85	96	97	97
	6	21	84	95	97	98
	7	26	84	95	95	96
	8	27	82	96	96	98
	9	28	83	93	95	97
200	10	24	83	94	97	98
	11	25	81	95	97	96
	12	27	84	95	97	98
	13	29	79	96	97	95
	14	23	80	95	95	94
	15	26	81	94	97	97
	16	25	80	96	96	98
	17	27	79	95	95	98
	18	27	83	92	96	96
	19	26	83	97	97	96
	20	25	84	97	96	97
	21	27	79	93	92	98
	22	28	84	92	96	96
	23	26	83	94	95	96
420	24	27	82	96	97	98
	25	25	80	95	97	98
	26	26	79	96	98	97
	27	29	81	94	94	96
	28	24	81	95	94	96

from 200 mm/wk to 420 mm/wk and the tests were continued without interruption for another 8 weeks. It can be seen from the results that the average time required for the soil columns to produce consistent treatment efficiencies was approximately two weeks. Initially the removal rate was low in all the columns. However, columns dosed with feed solutions containing high C:N ratios showed increased removal rates after the first week. Figures 5.1 to 5.4 show the variation of two-week means of percent nitrate removal for 16 weeks for the four soil depths. The data for these figures are tabulated in Tables D1 to D4, Appendix D, (pp. 257-260). After the first two weeks all the soil columns removed nitrate from the influent consistently. A C:N ratio of 2:1 failed to produce more than 29% removal of nitrate. The next higher ratio (C:N=3:1) was more efficient and the removal rate reached a high of 85% for the 450 mm soil column. A C:N ratio of 4:1 or higher resulted in a high removal of nitrate in all the soil columns. It has been reported that a carbon to nitrogen ratio of approximately 3:1 is sufficient to complete denitrification when methanol is used as the carbon source (85). From the results it is clear that for this kitchen waste, the minimum ratio necessary for successful denitrification in the columns is 4:1.

Table D5, Appendix D, (p. 261) tabulates the data which depict variations of overall average nitrate removal with respect to soil depths and C:N ratios. These results are plotted in Figure 5.5. Since the system was not stabilized until

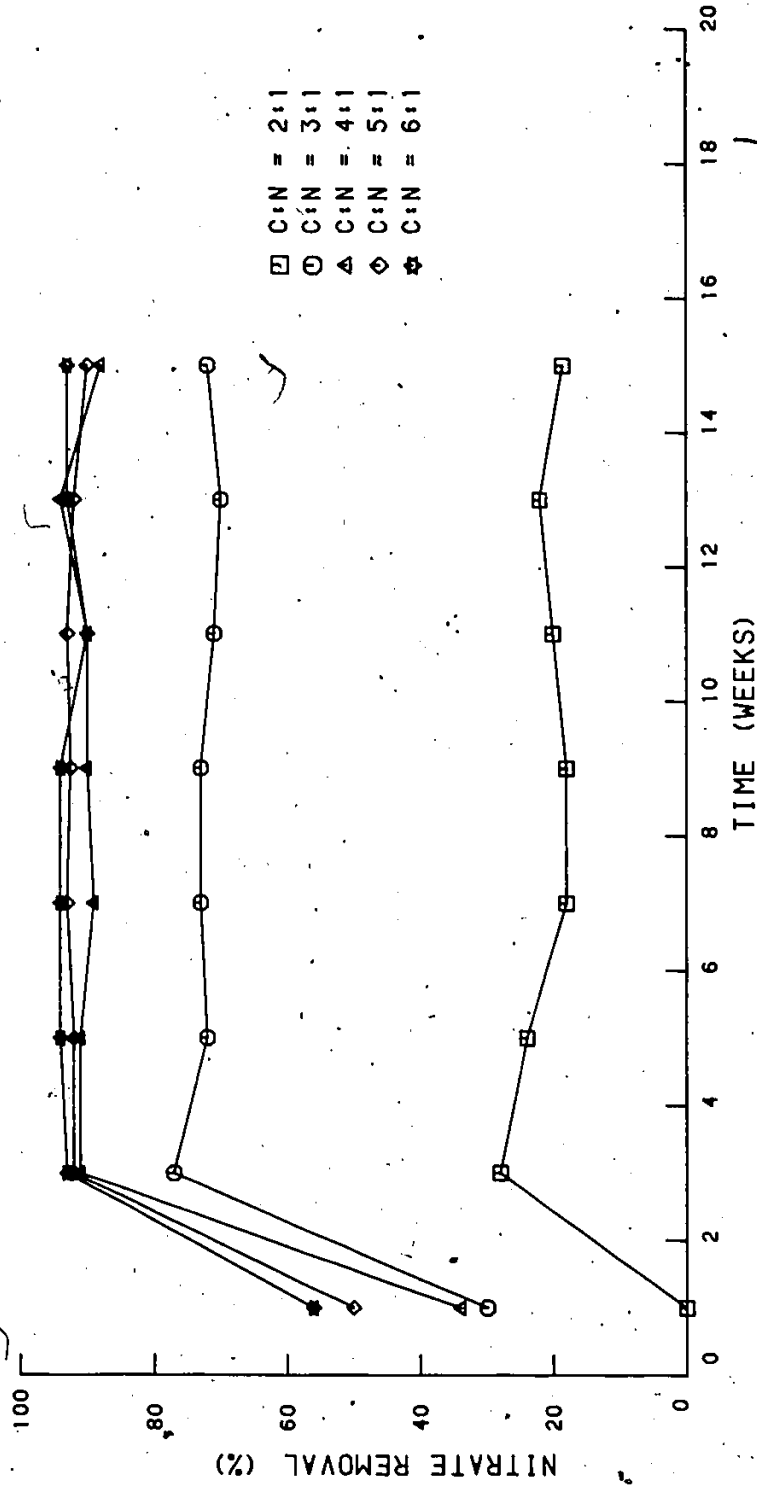


Fig. 5.1. Variation of Percent Nitrate Removal (Two Weeks Mean) with Time in 150 mm Soil Columns

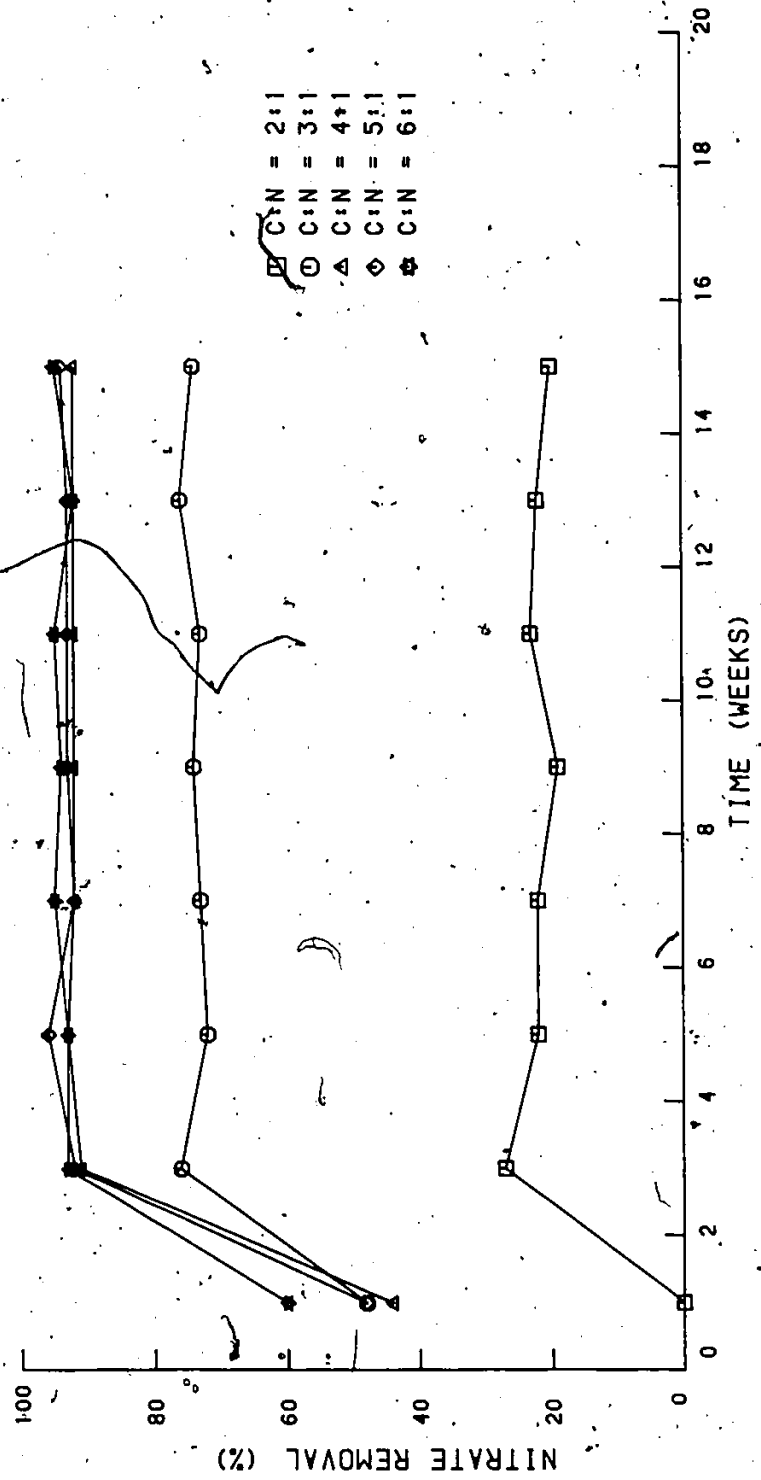


Fig. 5.2. Variation of Percent Nitrate Removal (Two Weeks Mean) with Time in 250 mm Soil Columns

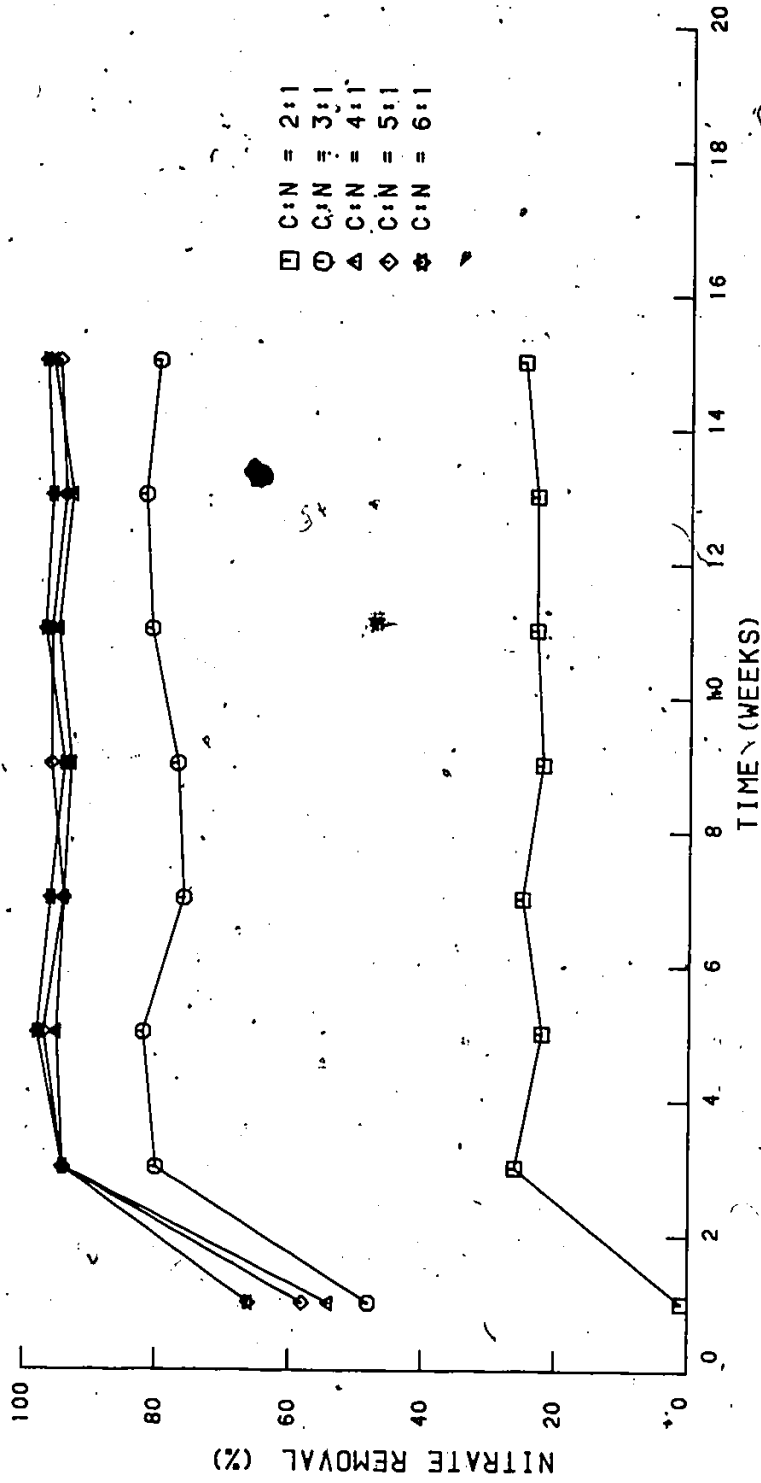


Fig. 5.3. Variation of Percent Nitrate Removal (Two Weeks Mean) with Time in 350 mm Soil Columns

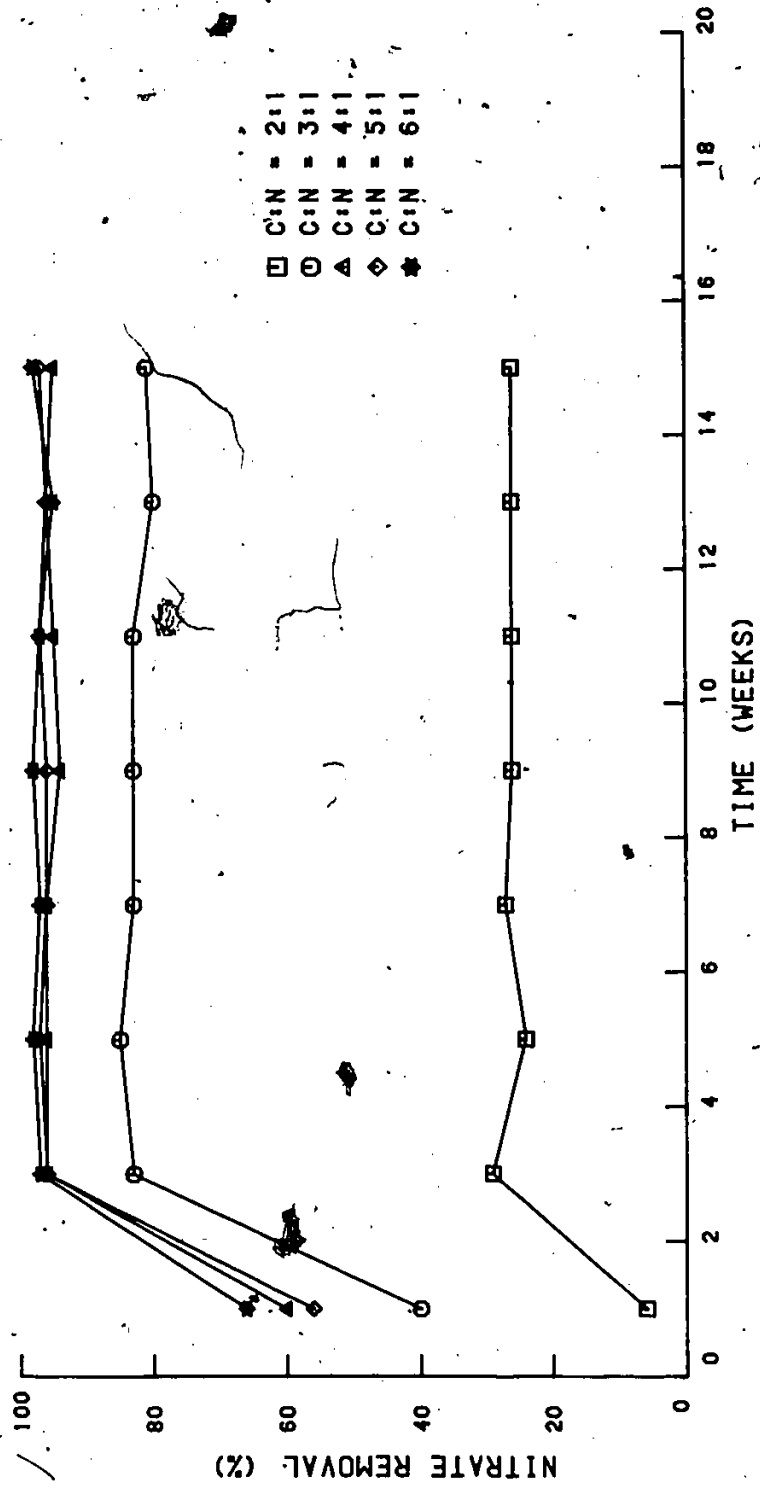


Fig. 5.4. Variation of Percent Nitrate Removal (Two Weeks Mean) with Time in 450 mm Soil Columns

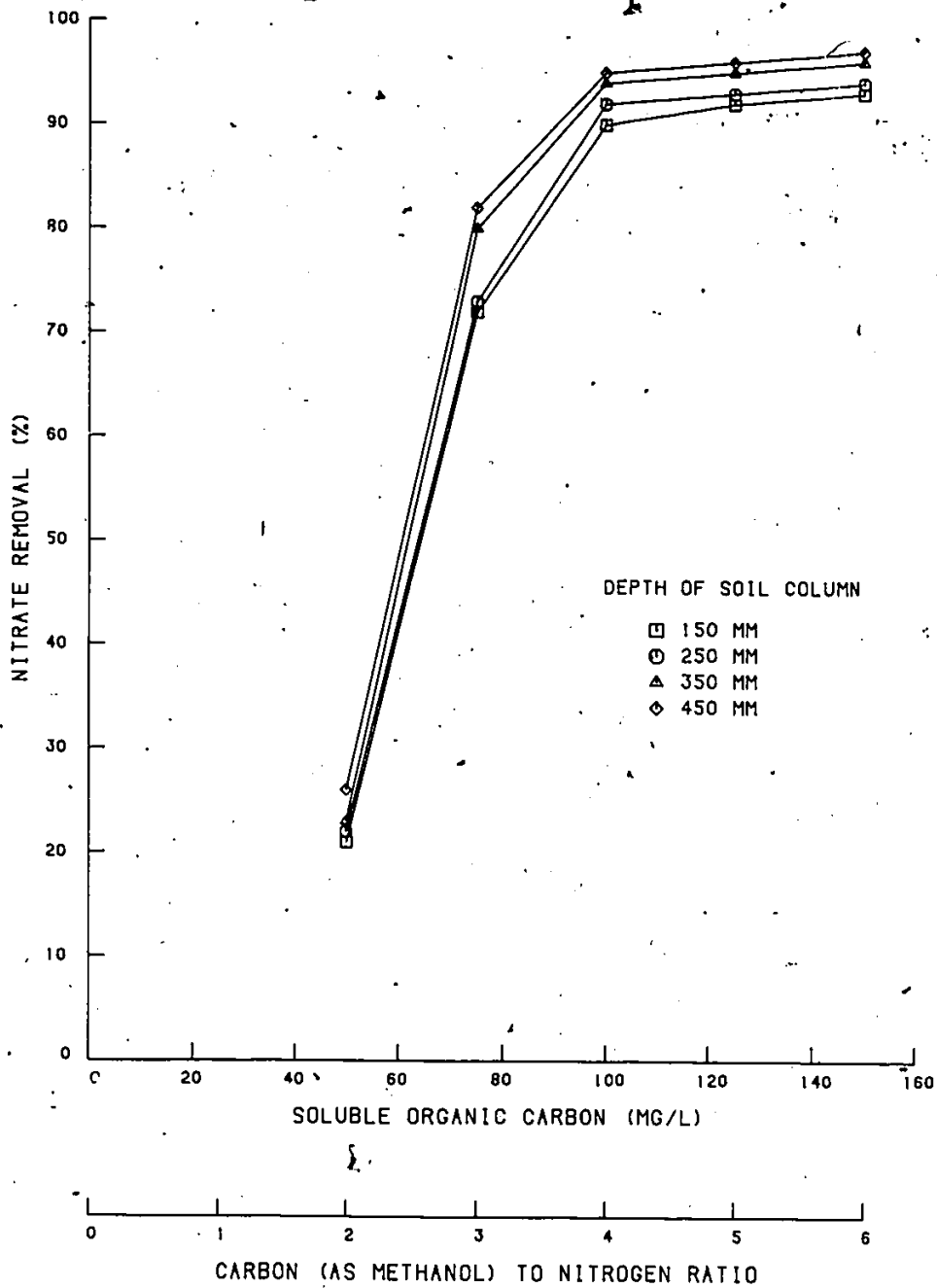


Fig. 5.5. Mean Removal of Nitrate Over 20 Weeks -
Application Rate = 200 mm/wk.

the third week of operation, results of the first two weeks were not used in this calculation. It is obvious from Figure 5.5 that the depth of soil shows very little effect on nitrate removal in this experiment. In 50 mm diameter tubes, a depth of 150 mm was sufficient to produce a conducive environment for denitrification. A C:N ratio higher than 4:1 did not influence the overall nitrate removal significantly and the differences were often less than 5 percent for the same depth of soil. It can be concluded that available organic carbon was the limiting factor in denitrification for those columns fed with C:N ratios less than 4:1.

After 20 weeks of operation the application rate was increased to 420 mm/wk (1.8 g/d/ft^2). This was done to observe the effect of a higher loading rate on denitrification. From the data given in Tables 5.2 to 5.5, mean nitrate removals were calculated and plotted in Figure 5.6. (Data are given in Table D6, Appendix D, (p. 262)). A comparison between Figures 5.5 and 5.6 reveals that the mean values of nitrate removals are very similar in all the columns for both the application rates, excepting one 150 mm soil column which received a 2:1 ratio. This particular column produced only 9 percent removal whereas the same column when dosed at the rate of 200 mm/wk produced 21 percent nitrate removal. Barring this, the higher application rate of 420 mm/wk is found to have very little effect on nitrate removal. However, as before, the shallower depths in general produced slightly lower values than the deeper ones.

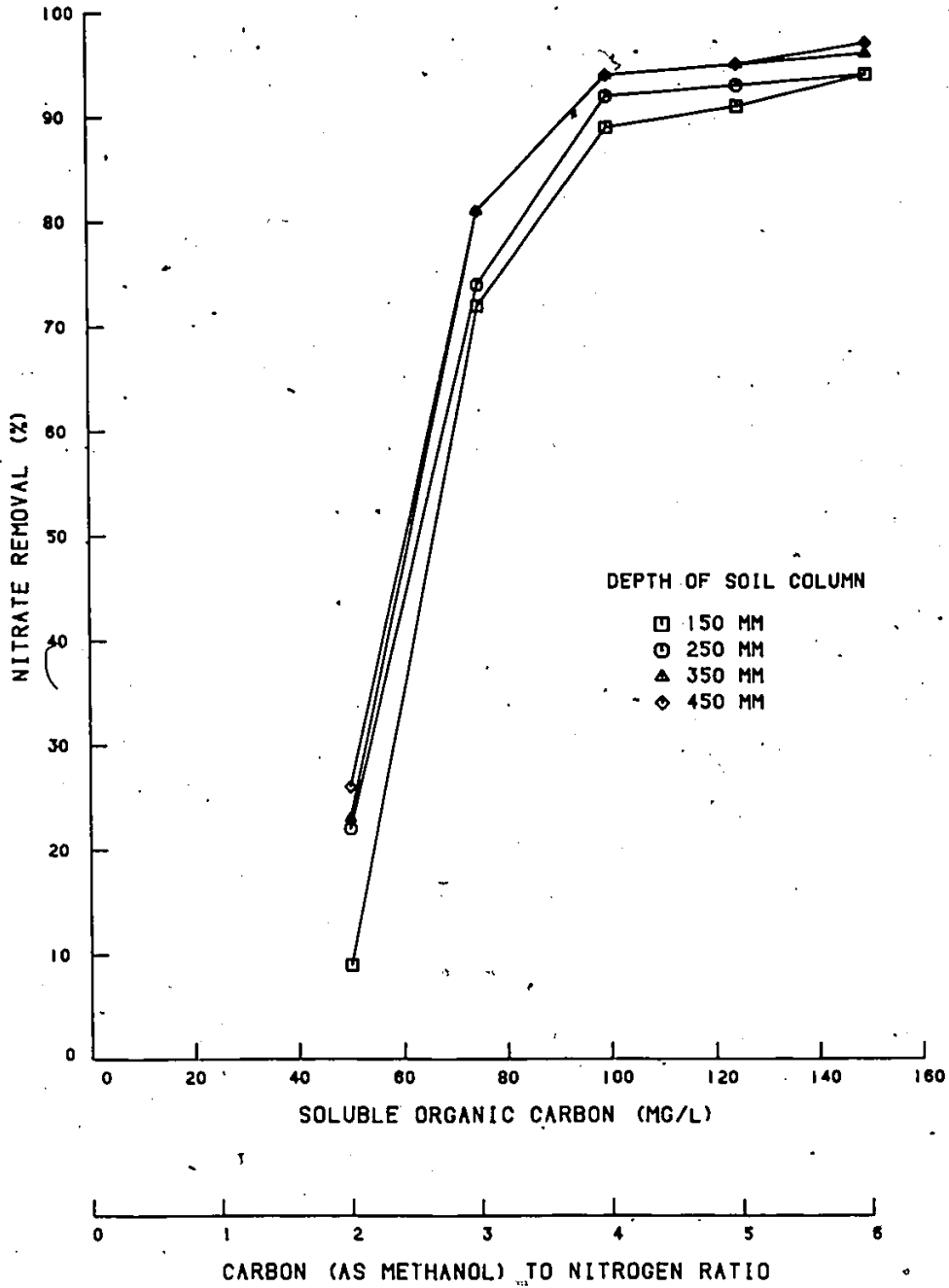


Fig. 5.6. Mean Removal of Nitrate Over 8 Weeks
- Application Rate = 420 mm.

Nitrite

Tests for nitrite started from the second week of the investigation. During the second week all the column effluents showed presence of nitrite. From the third week of operation nitrite was not detected in columns where the feed solution contained a carbon to nitrogen ratio of 4:1 or higher. Stable, near-complete, denitrification may be the reason for this phenomenon. Therefore, after 8 weeks of investigations these column effluents were not analyzed for nitrite. Columns receiving 2:1 and 3:1 levels of carbon to nitrogen ratios showed detectable levels of nitrite at all times. Average values for 20 weeks (excluding the first two weeks) of nitrite levels and corresponding levels of nitrate removal are shown in Table 5.6. The individual weekly values from which these averages are calculated are given in Tables C2 and C3, Appendix C. Apparently, the soil columns receiving a 2:1 ratio transformed a small amount of nitrate to nitrogen gas. The remaining portion of the nitrate which did not show in the nitrate tests was reduced to nitrite. A ratio of 3:1 reduced most of the nitrates; however, a small amount of nitrite was always detected in the treated effluents. Collection and analysis of gas samples were not done in this investigation and therefore a balance of nitrogen compounds is not possible. The results show that the presence of nitrite may have a very limited effect, if any, on the denitrification system. This is very important because in a practical subsurface denitrification system, due to the uncertainty of

Table 5.6. Mean Variations of Nitrite and Levels of Nitrate Removal in Soil Columns Over 20 weeks of Operation - Application Rate = 200 mm/wk.

C:N	150 mm soil depth		250 mm soil depth		350 mm soil depth		450 mm soil depth	
	Nitrite -N (mg/L)	Nitrate removal (%)	Nitrite -N (mg/L)	Nitrate removal (%)	Nitrite -N (mg/L)	Nitrate removal (%)	Nitrite -N (mg/L)	Nitrate removal (%)
2:1	3.8	21	3.3	22	3.5	23	2.8	26
3:1	3.2	72	3.1	73	1.9	80	1.2	82

wastewater flows, chances of nitrite production are high.

Tests for nitrite were continued when the application rate was increased to 420 mm/wk. Table 5.7 depicts the mean values for 8 weeks of study. Again, columns receiving C:N ratios higher than 3:1 did not show any presence of nitrite and were excluded after the first week. The soil column with 150 mm depth shows only 9 percent of nitrate removal when fed with 2:1 C:N ratio. In some of these cases the total nitrogen (nitrate + nitrite) levels often exceeded the total inorganic nitrogen present in the feed solutions (25 mg/L $\text{NO}_3\text{-N}$). Treated samples from soil columns dosed with 2:1 and 3:1 feed solutions, respectively, were analysed for nitrite prior to the nitrate tests. Therefore, nitrites present in the samples preserved for nitrate tests may have been oxidated to nitrates. These discrepancies may also have been caused by reaeration during collection of samples and by errors in the analyses. Furthermore, a portion of the organic nitrogen present in the feed solutions may have been transformed to either nitrite or nitrate and possibly have affected the nitrate balance. It is clear that if the 'nitrate removal' is considered as reducing nitrate to nitrogen gas, the actual levels of effective nitrate removal are somewhat lower than the values given so far. Effective nitrate removal can be calculated by including the nitrite levels with the various levels of nitrate removal for the columns which received feed solutions of 2:1 and 3:1, respectively; these new values along with the rest are shown in Table 5.8. These are

Table 5.7. Mean Variations of Nitrite and Levels of Nitrate Removal in Soil Columns Over Final 8 weeks of Operation - Application Rate = 420 mm/wk.

C:N	150 mm soil depth		250 mm soil depth		350 mm soil depth		450 mm soil depth	
	Nitrite -N (mg/L)	Nitrate removal (%)	Nitrite -N (mg/L)	Nitrate removal (%)	Nitrite -N (mg/L)	Nitrate removal (%)	Nitrite -N (mg/L)	Nitrate removal (%)
2:1	3.1	9	3.5	22	4.1	23	3.5	26
3:1	5.6	72	5.1	74	5.1	81	3.7	81

Table 5.8. Mean Values of Effective Removal of Nitrate in the Soil Columns for Both Application Rates

C:N	Application rate = 200 mm/wk					Application rate = 420 mm/wk						
	150 mm	250 mm	350 mm	450 mm	150 mm	250 mm	350 mm	450 mm	150 mm	250 mm	350 mm	450 mm
	soil depth (%)	soil depth (%)	soil depth (%)	soil depth (%)	soil depth (%)	soil depth (%)	soil depth (%)	soil depth (%)	soil depth (%)	soil depth (%)	soil depth (%)	soil depth (%)
2:1	6	9	9	15	0	8	7	12				
3:1	60	61	72	77	50	54	61	66				
4:1	90	92	94	95	89	92	94	94				
5:1	92	93	95	96	91	93	95	95				
6:1	93	94	96	97	94	94	96	97				

1
86
1

plotted in Figures 5.7 and 5.8 and the higher application rate is found to reduce the effective nitrate removal by around 10 percent from the values obtained by the lower application rate when the feed solution contained 3:1 carbon to nitrogen ratio. For comparison, all the curves shown in Figures 5.5 and 5.6 are also shown here. With the inclusion of nitrite, C:N ratios of 2:1 and 3:1 show much lower nitrate reduction levels compared to the results obtained by using C:N ratios of 4:1 and higher. This has also been noted in other studies (54). Effects of soil depth are also more pronounced when insufficient carbon is provided to the denitrifying bacteria. For example, a depth of 450 mm resulted in removal of 16 percent more nitrate than the 150 mm soil column under similar conditions (C:N ratio of 3:1). This may have been caused either by the presence of extra organic carbon in the deeper soil because of its larger volume or by the creation of a more conducive environment for denitrifiers in a larger soil column, or a combination of both. After carrying out denitrification in a soil column, Magdoff, et al (52) also reported increased efficiencies due to the extra organic matter present in deeper soil profile.

Ammonia

Ammonia was not detected during this investigation and was omitted from the schedule of analysis after the third week of operation. One of the reasons may have been the low levels of TKN present in the synthetic feed solutions. In an actual field condition, however, it may be expected that some

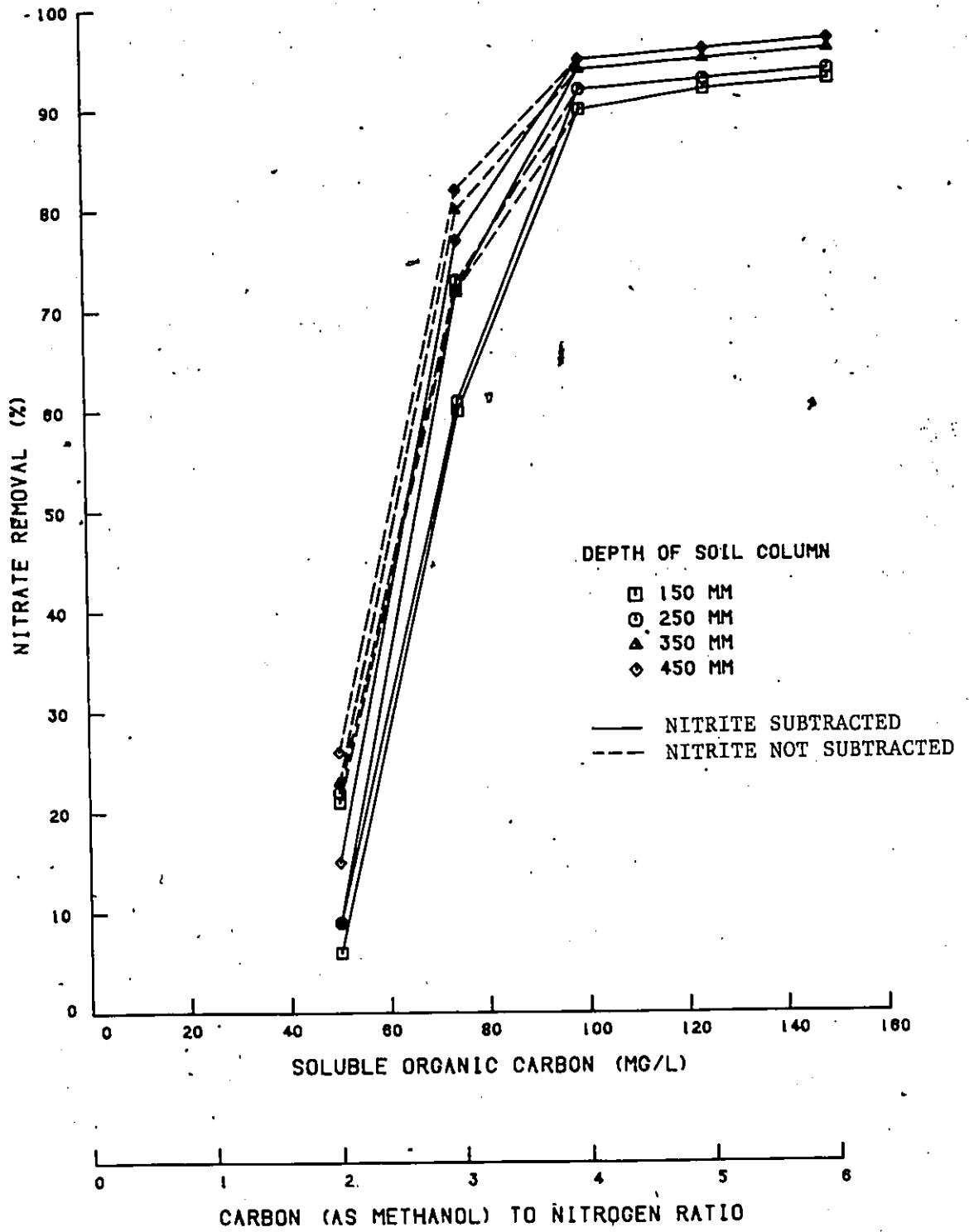


Fig. 5.7. Mean Effective Nitrate Removal
- Application Rate = 200 mm/wk.

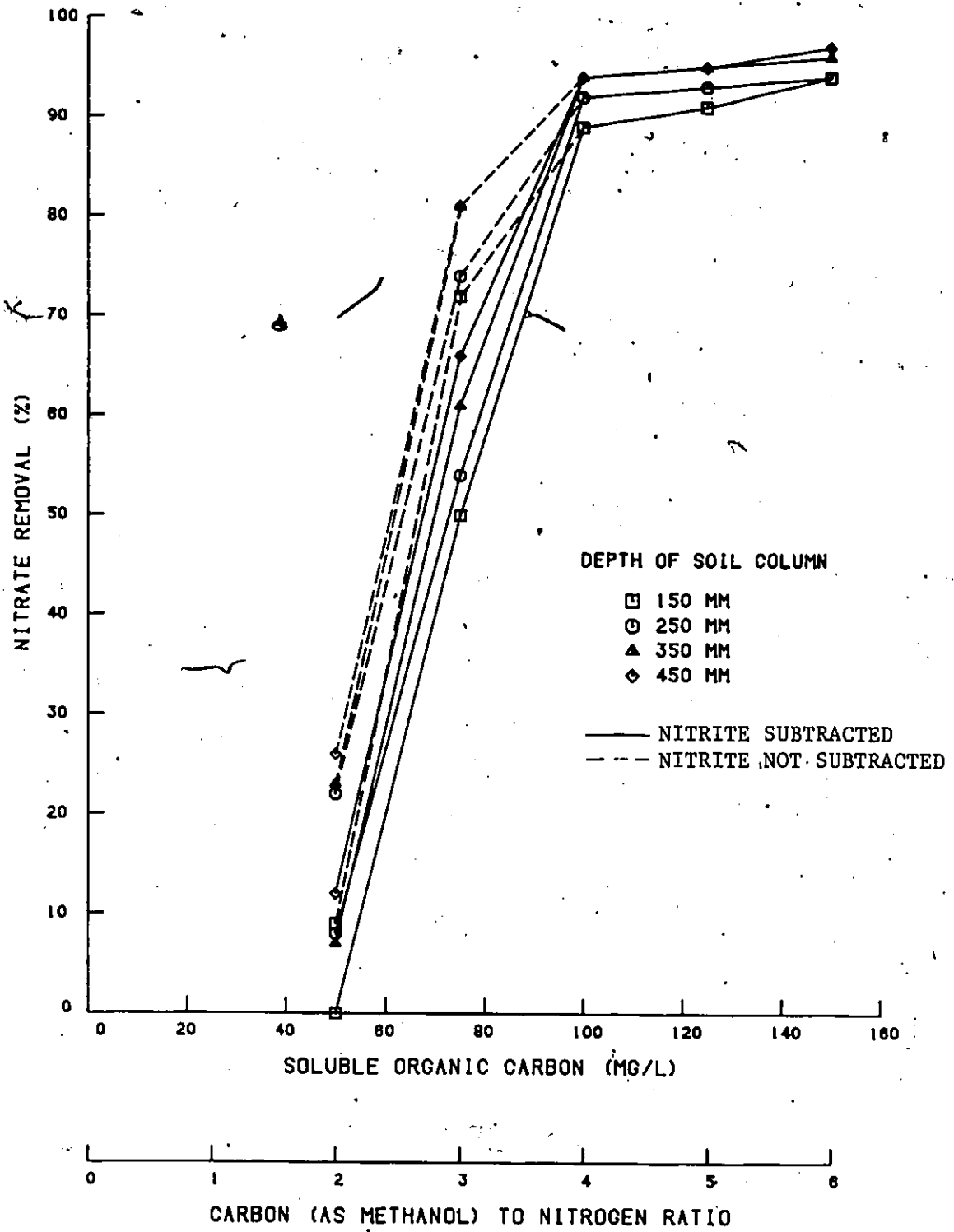


Fig. 5.8. Mean Effective Nitrate Removal - Application Rate = 420 mm/wk.

amount of ammonia will be detected in the effluent.

Total Kjeldahl Nitrogen (TKN)

TKN was determined both for the feed solutions and the treated effluents on a regular basis. Table 5.9 shows the average levels of TKN present in the feed solutions, the treated effluents and the amount gained by the soil during the study, as derived from data of Tables C1, C2 and C3, Appendix C. Almost all of the TKN present as shown in Table 5.9 is believed to be organic nitrogen. The fate of organic nitrogen in the soil is not well understood. However, it is believed that some of the organic nitrogen was transformed to ammonia or ammonium ion. Presumably, part of this was volatilized, some was incorporated into the cell growth mechanism and the rest of the ammonium ion may have been oxidized to nitrate. These presumed reactions, coupled with the slight gain of organic nitrogen in the soil itself, may explain the overall decrease of the organic nitrogen in the treated effluent. On a percentage basis, reduction of TKN varied between 0 and 58 percent. Figure 5.9 shows the variations with respect to C:N ratios for various soil depths. Levels of reduction in soil depths greater than 150 mm are in the same range whereas in the 150 mm soil depth the decrease was less than 30 percent. In general, a higher C:N ratio produced a higher reduction in TKN than the lower ones. However, Walker, et al (92) carried out some field studies where the loss of TKN was found to be much higher than the values obtained in

Table 5.9. Mean Levels of TKN Present in Feed Solutions and Column Effluents Over 28 weeks

Column No.	C:N	TKN		
		Feed solutions (mg/L)	Effluents (mg/L)	Decrease (%)
1	2:1	2.6	2.6	0
2	3:1	3.6	3.4	6
3	4:1	5.3	4.0	25
4	5:1	6.4	4.7	27
5	6:1	7.7	5.4	30
6	2:1	2.6	2.2	15
7	3:1	3.6	2.7	25
8	4:1	5.3	3.0	43
9	5:1	6.4	3.4	47
10	6:1	7.7	4.3	44
11	2:1	2.6	1.6	39
12	3:1	3.6	3.0	17
13	4:1	5.3	2.9	45
14	5:1	6.4	3.6	44
15	6:1	7.7	3.9	38
16	2:1	2.6	1.9	27
17	3:1	3.6	2.4	33
18	4:1	5.3	2.8	47
19	5:1	6.4	2.7	58
20	6:1	7.7	3.2	58

Note: Initial average TKN levels in the soil was 1.2 µg/g and final TKN levels in the columns 3,8,14&20 were 3.4, 4.2; 3.6, and 4.2 µg/g, respectively.

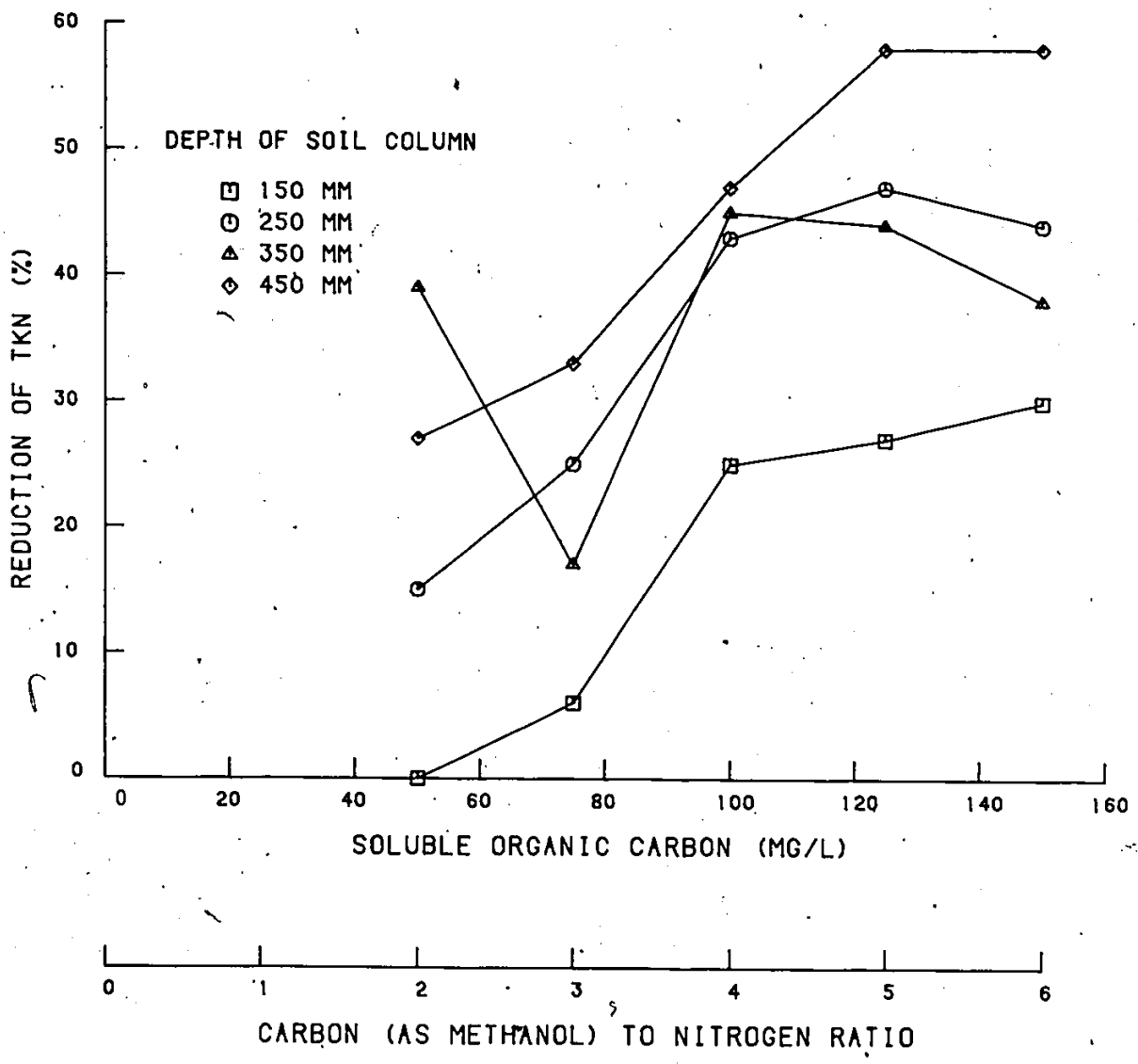


Fig. 5.9. Mean Variation of TKN for Various Soil Depths

this work. They reported a decrease of over 80% at a depth of 200 mm of soil. On the other hand, in a laboratory study Magdoff, et al (52) reported only a 50 percent reduction of TKN at a depth of 550 mm of soil column.

COD

COD levels in all the soil column effluents for 28 weeks are tabulated in Table C4 in Appendix C (p. 227). Tables D7 and D8 in Appendix D (pp. 263-264) show the mean COD removal for application rates of 200 mm/wk and 420 mm/wk respectively. Removals of COD for the application rate of 200 mm/wk are plotted in Figure 5.10. Test data on COD and also COD removals are tabulated in Tables C1 to C4, Appendix C and Tables D7 and D8, Appendix D. A soil depth of 150 mm produced the lowest percentages of COD reduction ranging from 41 to 62%. The maximum reduction achieved for a soil depth of 250 mm was 79%. Ninety percent reduction was obtained for both soil depths of 350 and 450 mm when the influent C:N ratio was 6:1. It can be observed that curves plotted for higher C:N ratios always produced a slight increase in the removal rate of COD for the same soil depth. This may have been caused by the fact that feed solutions with larger C:N ratios had higher COD values resulting from the presence of a greater proportion of kitchen waste. Using a soil column of 1000 mm length, Magdoff, et al (51) found nearly complete COD removal for both saturated and unsaturated soil conditions.

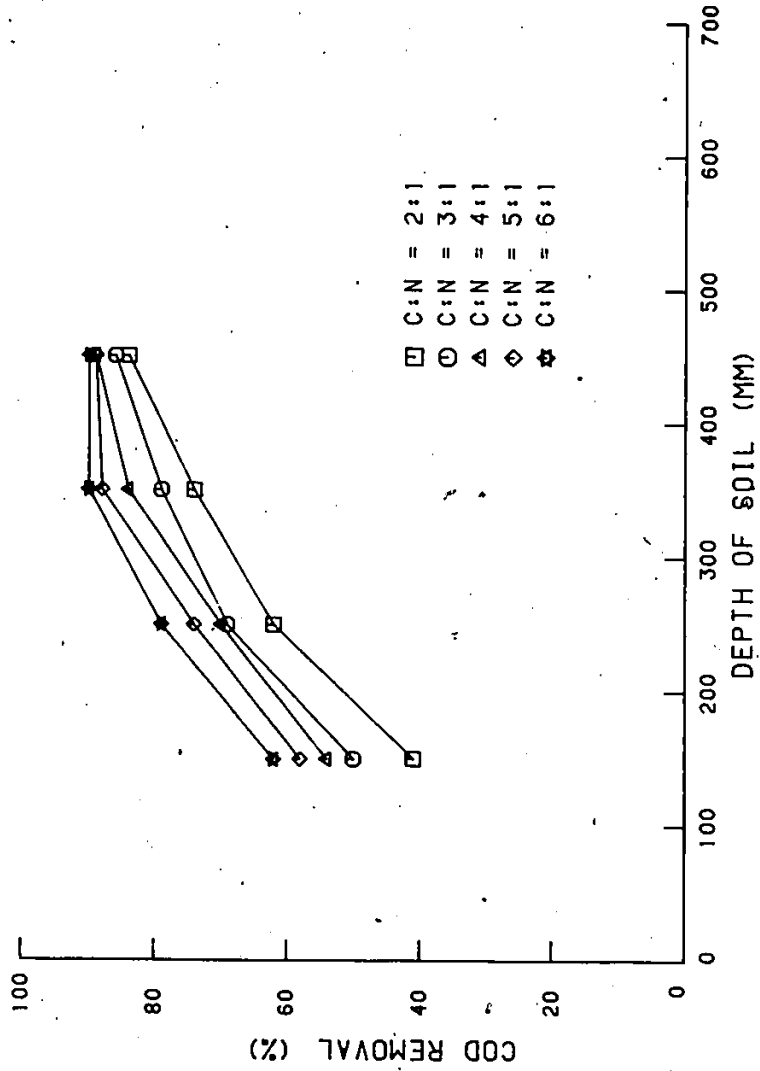


Fig. 5.10. Removal of COD with Soil Depths - Application
Rate = 200 mm/wk.

Figure 5.11 illustrates the present COD removal for application rate of 420 mm/wk. By comparing Figures 5.10 and 5.11, it can be seen that the removal efficiencies were almost identical for soil depths of 350 mm and higher. However, an increased application rate affected the COD removal efficiencies for soil depths of 150 mm and 250 mm, respectively. For both depths the efficiencies were lower for the higher application rate and the differences ranged from 4% to a high of 17%. It is clear that the depth of soil in a shallow tile field becomes more important for COD removal as the application rate increases.

Dissolved Oxygen

Column effluents were also tested for dissolved oxygen concentrations (Tables C2 and C3, Appendix C). Mean values for various levels of DO for both application rates were calculated separately; however, the application rate was found to make no appreciable difference. Therefore, results of 28 weeks were used to calculate the overall mean values shown in Figure 5.12 and tabulated in Table D9, Appendix D. Both higher C:N ratios and larger soil depths appear to favour reduction in dissolved oxygen concentration. Feed solutions were not deoxygenated in this study. However, the effect of a relatively high concentration of dissolved oxygen in the feed solutions on the denitrification process appeared to be insignificant. For example, a feed solution containing 75 mg/L (C:N=3:1) of

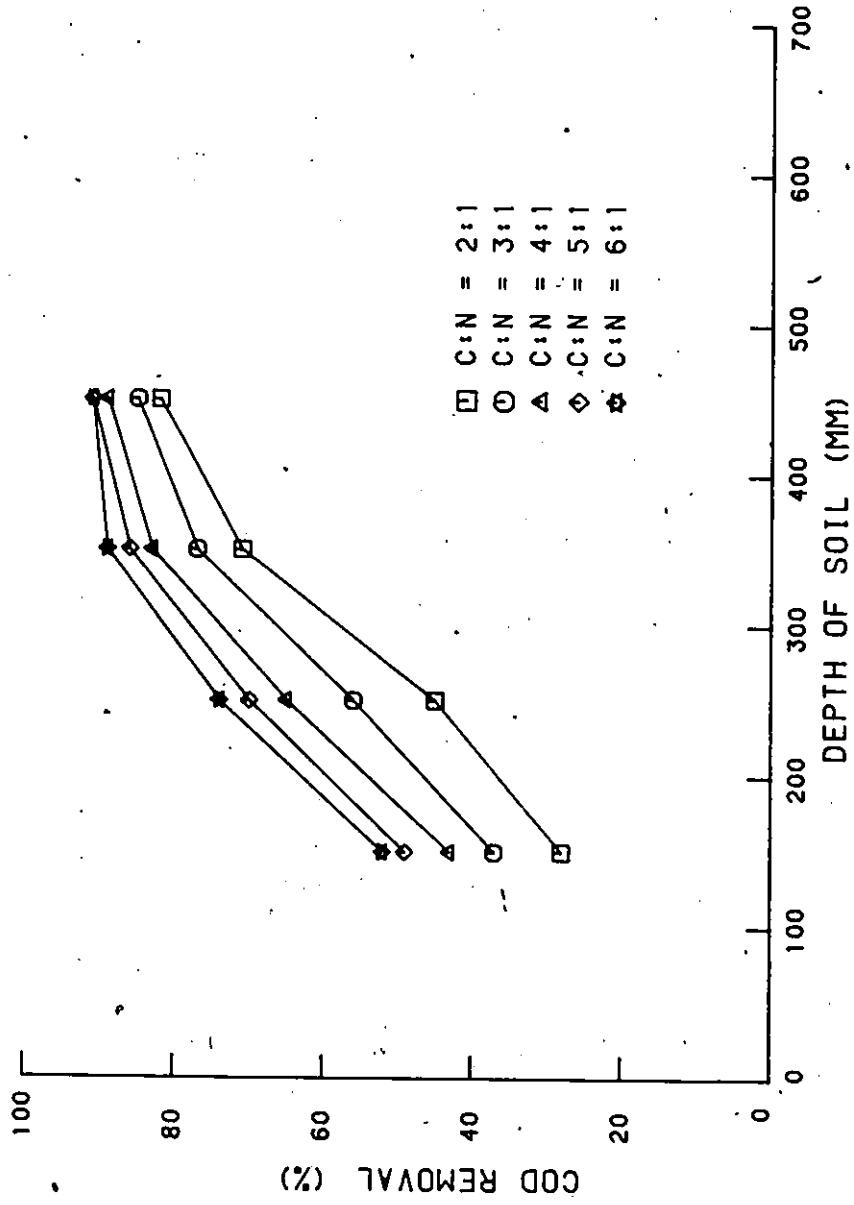


Fig. 5.11. Removal of COD with Soi Depths - Application
Rate = 420 mm/wk.

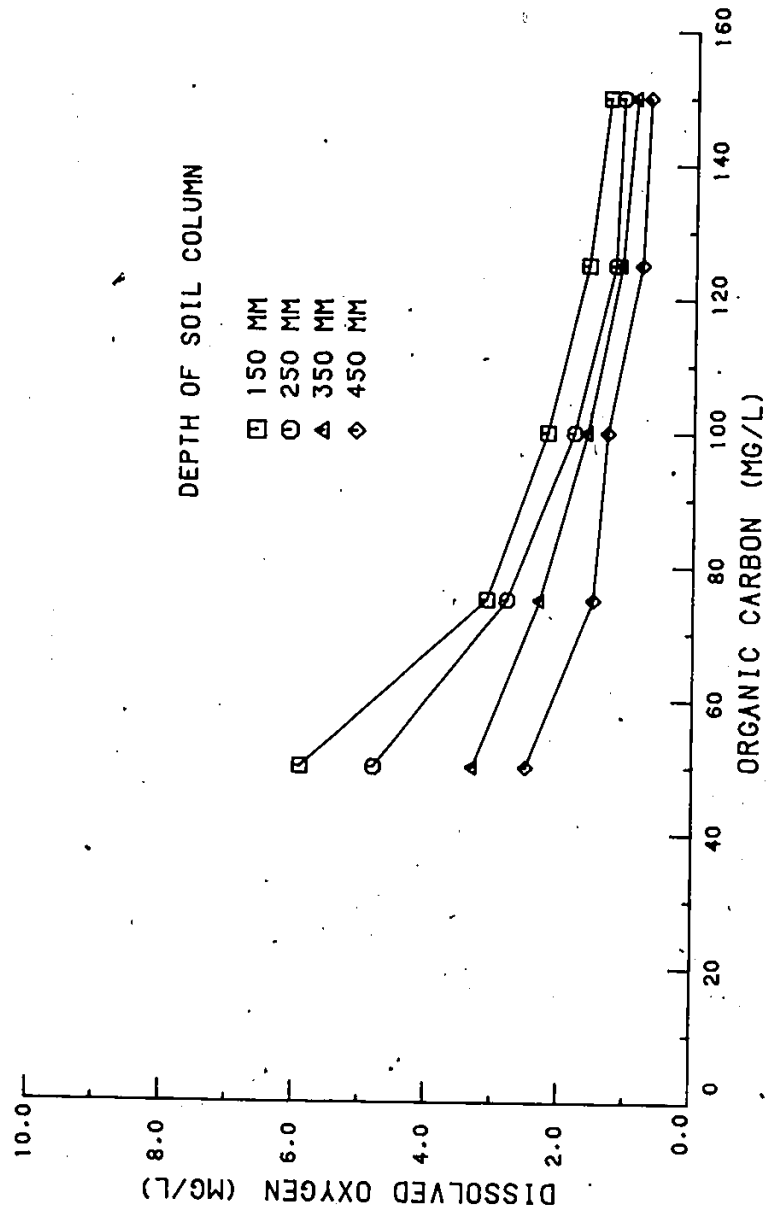


Fig. 5.12. Mean Concentrations of Dissolved Oxygen Over 28 weeks.

soluble organic carbon removed 60 percent of applied nitrate (Table 5.8, p. 86) in a 150 mm soil column where the average concentration of DO was 3.1 mg/L. Theoretically, facultative heterotrophic bacteria should consume all the oxygen before using nitrate as electron acceptor. In a soil column the environmental conditions may not be homogeneous throughout the column. Some sections or micro zones in the soil may have experienced a complete reduced state and the oxygen was used up prior to denitrification. Other zones may have never reached this level and oxygen was not fully utilized; denitrification may not have taken place in these zones. However, the treated effluents were a combination of all the feed solutions which went through these various environments in the soil columns. Therefore, the effluents still had some oxygen left in solution and at the same time were denitrified to various degrees. Columns fed with low C:N ratio feed solutions had more residual dissolved oxygen in their respective effluents. Lowest oxygen concentrations in the column effluents were around 1 mg/L. Complete deoxygenation was never encountered even with C:N ratio as high as 6:1. Smith, et al (77) also observed the same phenomenon even with soil columns as deep as 3000 mm and a C:N ratio of 3:1 where methanol was used as the organic carbon. The lowest concentration in that study was around 0.7 mg/L; a level of 1.5 mg/L of dissolved oxygen was reported at a depth of 1300 mm.

Alkalinity

Tests for alkalinity were carried out throughout the

study both for feed solutions and the treated effluents (Tables C1 and C2, Appendix C). Synthetic feed solutions, as expected, had low alkalinity. Phenolphthalein alkalinity was not present. Total alkalinity (Methyl orange end point) for feed solutions ranged between 50 and 75 mg/L as CaCO_3 . Mean values of total alkalinity for five different C:N ratios in the feed solutions are given in Table 5.10. Also, for treated effluents average amounts of total alkalinity and corresponding amounts of nitrate removed are given in Table 5.10. (These data are derived from the test values of Tables C1 and C2). During biological denitrification bicarbonate alkalinity is produced. Stoichiometrically 3.57 mg alkalinity as CaCO_3 is produced for each mg of nitrate reduced to nitrogen gas. However, in this study the ratio ranged from 2.44 for 350 and 450 mm soil columns receiving 3:1 (C:N) feed solution to 4.78 obtained for a 250 mm soil column fed with 2:1 (C:N) feed solution. However, all the soil columns fed with the C:N ratio of 2:1 produced very high values. Errors may have been introduced during measurement and consequent computations of the nitrate removal for these columns because of their low efficiencies. A graphical representation is presented in Figure 5.13. For an attached growth system it has been reported that the resulting alkalinity averaged 2.95 mg as CaCO_3 per mg of nitrogen removed (85). In general, ratios obtained in this study are slightly lower than this value excepting those cases where feed solutions contained low (2:1) C:N ratio. Levels of total alkalinity during the last 8 weeks

Table 5.10. Mean Variation of Alkalinity with Soil Depth and Removal of Nitrate, Over 20 weeks of Operation - Application Rate = 200 mm/wk.

Column no.	C:N	Soil depth (mm)	Total Alkalinity as CaCO ₃		Nitrate removed (mg/L)	Ratio of change in alkalinity to nitrate removed
			Feed (mg/L)	Effluent (mg/L)		
1	2:1	150	55	62	1.5	4.67
2	3:1	150	60	97	15.0	2.47
3	4:1	150	60	117	22.5	2.53
4	5:1	150	62	120	23.0	2.52
5	6:1	150	64	129	23.3	2.79
6	2:1	250	55	66	2.3	4.78
7	3:1	250	60	100	15.3	2.61
8	4:1	250	60	122	23.0	2.70
9	5:1	250	62	125	23.3	2.70
10	6:1	250	64	131	23.5	2.85
11	2:1	350	55	65	2.3	4.35
12	3:1	350	60	104	18.0	2.44
13	4:1	350	60	126	23.5	2.81
14	5:1	350	62	127	23.8	2.73
15	6:1	350	64	133	24.0	2.88
16	2:1	450	55	69	3.8	3.68
17	3:1	450	60	107	19.3	2.44
18	4:1	450	60	132	23.8	3.03
19	5:1	450	62	129	24.0	2.79
20	6:1	450	64	135	24.3	2.92

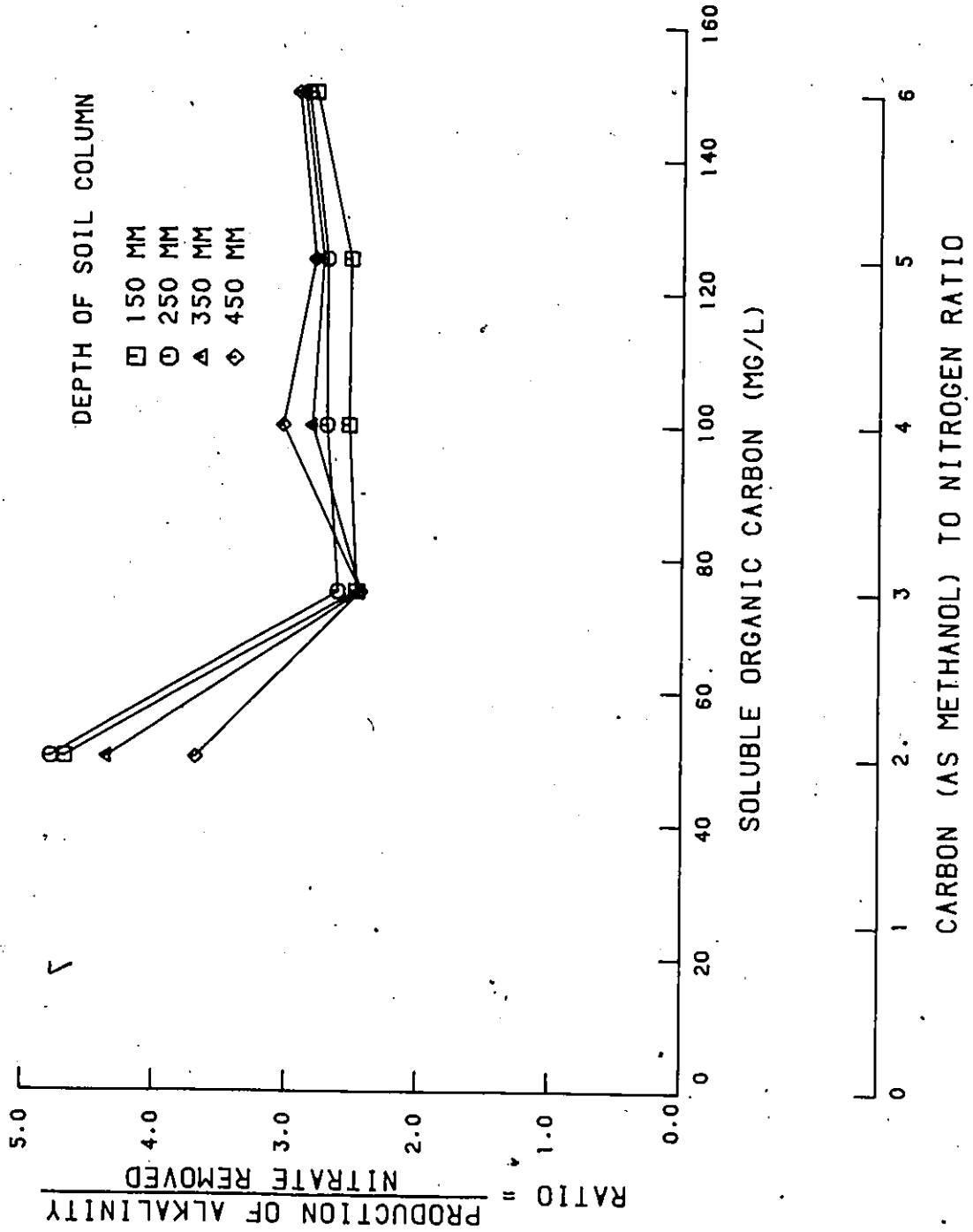


Fig. 5.13. Variation of Ratio (Alkalinity/Nitrate Removed) with Applied Organic Carbon for Various Soil Depths- Application rate = 200mm/wk.

of operation at the higher application rate were very similar (Table C3, Appendix C) to the results shown in Table 5.10 and are not presented here. Oxidation of excess COD (CO_2 produced) may have reduced alkalinity.

Soluble Organic Carbon

The Soluble Organic Carbon (SOC) was monitored both for the feed solutions and the treated effluents for all the columns. For the feed solutions the levels of SOC were predetermined. Relationships between SOC applied and mean residual SOC for various soil columns are shown in Figure 5.14. (Data tabulated in Table D10, Appendix D). These values represent the mean levels of residual SOC for the entire study (28 weeks). Columns with C:N ratios of 2:1, 3:1 and 4:1, respectively, produced very low residual carbon levels in the final effluents. Feed solutions of higher C:N ratios, as expected, generated effluents with slightly higher levels of soluble organic carbon. Depth of soil also influenced the results slightly; for example, a soil depth of 450 mm when subjected to a loading of 5:1 produced only 4 mg/l of residual SOC, while the same feed solution when applied to a 150 mm soil column had 11 mg/L of residual SOC. Since a C:N ratio of 4:1 was found to be sufficient for complete denitrification, it was expected that excess applied organic carbon would be present in the feed solutions with higher C:N ratios. However, only a fraction (less than 20%) of this excess carbon was recovered and was further reduced for larger soil depths. This phenomenon may be attributed to the

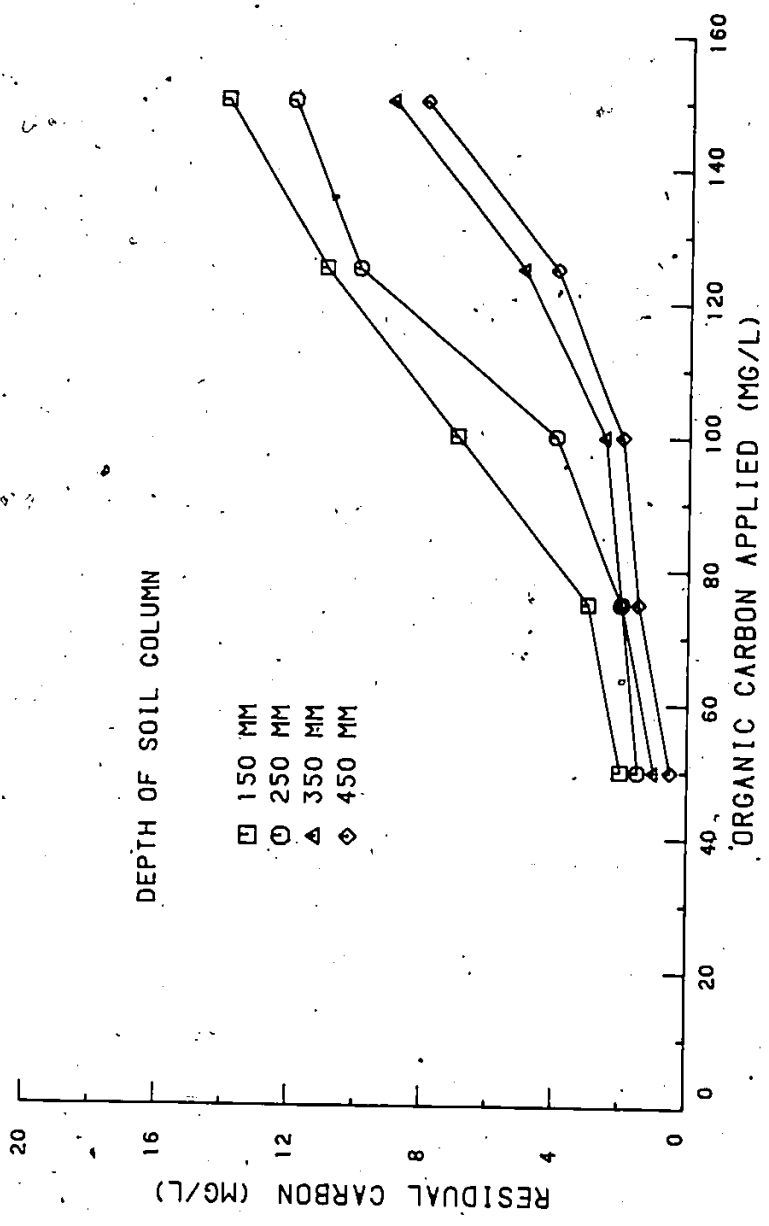


Fig. 5.14. Residual SOC for Various Amounts of Applied Organic Carbon

fact that other heterotrophic bacteria not involved in denitrification are present in the soil and may have used a portion of the excess organic carbon. Lance (47) observed a slightly higher rate of recovery of organic carbon in his soil columns. However, because of the different environmental conditions which existed in his study a direct comparison is not possible..

Suspended Solids

Tests for TSS and VSS were carried out only five times during the soil column investigation. The mean values have been calculated and are shown in Table 5.11. Each time the samples included five feed solutions and all the corresponding treated effluents from the soil columns. The results are shown in Tables C1 and C2, Appendix C. It can be seen that, contrary to expectation, the treated effluents quite often contained a higher level of TSS than in the feed solution, especially for shorter soil columns. Figure 5.15 reveals that only the soil depth of 450 mm produced any reduction of TSS for at least four C:N ratios and the maximum removal was only 31 percent. The levels of VSS were also higher in all the treated effluents as compared to the feed solutions. This could imply that cells were washed away regularly in the treated effluents resulting in higher solids concentrations. This was also observed by Laak (52) in the RUCK System, when grey water was used as carbon source; the effluent from a rock filter (denitrification chamber) sometimes contained almost twice the level of suspended solids in the influent.

Table 5.11. Mean Variation of TSS and VSS in the Feed and Treated Effluent for the Soil Columns

Column no.	C:N	Soil depth (mm)	Feed			Effluent			Reduction of TSS (%)
			TSS (mg/L)	VSS (mg/L)	$\frac{VSS}{TSS} \times 100$ (%)	TSS (mg/L)	VSS (mg/L)	$\frac{VSS}{TSS} \times 100$ (%)	
1	2:1	150	23	13	56	28	19	68	-
2	3:1	150	28	16	57	35	24	69	-
3	4:1	150	30	19	63	33	22	67	-
4	5:1	150	33	21	64	37	28	76	-
5	6:1	150	42	24	57	44	30	68	-
6	2:1	250	23	13	56	27	17	63	-
7	3:1	250	28	16	57	31	21	68	-
8	4:1	250	30	19	63	36	24	67	-
9	5:1	250	33	21	64	31	24	77	6
10	6:1	250	42	24	57	38	26	68	10
11	2:1	350	23	13	56	25	18	72	-
12	3:1	350	28	16	57	26	20	77	7
13	4:1	350	30	19	63	32	24	75	-
14	5:1	350	33	21	64	31	24	77	6
15	6:1	350	42	24	57	33	24	73	21
16	2:1	450	23	13	54	24	18	75	14
17	3:1	450	28	16	58	24	18	75	10
18	4:1	450	30	20	66	27	19	70	12
19	5:1	450	33	21	64	29	21	72	31
20	6:1	450	42	24	57	29	23	79	-

Note: '-' signifies an indicated increase in TSS.

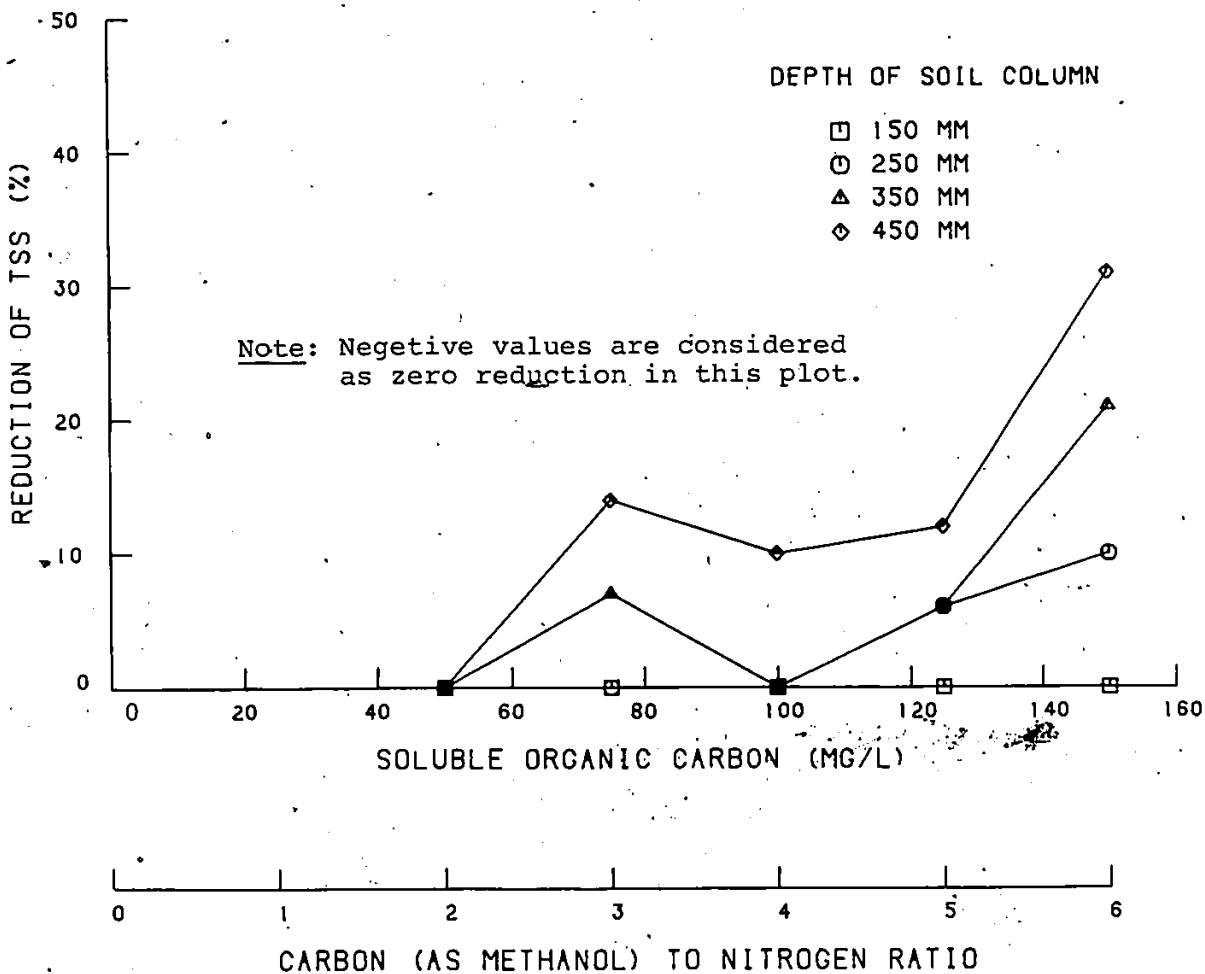


Fig: 5.15. Removal of TSS for Various Soil Depths

Overall Nitrogen Removal in the Soil Columns

Table D12 in the Appendix D, shows overall nitrogen removal in the soil column systems for the application rate of 200 mm/wk. The results are plotted in Figure 5.16a. In this calculation all the nitrogen compounds such as nitrite, nitrate, ammonia and TKN are taken into account. The maximum removal was obtained in the deepest soil column (450 mm) and the level was 87%. This value is slightly less than the high efficiencies found in the soil columns when only nitrate is considered. A C:N ratio of 4:1 removed 79% of the total influent nitrogen in this study at an application rate of 200 mm/wk. Similar results were also obtained for higher application rate and therefore are not presented here. A flow diagram showing the possible transformation of various nitrogen compounds in the soil columns are depicted in Figure 16b.

Statistical Analysis

A linear regression model was chosen in the form of $y = C + a_1x_1 + a_2x_2 + a_3x_3$ for the analysis (100). Two models were tested using Nitrate as the dependent variable (y). Depth, DO and SOC were the independent variables in the first model and a very high coefficient of determination ($R^2=0.935$) was obtained (Tab. F1, App. F). In the second model SOC was replaced by COD without changing the other independent variables. This model produced a much lower value of R^2 (0.547) compared to the previous model (Tab. F2, App. F). It is clear that the general linear model No.1, where SOC, DO and depth were the independent variable is a better model in predicting nitrate removal.

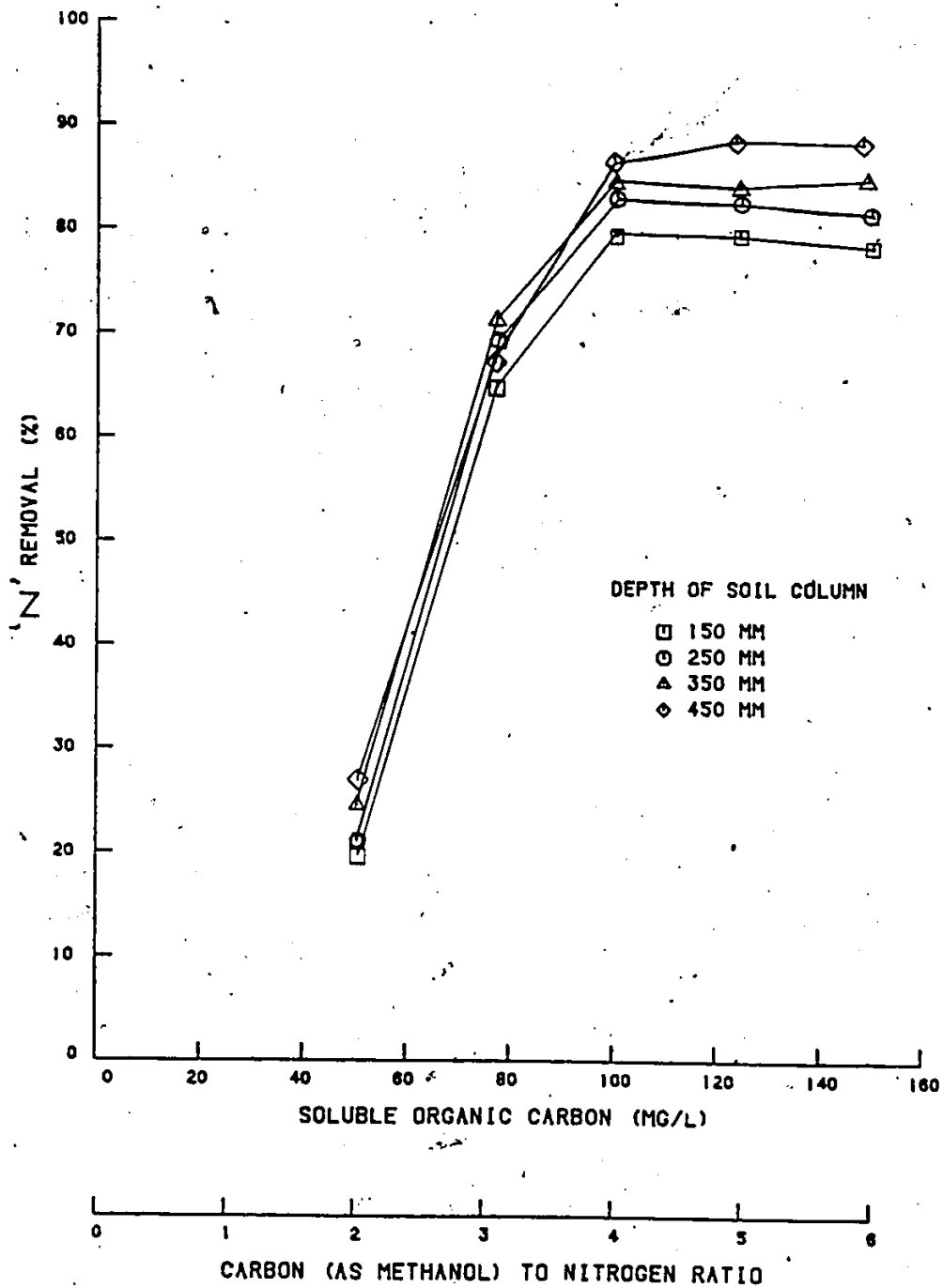


Fig. 15A. Total Nitrogen Removal in Soil Columns
Application Rate = 200 mm/wk

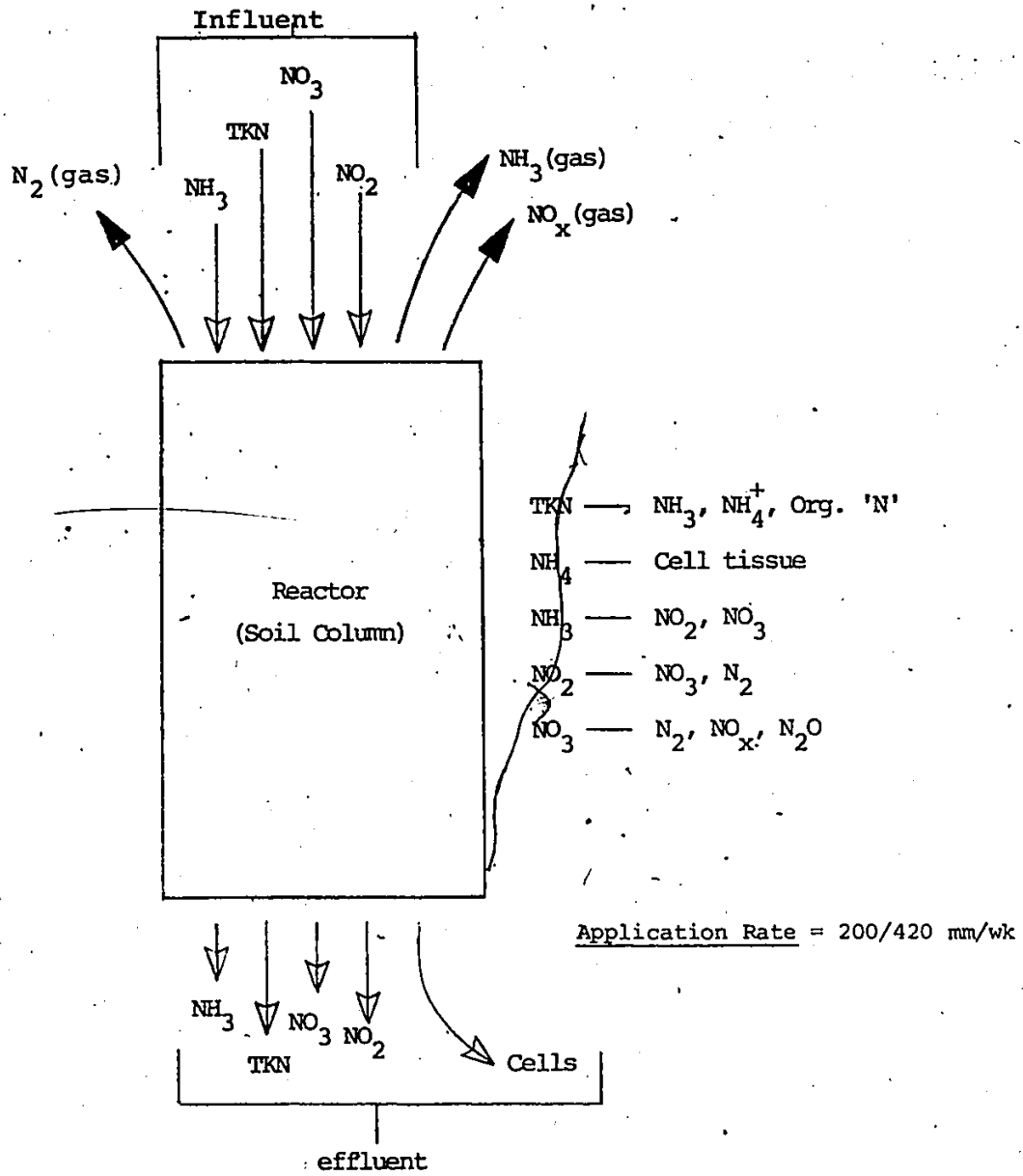


Fig. 15 B. A General Flow Chart Showing the Fate of Nitrogen Compounds in a Soil Column.

5.1.2 Environmental Factors

pH

Feed solutions and the treated effluents were analyzed for pH and the mean levels are shown in Table 5.12 (from Tables C1, C2 and C3 in Appendix C). Column effluents generally showed a slight increase in pH levels compared to that of feed solutions. Influence of soil depths seems to be insignificant.

Temperature

The mean temperature was 24°C with a maximum variation of $\pm 1^\circ\text{C}$. Because of this very limited fluctuation, the effect of temperature was not considered in this study. Ambient weekly temperature variations are shown in Table E1, Appendix E, p. 269.

5.2 Study with Model Tile

Consideration of the results obtained in the soil column study revealed that a level of carbon to nitrogen ratio of 4:1 was an optimum value for the synthetic feed solutions for successful columnar denitrification. Therefore, it was decided to use only this ratio in the tile installation described in the following paragraph.

After laying the tile in the tank and installing the sampling devices (as described in Chapter 4) the leaching bed was loaded daily at an application rate of 80 L/m²/d (2 g/ft²/d) for 6 months. The feed solution had a C:N ratio of 4:1 and was

Time 5.12. Mean Variations of pH in the Feed Solutions and the Column Effluents

Column No.	Soil depth (mm)	C:N ratio	Average pH of feed solution	Average pH of column effluent	Remarks
1	150	2:1	6.8	7.0	Range of pH levels for feed solution was from 6.7 to 7.1
2	150	3:1	6.8	7.1	
3	150	4:1	6.8	7.3	
4	150	5:1	6.9	7.3	
5	150	6:1	6.9	7.4	Range of pH levels for column effluents was from 6.6 to 7.7
6	250	2:1	6.8	7.1	
7	250	3:1	6.8	7.1	
8	250	4:1	6.8	7.2	
9	250	5:1	6.9	7.4	
10	250	6:1	6.9	7.4	
11	350	2:1	6.8	7.1	
12	350	3:1	6.8	7.2	
13	350	4:1	6.8	7.3	
14	350	5:1	6.9	7.3	
15	350	6:1	6.9	7.4	
16	450	2:1	6.8	7.1	
17	450	3:1	6.8	7.2	
18	450	4:1	6.8	7.3	
19	45	5:1	6.9	7.4	
20	45	6:1	6.9	7.4	

prepared everyday in the laboratory following the technique used in the study with soil columns.

The specific objectives of this study were:

- 1) to evaluate the effects of soil depth on the variation of different parameters, such as nitrate, nitrite, ammonia, TKN, chemical oxygen demand, solids, alkalinity and dissolved oxygen using a model tile installation;
- 2) to observe the levels of denitrification below and above the groundwater table. Favourable results could justify the direct application of the mixed stream of nitrified wastewater and kitchen waste to a tile field disposal system, eliminating the need for an enclosed denitrification reactor.

A detailed characterization of raw kitchen waste was done regularly for six months and the results are shown in Table 5.13. By comparison to Table 5.1 it can be seen that the levels of various parameters are similar to those obtained during the soil column studies. Most of the nitrogen was present in the form of organic nitrogen. The COD levels ranged from 1700 to 3700 mg/l. Levels of SOC were also in the range of 2000 mg/l. Prior to the preparation of 4:1 feed solution each day, exact amounts of the SOC were determined for the raw kitchen waste to be used. These feed solutions were analyzed for various chemical characteristics on a weekly basis and the results are shown

Table 5.13. Raw Kitchen Wastewater Characteristics

Date	Characteristics*										
	SOC (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	pH
12/2/81	1840	0.0	1.0	0.0	98.8	130	155	98	4500	8.2	7.1
16/3/81	2120	0.0	0.0	0.0	115.2	190	130	110	5750	8.1	6.8
5/4/81	1980	-	0.0	2.1	79.7	180	105	65	5250	8.1	7.0
28/5/81	2460	-	0.0	0.0	105.8	150	195	134	4250	8.2	6.9
16/6/81	4800	-	0.0	0.0	120.5	180	165	118	9250	8.0	6.7
6/7/81	2360	-	0.0	0.0	89.2	160	135	86	5250	8.1	6.6

* Samples were allowed to settle for two hours before carrying out the tests on the supernatant.

in Table C5 in Appendix C, p. 231 . The concentration of nitrate nitrogen was 25 mg/L.

Samples were collected every week through the sampling ports and were analyzed for various characteristics (Table C6, Appendix C). The only exceptions were those samples collected between April 30, 1981 and May 21, 1981. During this time period four sets of samples were collected and the analyses were restricted only to the levels of nitrate. The tile bed reactor failed to remove nitrate during this period and a sudden increase in the solids concentration in the effluent indicated that there was death of microorganisms in the reactor. These dead cells of microorganisms increased the VSS concentration in the effluents substantially. Although the exact reason for this instability was not conclusively established, contaminated feed solution was thought to be the cause. However, the system regained stability thereafter and further tests were carried out for another two months.

5.2.1 Variation of Parameters with Soil Depth and Time

Nitrate and Nitrite

Table 5.14 shows the percentage removal of nitrate for various soil depths over six months. The results from the first three weeks were not included in the calculation. Actually results shown in Table C6 (Appendix C, p. 232) illustrate that denitrification started during the first week of loading;

Table 5.14. Effective Removal of Nitrate with Soil Depth & Time

Date	Percentage removal of nitrate (%)						
	1000 mm soil depth	900 mm soil depth	800 mm soil depth	700mm soil depth	600 mm soil depth	500mm soil depth	400 mm soil depth
26/2/81	71	74	69	62	47	30	23
5/3/81	84	82	81	71	43	29	14
12/3/81	81	79	77	70	46	26	21
19/3/81	83	80	78	78	39	29	27
26/3/81	85	82	84	75	49	30	22
2/4/81	82	83	79	71	68		
9/4/81	81	80	78	66	62		
16/4/81	78	77	76	64	15		
23/4/81	78	76	62	56	12		
4/6/81	72	71	61				
11/6/81	74	79	72				
18/6/81	78	75	74				
25/6/81	81	80	77	70			
2/7/81	80	75	78				
9/7/81	82	82	80	60			
16/7/81	80	80	75	62			
23/7/81	81	82	78	64			
Mean	79	78	75	67	42	29	21

Note: Effective removal includes the effect of nitrite levels (see p. 84).

however, the system did not remove nitrate consistently until the fourth week of operation. Nitrite was also detected only during the first three weeks, during which the denitrification rate increased progressively. As mentioned before, the system showed an unstable condition (very low removal of nitrate) for at least three weeks during the month of May, as well, and these results were also omitted from the calculations for the values in Table 5.14. Mean values for percentage removal were calculated for all the soil depths and are plotted in Figure 5.16. It can be seen that only 21% reduction was obtained at a depth of 400 mm although the feed solution contained sufficient organic carbon as indicated by the soil column study. This depth is measured from the top of the soil and not from the point of application which is not the case in the soil columns. In soil columns the entire depth was effective in the treatment. Even a depth of 1000 mm failed to produce more than 79 percent removal of nitrate. At a depth of 800 mm of soil and beyond the variation in the efficiency of nitrate removal was insignificant and increased from 75% for 800 mm to 79% for 1000 mm, respectively. Between the depths of 500 mm and 800 mm the percent reduction of nitrate increased sharply. It is clear that, in the tile installation, the depth of soil does affect denitrification significantly and a minimum depth of 800 mm was needed in this case to achieve a reduction higher than 75%. This is contrary to the findings resulting from the previous tests carried out using soil columns. For example, over 80% nitrate removal was

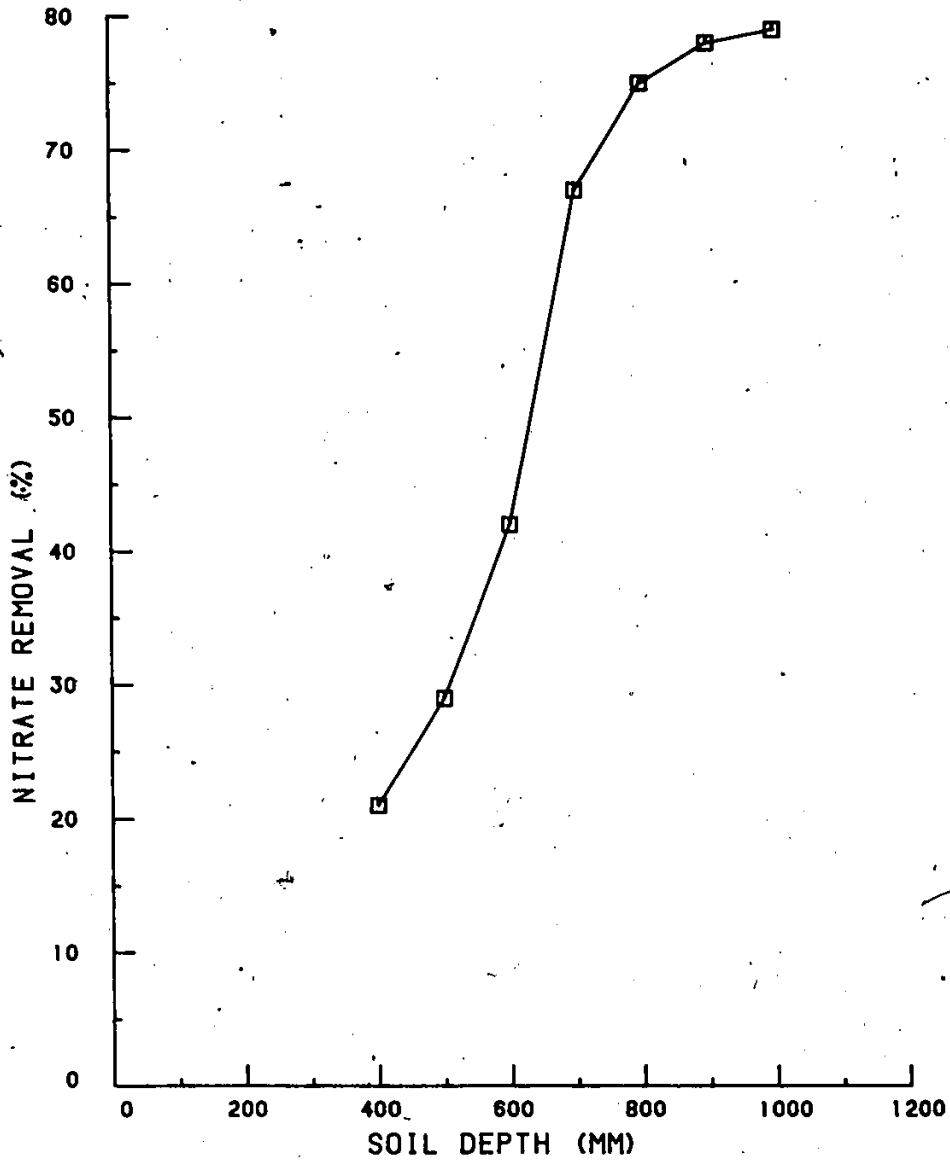


Fig. 5.16. Variation of Effective Nitrate Removal in the Tile Field with Soil Depth

obtained from soil columns having a depth of only 150 mm. This may be attributed to the fact that in soil columns, only a very small amount of surface area is exposed to the atmosphere, whereas, in the tile installation there is an unsaturated zone from which the oxygen may be supplied. This may indicate that a higher C:N ratio is required for the tile installation in order to achieve nitrate removals comparable to those obtained in the columns.

Total Kjeldahl Nitrogen (TKN)

Calculated percent reductions of TKN are given in Table 5.15. These values have been derived from results for TKN analyses in the treated samples which are given in Table C6, Appendix C. All the soil depths showed reductions in TKN levels and the mean varied from 25 to 52 percent as shown in Figure 5.17. The variation of TKN with time shown in Table 5.15 demonstrates that the organic nitrogen was removed by soil from the first week of loading, although the percentage reductions were somewhat lower than the average. Tests carried out on the samples collected on the 4th of June, 1981 showed slightly higher levels of TKN than in the respective feed solution. This may have been due to the breakdown of the denitrification system during the month of May which resulted in an excess level of dead cells in all the samples. However, percentage reductions of TKN in the same samples returned to normal in the following week.

Table 5.15. Reduction of TKN at Various Depths in the Tile Field

Date	TKN in feed solution (mg/L)	Percentage reduction of TKN (%)											
		1000 mm soil depth	900 mm soil depth	800 mm soil depth	700 mm soil depth	600 mm soil depth	500 mm soil depth	400 mm soil depth					
5/2/81	7.7	27	18	27	36	27	54	36					
12/2/81	5.6	38	25	38	13	50	25	13					
19/2/81	6.3	44	44	33	22	11	22	22					
26/2/81	9.1	46	39	31	31	23	15	15					
5/3/81	5.6	62	50	38	38	25	13	25					
12/3/81	7.0	50	50	44	20	30	30	20					
19/3/81	7.7	46	55	36	36	27	27	36					
26/3/81	6.3	78	44	56	56	33	44	33					
2/4/81	6.3	56	44	44	33	33							
9/4/81	9.1	54	46	39	39	39							
16/4/81	8.4	58	50	50	33	42							
23/4/81	7.0	40	50	30	40	50							
4/6/81	5.6	0	0	0									
11/6/81	8.4	50	42	33									
18/6/81	7.7	27	36	36									
25/6/81	6.3	56	33	44	33								
2/7/81	7.0	50	40	40									
9/7/81	9.1	39	39	31	31								
16/7/81	7.7	46	36	36	27								
23/7/81	7.0	50	40	40	30								
Mean		52	46	43	40	32	29	25					

NOTE:
TKN (initial) in soil = 1.2 µg/g
TKN (final) in soil = 2.6 µg/g

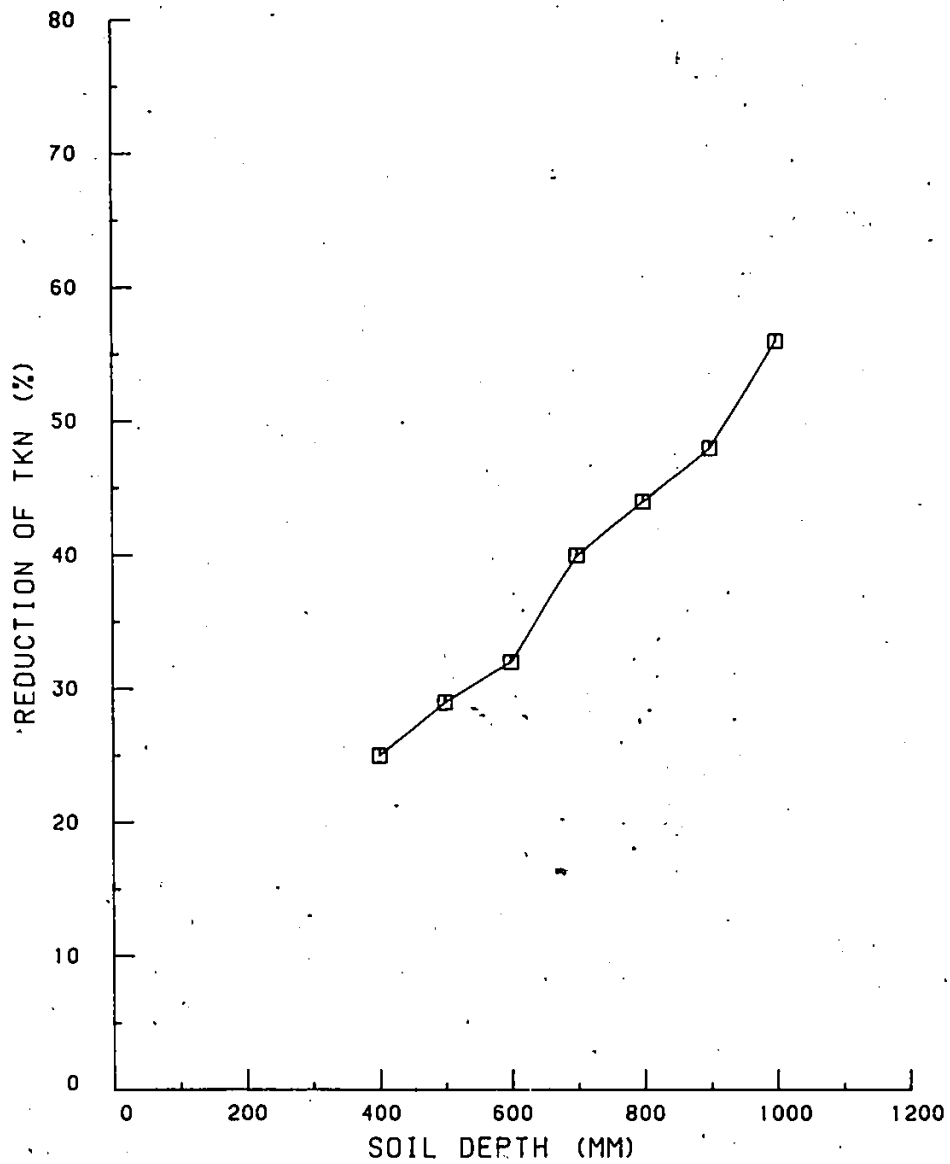


Fig. 5.17. Reduction of TKN at Various Depths in the Tile Installation

The levels of TKN reduction in column studies were very similar. For C:N ratio of 4:1, the levels varied from 24 to 48 percent; however, these were achieved at a much shallower depth.

Alkalinity

During the model tile study, total alkalinities of both the feed solutions and the treated effluents were monitored and levels are shown in Table 5.16. The ratio between production of alkalinity and corresponding level of nitrate removal (from Table C6, Appendix C), for all the samples are also given in Table 5.16. Mean values of these ratios are calculated and plotted against soil depth in Figure 5.18. A depth of 400 mm produced a mean ratio of 4.09 (mean of five values) which is much higher than the theoretical value (3.53 mg as Ca CO₃ per mg of nitrate nitrogen removed). All the other depths produced slightly lower mean ratios compared to those obtained in the previous study using soil columns as well as being lower than the theoretical value. The lowest mean ratio (2.27) was found at the depth of 800 mm. The only reported value of alkalinity reported for an attached growth system is 2.95 mg as CaCO₃ per mg of nitrogen reduced (85). This is also lower than the theoretical value. However, the results from this study show that for high degree of nitrate removal, the theoretical ratio between alkalinity production to nitrate removal exceeds the observed ratios by approximately 30 percent.

Table 5.16. Variation of Total Alkalinity with Soil Depth in the Tile Field

Date	TA in feed as CaCO ₃ (mg/L)	Total alkalinity in the percolates as CaCO ₃													
		1000 mm soil depth (mg/L)	Ratio	900 mm soil depth (mg/L)	Ratio	800 mm soil depth (mg/L)	Ratio	700 mm soil depth (mg/L)	Ratio	600 mm soil depth (mg/L)	Ratio	500 mm soil depth (mg/L)	Ratio	400 mm soil depth (mg/L)	
26/2/81	60	100	2.26	100	2.15	95	2.02	90	1.92	90	2.54	85	3.29	85	4.31
5/3/81	65	115	2.38	110	2.20	110	2.23	110	2.39	100	3.27	90	4.46	85	5.88
12/3/81	65	120	2.72	115	2.53	115	2.60	105	2.27	95	2.63	80	2.27	80	2.88
19/3/81	70	120	2.40	125	2.76	115	2.30	115	2.32	95	2.58	90	2.78	90	2.94
26/3/81	65	120	2.59	115	2.43	115	2.38	105	2.13	100	2.87	80	2.03	90	4.46
2/4/81	65	115	2.43	115	2.40	110	2.28	110	2.53	100	2.07				
9/4/81	70	125	2.59	120	2.50	120	2.58	115	2.12	105	2.24				
16/4/81	75	120	2.32	120	2.34	115	2.11	115	2.80	90	3.95				
23/4/81	65	115	2.55	105	2.12	100	2.44	100	2.17	80	5.00				
4/6/81	60	105	2.50	100	2.26	90	1.97								
11/6/81	60	105	2.43	105	2.28	100	2.24								
18/6/81	65	110	2.30	105	2.13	105	2.15								
25/6/81	65	120	2.72	115	2.51	110	2.33	105	2.27						
2/7/81	60	115	2.75	105	2.39	100	2.16								
9/7/81	60	110	2.43	110	2.45	105	2.26	110	2.67						
16/7/81	65	110	2.26	115	2.50	110	2.41	110	2.58						
23/7/81	60	115	2.71	115	2.68	100	2.04	105	2.19						
Mean			2.49		2.39		2.27		2.32		3.01		2.97		4.09

Note: TA - Total alkalinity; Ratio - Production of alkalinity/Nitrate removed.

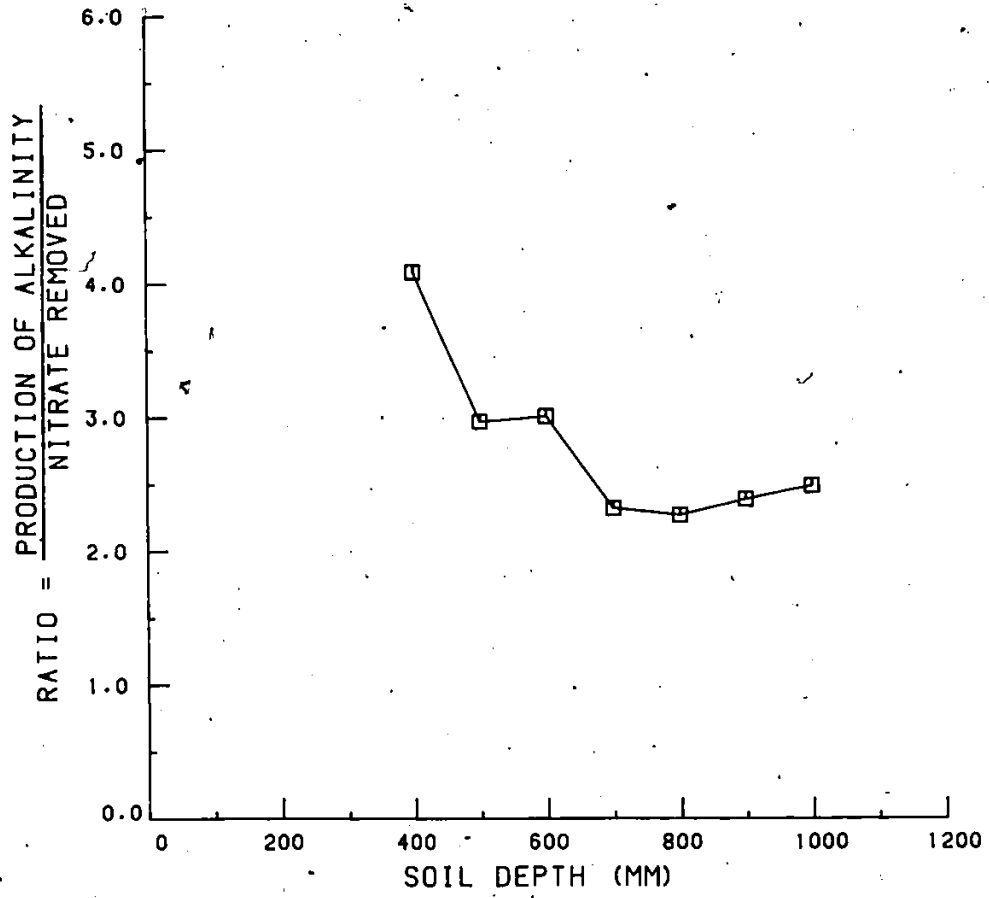


Fig. 5.18. Variation of the Ratio (Production of Alkalinity/Nitrate Removed) with Soil Depth

Suspended Solids

The mean values of TSS and VSS for both the feed solutions and various effluents are shown in Table 5.17. These values were computed from concentrations of solids in the feed solutions and the corresponding effluent samples which were determined eleven times during the investigation (Tables C5 and C6, Appendix C). Figure 5.19 shows the percentage reduction in TSS with respect to soil depth. It is interesting to note that in three sampling ports out of seven the levels of TSS in the effluent were higher than the TSS levels in the feed solutions. Only two sampling ports at 700 and 800 mm respectively, showed any appreciable amount of reduction. One of the reasons for sampling ports at the bottom end of the tank exhibiting high TSS concentrations in their effluents may have been the presence of washed out cells from the denitrification zones. Samples collected from both the depths of 900 and 1000 mm showed a higher ratio of VSS than those obtained in the other samples as well as in the influent. This may have been caused by the presence of microorganisms which contributed to the increase of VSS content of the samples. This was also observed in the soil column study (Table 5.11, p.105). A similar phenomenon was also reported by Laak (42) in his recent study.

Chemical Oxygen Demand

Subsequently the percentage reductions of COD at various depths have been computed and are given in Table 5.18.

Table 5.17. Variation of Suspended Solids with Soil Depth in the Tile Field

Feed solution			Soil depth (mm)	Percolate			Reduction of TSS (%)
TSS (mg/L)	VSS (mg/L)	$\frac{VSS}{TSS} \times 100$ (%)		TSS (mg/L)	VSS (mg/L)	$\frac{VSS}{TSS} \times 100$ (%)	
33	21	64	1000	53	38	72	-60
			900	36	26	72	-10
			800	26	17	65	-21
			700	24	14	58	27
			600	34	16	47	-30
			500	31	16	52	6
			400	32	16	50	3

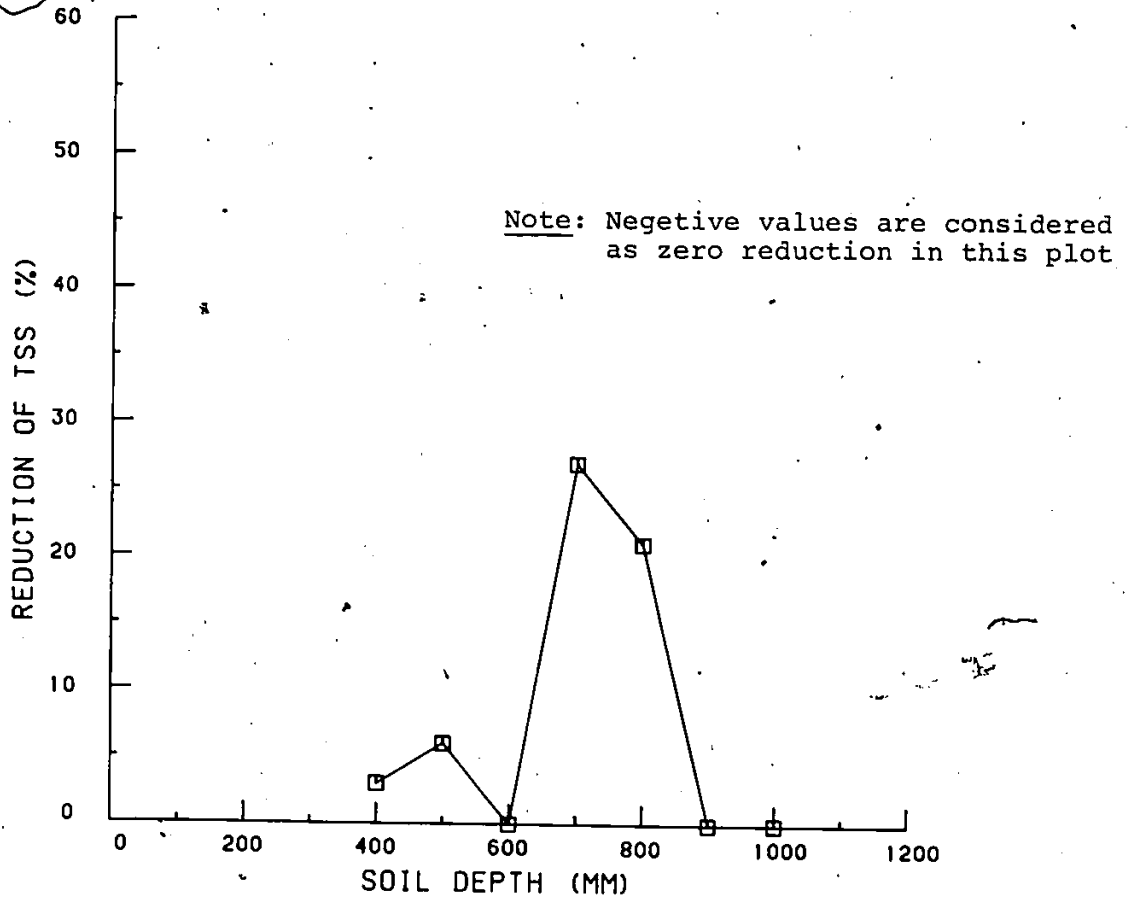


Fig. 5.19. Reduction of TSS at Various Depths in the Tile Field

Table 5.18. Reduction of COD at Various Depths in the Tile Field

Date	COD in feed solution (mg/L)	Percentage reduction of COD (%)						
		1000 mm soil depth	900 mm soil depth	800 mm soil depth	700 mm soil depth	600 mm soil depth	500 mm soil depth	400 mm soil depth
5/2/81	210	63	60	62	52	43	50	29
12/2/81	130	75	69	71	60	59	48	54
19/2/81	180	74	69	73	68	62	54	56
26/2/81	150	71	63	60	55	48	43	36
5/3/81	210	84	80	76	70	65	64	66
12/3/81	250	85	79	81	71	62	78	69
19/3/81	170	72	62	69	55	61	46	41
26/3/81	180	76	78	68	74	60	64	57
2/4/81	130	75	77	65	60	48		
9/4/81	200	70	72	56	50	57		
16/4/81	260	85	83	72	63	65		
23/4/81	210	71	72	64	73	71		
4/6/81	165	21	55	55				
11/6/81	250	76	71	66				
18/6/81	130	72	69	63				
25/6/81	180	79	81	78	67			
2/7/81	200	80	76	72				
9/7/81	210	82	84	75	83			
16/7/81	170	77	77	74	73			
23/7/81	150	65	75	71	73			
Mean		73	72	69	65	58	56	51

Tables C4 and C5, Appendix C, show the levels of COD in the feed solutions and the percolates respectively, analyzed during the investigation from which the percentage reductions have been calculated. Reduction of COD was achieved from the first week and by the second week of operation the removal rate was almost consistent at all depths. No results were obtained during the month of May, 1981, when the system was unstable. Samples collected in the first week of June, 1981 showed high levels of COD in all the samples, especially at 1000 mm and consequently resulted in poor reduction of COD. The mean values are calculated and plotted against soil depth in Figure 5.20. All the samples show more than 50 percent reduction of COD. It is evident that most of the reductions took place in the top part of the soil. For example, at 700 mm the removal was 65% whereas at 1000 mm the percentage reduction increased only by 8%. However, the high reduction (90%) of COD obtained during the soil column studies (Figure 5.11, p. 105) was not achieved in the tile installation even at a much deeper soil zone.

Dissolved Oxygen

The dissolved oxygen in the percolates varied between a low value of 1.6 mg/L and a high value of 6.4 mg/L (Table 5.19). During the first three weeks of operation, DO contents in all the samples were higher than 4.0 mg/L. However, an appreciable drop in DO levels was observed after the third week in samples collected below 700 mm. Variation of DO with soil depth is shown in

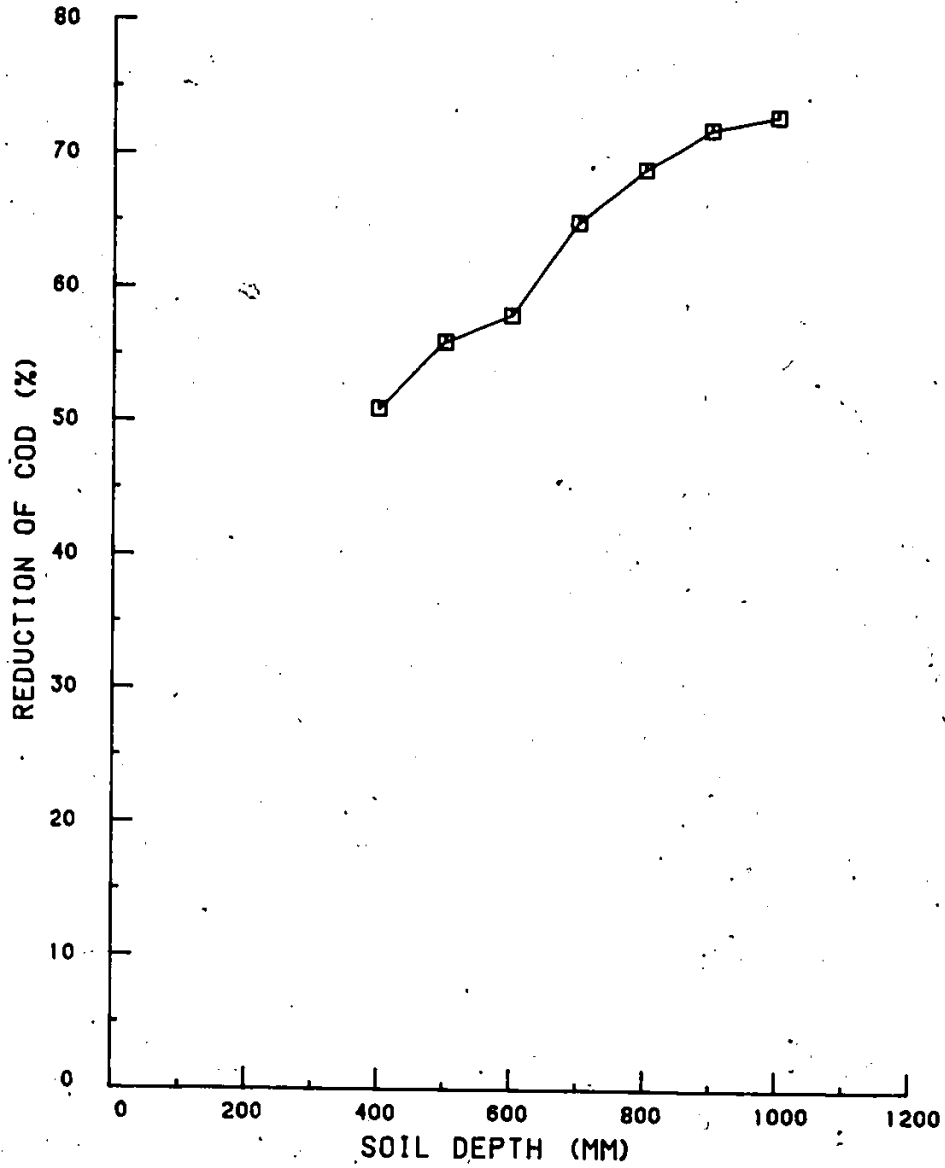


Fig. 5.20. Mean Removal of COD in the Tile Installation at Various Depths

Table 5.19. Dissolved Oxygen Concentration in the Tile Field at Various Depths

Date	Dissolved oxygen in feed solution (mg/L)	Dissolved oxygen in percolates (mg/L)						
		1000 mm soil depth	900 mm soil depth	800 mm soil depth	700 mm soil depth	600 mm soil depth	500 mm soil depth	400 mm soil depth
5/2/81	7.8	5.2	5.6	6.0	5.8	6.6	6.4	6.3
12/2/81	7.9	5.0	5.0	4.8	5.6	5.8	5.7	5.6
19/2/81	7.9	4.2	4.7	4.5	5.4	5.8	5.0	5.0
26/2/81	7.8	2.8	3.1	2.9	3.2	3.0	4.9	4.9
5/3/81	7.8	1.7	1.7	2.0	2.3	2.6	5.1	5.0
12/3/81	7.8	2.0	1.9	2.3	2.4	2.8	3.8	4.6
19/3/81	7.9	1.8	2.4	2.4	2.5	2.9	4.7	3.9
26/3/81	7.8	1.6	2.1	2.2	2.4	3.0	3.9	4.2
2/4/81	7.7	1.8	2.1	2.6	2.8	3.6		
9/4/81	7.9	2.2	2.1	2.8	3.0	4.1		
16/4/81	7.9	2.0	2.3	2.8	3.1	4.3		
23/4/81	7.8	2.3	2.7	3.1	3.3	4.3		
4/6/81	7.6	2.7	2.7	2.8				
11/6/81	7.8	2.6	2.7	3.1				
18/6/81	7.8	2.1	2.4	2.9				
25/6/81	7.9	2.1	2.1	2.9	3.2			
2/7/81	7.7	1.9	2.2	2.7				
9/7/81	7.8	2.0	2.0	3.1	3.0			
16/7/81	7.8	2.1	2.3	2.7	3.3			
23/7/81	7.8	2.4	2.3	2.7	3.4			
Mean		2.5	2.7	3.1	3.5	4.3	4.9	4.9

Figure 5.21 where the DO levels are the mean values for respective depths. It is of interest to note that the lowest mean value obtained was 2.5 mg/L at the depth of 1000 mm, where the nitrate removal was on the order of 79 percent. Effects of a relatively high oxygen concentration on nitrate removal in the feed solution and in the tile bed were not significant.

Residual Soluble Organic Carbon

The residual SOC was found to be present in all the samples. The results are tabulated in Table 5.20. It can be seen that even during the early periods of the investigation when the nitrate removal rates were low, the residual SOC levels were only a fraction (less than 20 percent) of the applied amount which is similar to the values obtained in the soil columns (Figure 5.14). The overall mean values are plotted against soil depth in Figure 5.22. The rate of decline was fairly sharp at the beginning for shallow depths and was reduced for large depths. Beyond 700 mm this rate was fairly constant.

5.2.2 Denitrification Below and Above the Water Table

Figures 5.23 to 5.25 show mean values of nitrate removal and the corresponding mean dissolved oxygen levels for the three different water table levels used in the study. These figures have been prepared from the data which are shown in Table D11, Appendix D. This Table also gives the mean values of nitrate removal and corresponding levels of dissolved oxygen.

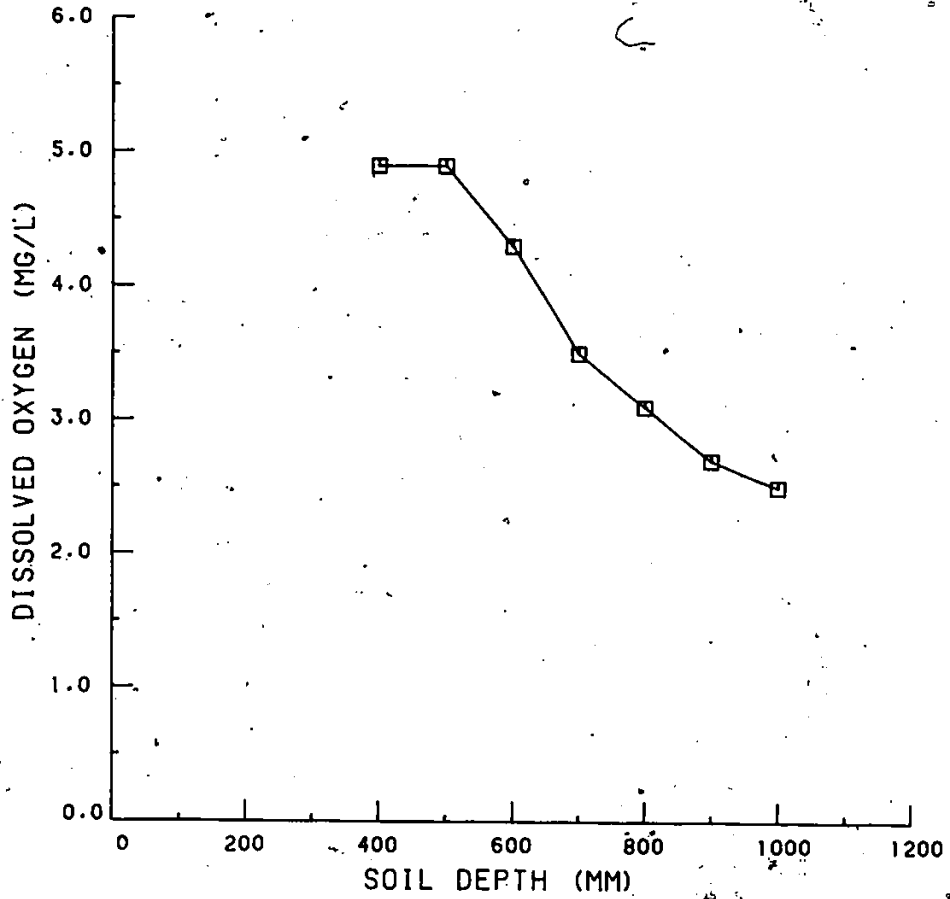


Fig. 5.21. Mean Variation of Dissolved Oxygen in the Tile Installation at Various Depths

Table 5.20. Mean Variation of Residual SOC with Depth and Time

Date	Residual SOC						
	1000 mm soil depth (mg/L)	900 mm soil depth (mg/L)	800 mm soil depth (mg/L)	700 mm soil depth (mg/L)	600 mm soil depth (mg/L)	500 mm soil depth (mg/L)	400 mm soil depth (mg/L)
19/2/81	7.0	8.4	11.2	13.4	15.2	14.6	15.8
26/2/81	5.2	6.8	7.2	7.0	8.4	10.2	10.6
5/3/81	4.0	6.6	8.2	8.4	11.0	10.8	11.6
12/3/81	5.4	5.0	7.2	7.6	8.0	8.2	10.8
19/3/81	4.2	5.6	6.8	6.8	7.6	9.4	8.0
26/3/81	5.0	6.0	5.8	7.6	8.2	8.6	10.4
2/4/81	3.4	4.2	4.8	6.2	6.6		
9/4/81	4.0	5.2	5.8	7.4	8.2		
16/4/81	4.6	6.2	5.8	7.0	8.2		
23/4/81	5.2	5.4	6.4	6.8	8.0		
4/6/81	10.0	8.2	8.4				
11/6/81	4.8	5.2	5.6				
18/6/81	4.4	5.0	5.2				
25/6/81	4.0	4.2	4.8	5.4			
2/7/81	4.0	4.0	5.2				
9/7/81	3.8	4.2	4.6	5.0			
16/7/81	4.2	4.2	4.8	5.0			
23/7/81	3.8	4.0	4.2	4.2			
Mean	4.8	5.5	6.2	7.0	8.9	10.3	11.2

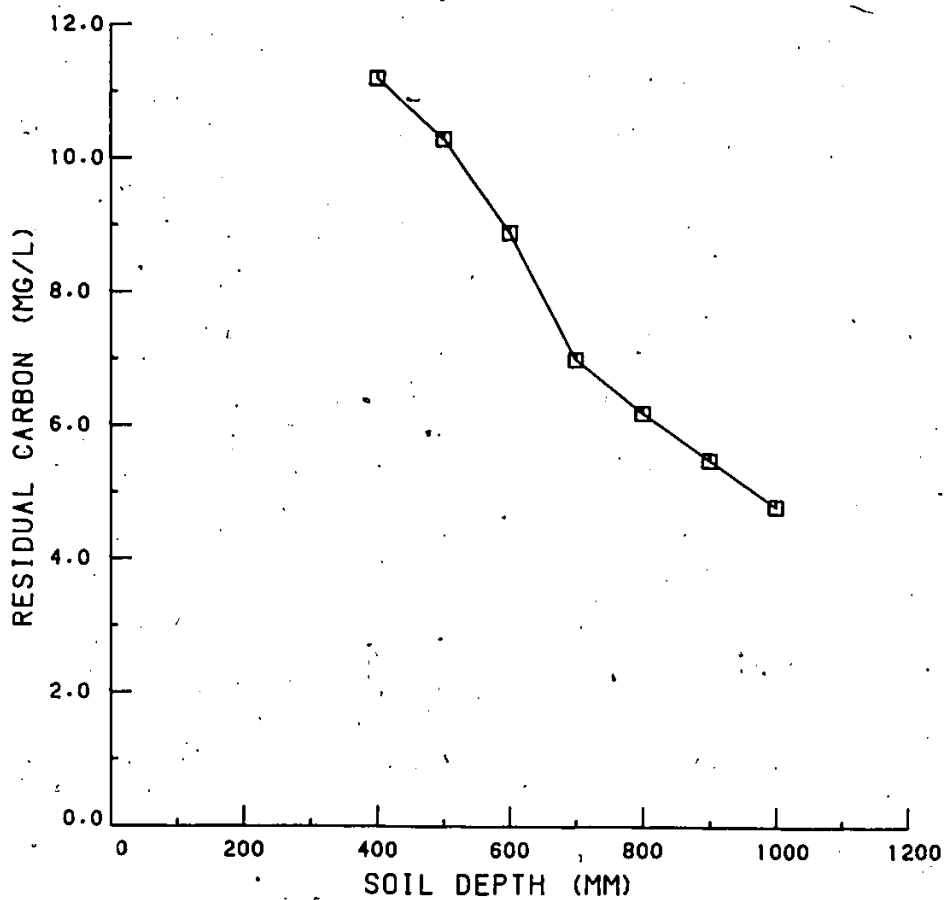


Fig. 5.22. Mean Variation of Residual Soluble Organic Carbon in the Tile Field at Various Depths

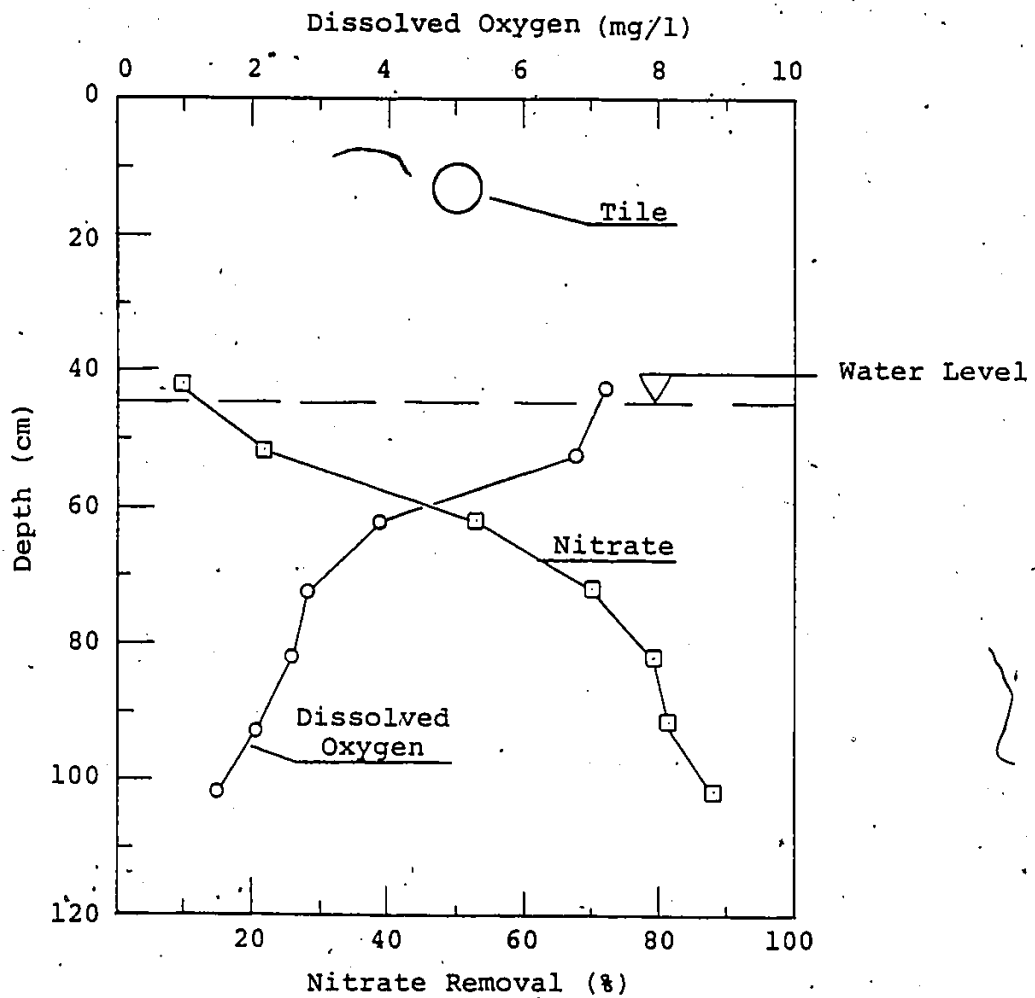


Fig. 5.23. Nitrate Reduction and Dissolved Oxygen Content in the Tile Field at Various Depths.

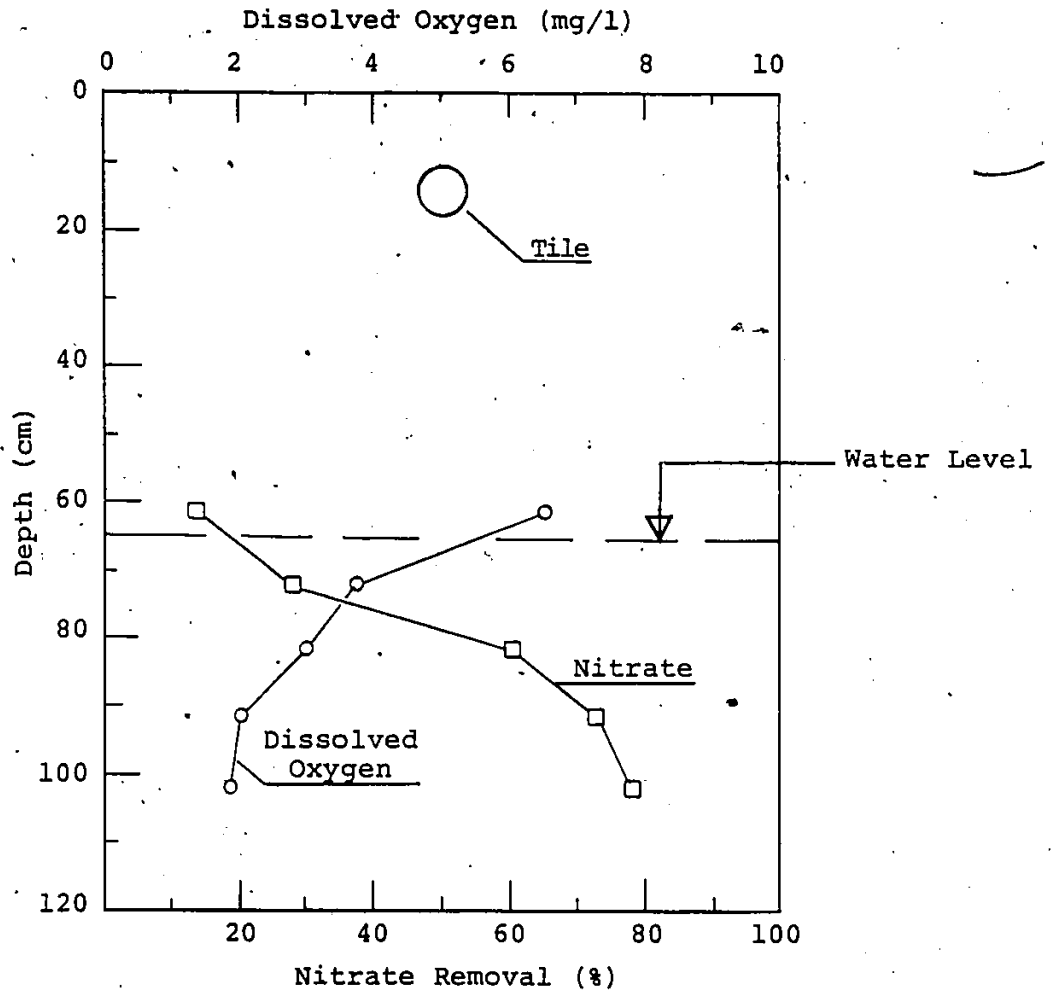


Fig. 5.24. Nitrate Reduction and Dissolved Oxygen Concentration at Various Depths in the Tile Field.

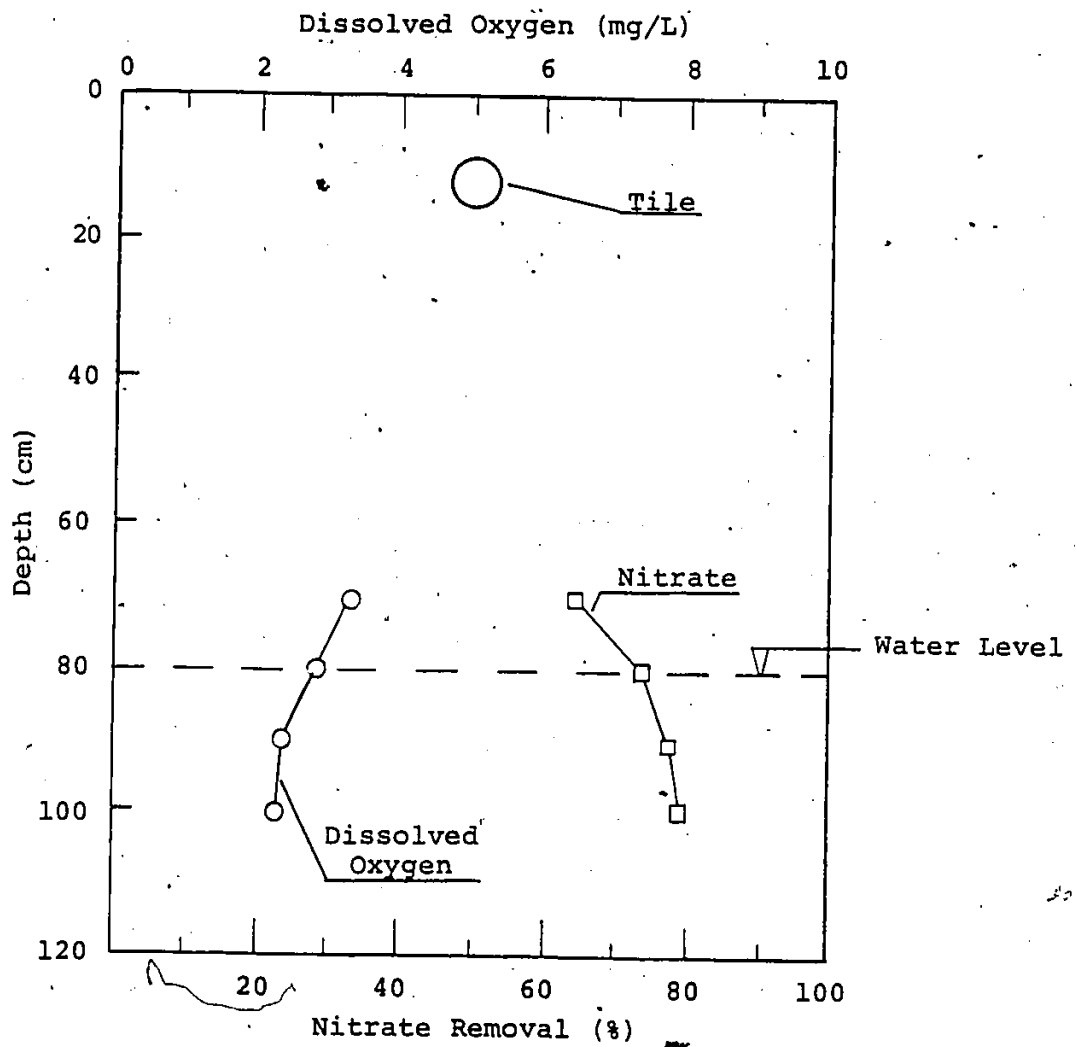


Fig. 5.25. Nitrate Reduction and Dissolved Oxygen Content in the Tile Field at Various Depths

concentrations for specific time period and groundwater depth, which have been calculated from Tables 5.14 and 5.19 respectively.

As expected, at shallow depths the concentrations of dissolved oxygen were higher and the concentrations decreased as the soil depths increased. In general, removal of nitrate was also high at a depth where oxygen concentrations were low. More than 60 percent nitrate removal was obtained when the depth of soil was equal to or more than 700 mm. At a sampling point 700 mm below the soil surface and for a water submergence of 250 mm (Figure 5.23) the nitrate removal was 71 percent, whereas for a submergence of 50 mm of water (Figure 5.24) the same sampling point exhibited 64 percent of nitrate removal. The dissolved oxygen concentrations were 2.6 and 3.0 mg/L respectively. The maximum level of nitrate removal was 81 percent at a depth of 1000 mm with a water submergence of 550 mm. At the same depth this value decreased only by 2 percent when the level of submergence was reduced to 200 mm, which means that the effect of water submergence on denitrification at a depth of 1000 mm was not significant. However, the level of nitrate removal is greatly reduced at depths lower than 700 mm. For example, at a depth of 600 mm and with a water submergence of 150 mm, the nitrate removal was only around 45 percent. Therefore, it is clear that for the tile installation which was used in this study, a soil depth of 700 mm is needed to obtain more than 60 percent nitrate removal.

In contrast a much higher level of denitrification was obtained during the soil column study (Figures 5.7 and 5.8) even at shallower depths. The oxygen concentrations found during the column study (Figure 5.11) were also lower than those found in the tile study. A higher water table did influence the dissolved oxygen concentrations in the tile bed; however, oxygen diffusion through the soil in the bed must have been fairly high. The gas collectors, the loading pipe and the top surface of the tile bed, all were exposed to the atmosphere and together these must have enhanced the aeration process. As a result, the levels of nitrate removal were lower than the values obtained from the column study.

Moisture content determination at various sampling points was not carried out during the investigation. However, it would appear that all the sampling points considered so far, with the exception of numbers 9 and 10 at the depth of 700 mm when the water table was at 800 mm, were in the saturated zone at all times. The percolates were collected without any external suction from these points. During the last part of the study when the water table was at 800 mm, on four occasions it was possible to collect sufficient amount of samples from ports 9 and 10 with the help of external suction. Suction was used within two hours after the completion of the loading operation and sometimes continued for more than two hours. This was different from the standard time of collection of one hour used for all other sampling points. Ordinary rubber bulbs and hand pumps were used

to provide the suction. As mentioned before, one of the objectives of this study was to determine the level of denitrification above the groundwater level in the unsaturated zone. Unfortunately only points 9 and 10 which might have been in the unsaturated zone, yielded any appreciable amount of sample. Other sampling points situated in the unsaturated zone did not produce the amount required for the analyses.

The environmental conditions for successful denitrification at these unsaturated locations were believed favourable with the possible exception of moisture content. Therefore, additional tests for moisture content were carried out at depths of 500, 600 and 700 mm respectively after the completion of the denitrification study. These moisture content tests are described as follows.

The exact loading operation as described in Chapter 4, p. 47 was followed with the exception of the feed solution which was replaced by tap water. Without disturbing the soil profile, three holes were made along the side of the tank to obtain soil samples from the aforementioned depths. Rubber stoppers were used to seal these openings during the loading operation. The water table was maintained at 800 mm. The soil samples were taken from the approximate centre of the tile bed with the help of an auger fitted into a 20 mm open tube long enough to reach the centre of the bed.

The loading was carried out at the rate of $80 \text{ L/m}^2/\text{d}$

and it took almost an hour to complete. The collection of soil samples did not start until an hour had elapsed after the completion of the loading operation. After that, two more samples were collected from each soil depth at every hour for the next two hours. This sampling procedure was repeated every day for six days and the moisture contents obtained are shown in Table A2, Appendix A. From these data mean moisture contents and the respective air-filled porosities have been calculated and are given in Table 5.21. Sample calculations for water content by volume and the respective air-filled porosity are shown in Appendix A. For the soil used in the study, the porosity was found to be 37% (Appendix A). Therefore, from Table 5.21 it is clear that all the sampling points were in the unsaturated zone including those at 700 mm (the Level of Sampling points 9 and 10) depth. At a depth of 500 mm, the moisture content was only 54% of the saturation value one hour after the end of loading. Both depths of 600 and 700 mm exhibited very high levels of moisture content after one hour. These values decreased in the subsequent sampling. Nault (59) carried out a field study where, in a mound type disposal system, the tile was placed in a sand fill and was loaded at the approximate rate of $40 \text{ L/m}^2/\text{d}$. Three cycles of dosing were used. A Neutron Probe was used to measure the soil moisture content throughout the cross-section of the bed and Nault reported a uniform distribution of high moisture content (over 33% by volume) over a period of four hours. The saturation value for the soil was 39% by volume. Due to the

Table 5.21. Mean Moisture Content and Air-filled Porosity in the Tile Bed at Various Depths

Soil depth	1 hr. after end of loading		2 hrs. after end of loading		3 hrs. after end of loading	
	Mean moisture content	Air-filled porosity	Mean moisture content	Air-filled porosity	Mean moisture content	Air-filled porosity
(mm)	(%)	(%)	(%)	(%)	(%)	(%)
500	12	20	17	15	22	10
600	17	28	8	13	15	17
700	19	32	6	16	10	20

Note: Air-filled porosity (%) = $(1 - \frac{\text{percent saturation (\%)}}{100}) \times \text{porosity (\%)}$

Sample calculations are given in Appendix A.

presence of a high groundwater table, moisture determination was restricted to a depth of about 600 mm only. However, these high levels of moisture content were not duplicated in this study especially at shallow depths and after a time of two hours from the completion of loading operation. Other environmental conditions e.g., rainfall, snow cover, groundwater fluctuation, which are associated with field studies may have contributed to these high levels.

Air-filled porosity is directly related to moisture content in the soil and Pilot (68) considered this as a governing factor for denitrification and reported some critical values for three different soils. He found that, for coarse textured Crevasse soil, medium textured commerce soil and moderately fine textured Mhoon soil, air-filled porosities of 11, 12 and 14 percent, respectively were high enough to prevent denitrification. Values lower than these had no effect on the denitrification process. Table 5.21 shows that, in this study, the air-filled porosity at a depth of 700 mm after an hour of loading was very low (6%) and increased to only 10 percent after two hours. Although, no critical value of air-filled porosity was determined for this soil, these low values are believed to show that the denitrification process was not inhibited at this level. Furthermore, at this depth the voids in the soil will contain a higher ratio of nitrogen to oxygen as compared to atmospheric air due to the denitrification taking place. This will affect the critical value of air-filled porosity. It is believed that

the moisture content at the 700 mm level was not critical to the denitrification process. Rather, it is felt that, since the percent nitrate removal at this level was not greatly different for the three water table levels, the degree of denitrification was dependent upon the diffusion of oxygen and the amount of organic carbon supplied.

5.3. Rate of Nitrate Removal with Time

From previous discussions it appears that there may be a certain time lapse after the end of the loading operation, after which parts of the denitrification bed may contain less than the critical amount of moisture needed for successful denitrification. Also, diffusion of oxygen into the unsaturated areas may hinder denitrification. In the present study, it appeared that at a depth of 700 mm sufficient moisture was present for at least two hours. The level of nitrate removal between April 2, 1981 and July 23, 1981, as indicated by the actual samples from this depth was in the order of 64% (Table D11, Appendix D, p. 267). The actual rate of nitrate removal with time in the tile bed could not be determined, and, therefore, a direct comparison was not possible. However, further investigations were carried out using soil columns to observe the nitrate removal rate with time.

Investigations were performed at 22°C with one soil column packed with soil (as described in Chapter 4, p. 39) to a

level of 450 mm. A ratio of 4:1 carbon to nitrate nitrogen ratio was used in the feed solution where the level of nitrogen was 25 mg/L as N. Five different levels of residence time were chosen; they varied from one to five hours with equal increments of one hour. Altogether 5 samples were collected for each time period and were analyzed for both nitrate and nitrite nitrogen. The soil column was saturated with the feed solution before the experiment began. After the third sample was collected the column was drained completely and the whole loading procedure was repeated for the next two samples which had residence times of four and five hours respectively. This was necessary because the soil column did not contain enough sample for the required tests.

The entire experiment was repeated three times and the results are shown in Table 5.22. Nitrite was not detected during this study. Mean values of nitrate remaining at any time period were used in the calculation of the reaction rate (Table 5.22). The reaction rate varied from -0.58 hr^{-1} to -0.42 hr^{-1} and the average value was found to be -0.49 hr^{-1} . A slightly higher reaction rate was obtained during the early part of the experiment and the values were very closely spaced thereafter. Figure 5.26 shows the graphical representation of nitrate removal with time. This depicts a curvilinear relationship.

The average value of remaining nitrate nitrogen concentration was in the order of 9 mg/L after two hours of

Table 5.22. Change in Nitrate Concentration with Time in a 450 mm Soil Column at 22°C (C:N = 4:1).

Time (hr)	NO ₃ -N remaining (mg/L)	Mean NO ₃ -N for each time period (mg/L)	Ratio of NO ₃ -N at any time to initi- al conc.	ln ratio	Reaction rate (hr ⁻¹)	Average reaction rate (hr ⁻¹)
0	25	25	1	0	-	
	13					
1	17	14	0.56	-0.58	-0.58	
	12					
	10					
2	8	9	0.36	-1.02	-0.51	
	9					
	6					
3	8	6	0.24	-1.43	-0.48	-0.49
	4					
	3					
4	6	4	0.16	-1.83	-0.46	
	3					
	4					
5	3	3	0.12	-2.12	-0.42	
	2					

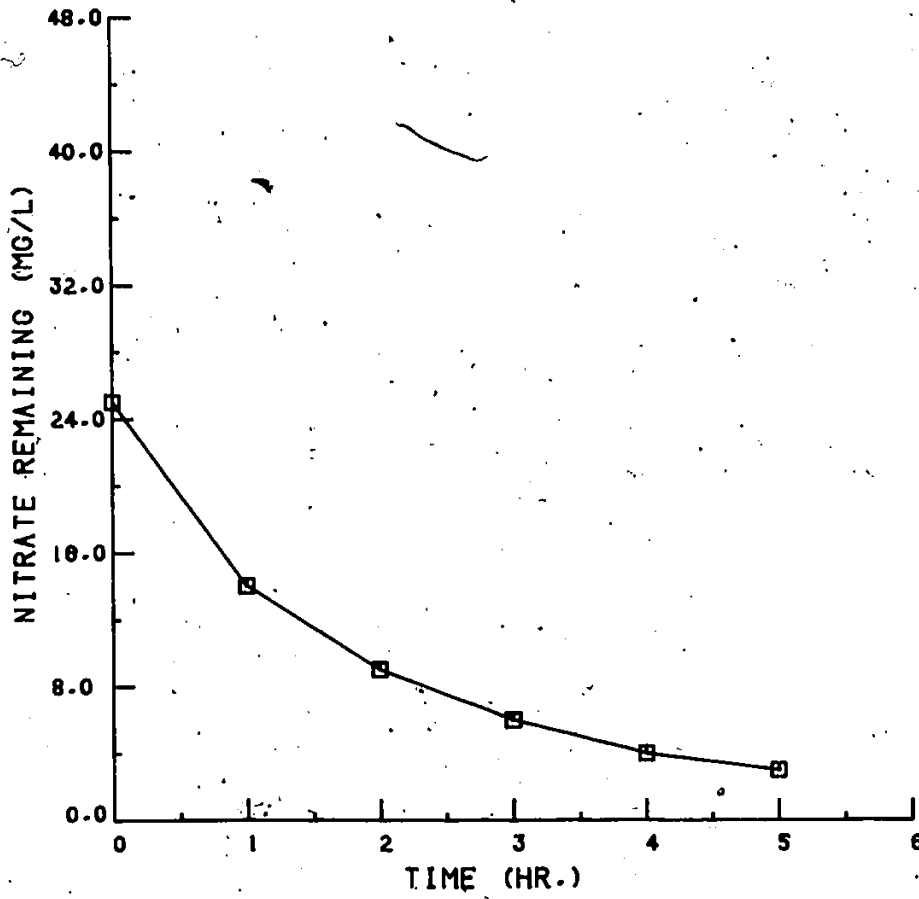


Fig. 5.26: Reduction of Nitrate Nitrogen with Time at 22°C (C:N = 4:1)

reaction time. This is a removal of 64 percent considering the initial concentration of 25 mg/L. Smith et al (77) observed much faster reduction of nitrate in a shorter contact time. He reported over 80 percent reduction within a fraction of an hour. Other higher values have also been reported in the literature (35). However, these values cannot be compared with the results obtained during this study because of the differences in feed solution characteristics and other environmental conditions. Therefore, it can be concluded from the present study that the denitrification process is not a slow process, and over 60 percent removal of nitrate can be obtained within a period of two hours in a tile bed if the environmental conditions are favourable for the microorganisms.

5.4. Consumptive Ratio

McCarty et al (54) referred to the ratio of the requirement for methanol to that required for nitrogen removal and deoxygenation as consumptive ratio, C_r , given by the relationship:

$$C_r = \frac{\text{Total filterable organic carbon utilized}}{\text{Filterable organic carbon required for denitrification and deoxygenation}}$$

If nitrate, nitrite and oxygen are reduced stoichiometrically by external sources of organic carbon, the consumptive ratio is equal to unity. However, a portion of the organic carbon is used for cell synthesis and therefore, the ratio is always

found to be greater than one. For various carbon sources
McCarty, et al, (54) listed observed C_r values (Table 5.23).

For kitchen waste, C_r was calculated as follows:

for C:N = 4:1, the percentage nitrogen removal

= 93% (Table 5.8, p.)

avg. residual SOC = 3.9 mg/L (Table D10, App. D)

avg. residual DO = 1.7 mg/L (Table C1, APP. D)

avg. DO in feed = 7.9 mg/L (Table C1, App. C)

$$\therefore C_r = \frac{100 - 3.9}{2.47(0.93 \times 25) + 0.87(7.9 - 1.7)}$$

$$= 1.53$$

It can be seen that the consumptive ratio (C_r) for kitchen waste is similar to those chemicals listed in Table 5.23, with the exception of sugar, which will produce a high quantity of biomass for the same degree of nitrate removal. This indicates that the use of kitchen wastewater in a subsurface denitrification process will not be expected to lead to any excessive biological growth, which may cause clogging of the soil.

Table 5.23 Consumptive Ratios for Various Sources of Organic Carbon (54)

Sources	Consumptive ratio C_r^*	Nitrogen removal (%)
Sugar	1.69	50
Acetate	1.31	83
Ethanol	1.47	96
Acetone	1.22	89
Kitchen Waste	1.53	93

$$*C_r = \frac{\text{Total filterable organic carbon utilized}}{\text{Filterable organic carbon required for denitrification and deoxygenation}}$$

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

6.1 Conclusions

The following conclusions can be drawn from this study involving the use of kitchen wastewater as the source of organic carbon in biological denitrification in soil:

1) A high level of denitrification was achieved using kitchen wastewater as a source of organic carbon in the soil columns consisting of four different depths (150 mm, 250 mm, 350 mm, 450 mm) of sandy soil and having a diameter of 50 mm. Over 90 percent removal of nitrate was possible when feed solutions contained C:N ratios of 4:1 (carbon expressed as methanol and nitrate concentration was 25 mg/L as N) or higher, for both the application rates of 200 mm/wk and 420 mm/wk respectively. A C:N ratio of 2:1 failed to produce more than 15 percent removal of nitrate.

Denitrification was also achieved in the model tile bed disposal system which was constructed by using the same soil in an open-top aluminium tank (2400x1200x1200 mm high) set up in the laboratory. The C:N ratio of the feed solution was 4:1 and three levels of water table were used. The loading rate was 80 L/m²/d. Disregarding any effect of the levels of water table, the maximum average nitrate removal

was 79 percent at a depth of 1000 mm. The lowest value was only 21 percent at a depth of 400 mm. This differs from the findings resulting from the soil column tests where over 80 percent removal of nitrate was obtained at a depth of 150 mm. This may be attributed to the fact that in soil columns, only a very small amount of surface area is exposed to the atmosphere. Thus, a more conducive environment for denitrification is produced in the columns as compared to the tile field when the large exposed surface area, vent pipes and the open pipe used for dosing contributed to an enhanced aeration process to a much greater depth.

2) Nitrite was not detected in the column effluents with the exception of those which were dosed with feed solutions containing less than 4:1 carbon to nitrogen ratios. However, nitrite did not appear to inhibit the denitrification process. For example, soil columns receiving 3:1 feed solution removed over 60 percent of the nitrate although nitrite was detected in the effluents consistently. In the tile installation where the C:N ratio was 4:1, nitrite was never detected even though at shallow depths the removal rates of nitrate were very low.

3) The denitrification process in the soil columns reached a steady state condition after two weeks of operation. In the tile installation this time lag was four weeks.

4) The depth of soil in a 50 mm diameter soil column was found to have very little effect on nitrate removal. In the saturated zone of the tile bed the levels of nitrate removal were significantly affected by the depth.

5) The increase in depth of water submergence in the tile bed did improve the level of nitrate removal in general. The effects were more pronounced at shallower depths. For example, at a sampling point 700 mm below soil surface and for a water submergence of 250 mm the nitrate removal was 71%; whereas with a submergence of 50 mm the same sampling point showed 64% nitrate removal. At a deeper sampling point (at 1000 mm) a drop in the level of water submergence of 250 mm showed only 2% decrease (from 81 to 79%) in the nitrate removal.

6) Due to the insufficient number of samples obtained from the unsaturated zone in the tile bed for the nitrate test, a conclusion on nitrate removal cannot be made. However, all the four samples collected at 700 mm produced over 60% removal of nitrate, with an average of 64%. The water table was at 800 mm. Moisture content by volume at 700 mm after 1, 2 and 3 hours of loading operation was 32, 27 and 20 percent respectively. The air-filled porosities were 6 and 10 percent for the first two hours at the same sampling point. These values are thought to be low enough to produce a conducive environment for successful denitrification.

7) The levels of TKN reductions were very similar in

both the columns and the tile bed. Maximum removal of TKN was around 50% of the influent concentration.

8) Reduction in COD increased with increase in soil depths for both the application rates in the soil column studies. However, for shallow soil depths, removal efficiencies were higher for the lower application rate. In the tile installation the removal of COD was found to be much lower than in the soil columns.

9) Presence of high dissolved oxygen concentration (over 7.0 mg/L) in the feed solution did not inhibit denitrification. This was true for both the soil column and the tile field. In soil columns higher C:N ratios and larger soil depths favoured reduction in DO concentration. Complete deoxygenation was never achieved. The lowest levels of DO for the soil columns and the tile field were around 1.0 mg/L and 2.5 mg/L respectively. The gas collector, the loading pipe and the comparatively larger soil surface in the tile bed were all open to the atmosphere and this would have enhanced the aeration process. The observed DO levels in the samples collected from the tile bed were slightly higher than those in the soil columns.

10) Alkalinity was produced during the denitrification process. The ratio of change in total alkalinity to respective levels of nitrate removal ranged from 2.44 to 3.03 in the soil columns and from 2.27 to 3.01 in the tile field respectively. These values are well below the theoretical value of 3.53 mg/L

as CaCO_3 . Complexity in the biological process and the production of CO_2 during excess COD oxidation (for high C:N ratios) may have been the reason for this discrepancy.

11) Soil columns receiving C:N ratios of 2:1, 3:1 and 4:1 respectively produced very low levels of residual SOC ranged from 4.8 to 11.2 mg/L for sampling points at 1000 mm and 400 mm respectively. For higher C:N ratios (5:1 and 6:1) used in the soil columns, the residual SOC levels were slightly higher (4 - 14 mg/L) than the lower ratios representing less than 20 percent of the excess applied SOC.

12) Reduction of TSS was not achieved in most of the soil columns with shallow depths of soil. A maximum reduction of 31 percent was obtained at a depth of 450 mm. An increase in TSS levels in the effluents were detected on many occasions, and a washing-out effect of microorganisms from the media may have contributed to these low reduction levels which were also noticed in the tile bed effluents. The observed reductions of TSS in the tile bed ranged from 3 to 27 percent.

13) The levels of pH in the treated effluents ranged from 6.8 to 7.6 and were found to be suitable to denitrification.

6.2. Recommendations for Further Research

Since the feed solution used in the tile field study contained only one level of carbon to nitrogen ratio (4:1), it is not possible to conclude that this ratio, using kitchen waste

as the source of organic carbon, is the optimum one for successful denitrification in a tile bed. Therefore, future studies using varying levels of carbon to nitrogen ratio should be carried out to establish an optimum value.

A full-scale field study on denitrification in a sub-surface disposal system without any denitrification chamber would be of interest. Kitchen waste could be used as the source of organic carbon for the denitrifiers. Nitrification of the ammonia can be achieved in a sand filter and this should be studied very carefully. The levels of low pH and requirements of oxygen in the nitrification study should be of interest. Effects of various environmental parameters on both nitrification and denitrification should be evaluated. These parameters include rainfall, temperature, snow cover etc. The effect of shock loading due to excess nitrate concentration or lack of necessary organic carbon on the overall denitrification process are also of interest.

Collection and analyses of gases produced during a controlled denitrification study would be very useful. This would help in carrying out a nitrogen balance for a given soil.

Detailed study on level of denitrification in unsaturated soil at various moisture concentrations should be carried out. This study should be undertaken for different soil types and for each soil type a typical characteristic curve

showing nitrate removal against moisture tension for fixed environmental conditions can be prepared. In this connection it would also be useful to know the composition of the gases present in the void spaces of the soil and the rates of oxygen diffusion to the soil depths.

Study of various denitrifying bacterial species, especially the predominant ones present during denitrification would be useful in obtaining the effect of different microbial populations on denitrification rates.

Denitrification, if carried out on a long term basis, may change the pH level in the soil. There may be a limiting value beyond which it may become inhibitory to the process and thus would force a change of disposal site. From a practical point of view this maximum value could be studied for different soils.

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APPENDIX A

SOIL ANALYSIS

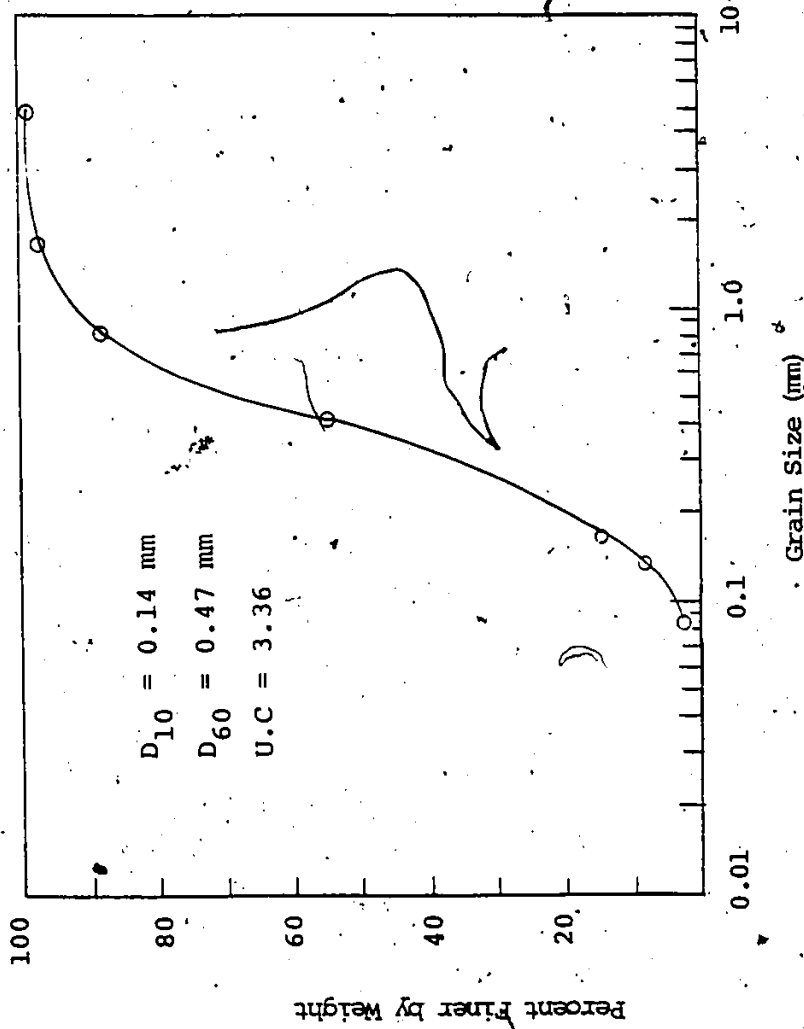


Fig. A1. Grain Size Distribution

Determination of Other Physical Properties of the Soil

The tests for the soil were carried out according to the Standard ASTM methods published by the American Society for Testing and Materials, U.S.A.

Minimum density	= 100 lbs/cft = 1.6 gm/cc
Maximum density	= 118 lbs/cft = 1.88 gm/cc
Density of an actual sample	= 104 lbs/cft = 1.66 gm/cc
Relative density	= 22%
Specific gravity	= 2.65
Porosity (%)	= 37%
At saturation	
water content by volume	= 37%
water content by weight	= $37/1.66 = 22.3\%$

Table A1. Physical Properties of Soil

Characteristics	Value
D ₆₀	0.46 mm
D ₁₀	0.14 mm
Uniformity Coefficient	3.36
Effective Size	0.14 mm
Density	1.66 to 1.88 gm/cc
Sp. Gravity	2.65
Porosity	37%
Saturated hydraulic conductivity	$.8.21 \times 10^{-3}$ cm/sec

Table A2. Moisture Content in the Tile Bed at Various Depths

Soil depth (mm)	No. of sample	Time of sampling after loading					
		1 hour		2 hour		3 hour	
		Moisture Content by wt. (%)	Moisture Content by vol. (%)	Moisture Content by wt. (%)	Moisture Content by vol. (%)	Moisture Content by wt. (%)	Moisture Content by vol. (%)
500	1	14	23	7	12	4	7
	2	12	20	11	18	9	15
	3	12	20	9	15	5	8
	4	8	13	11	18	7	12
	5	13	22	10	17	4	7
	6	10	17	7	12	8	13
600	1	17	28	14	23	9	15
	2	19	32	16	27	11	18
	3	18	30	12	20	7	12
	4	20	33	11	18	10	17
	5	16	27	13	22	12	20
	6	17	28	14	23	11	18
700	1	18	30	15	25	13	22
	2	19	32	17	28	12	20
	3	16	27	10	17	10	17
	4	21	35	16	27	13	22
	5	19	32	18	30	14	23
	6	20	33	17	28	11	18

Sample Calculations

- 1) Obtain water content (%) by volume for a sample from a given water content (%) by weight of 19%:

$$\text{porosity} = 37\%$$

$$\text{at saturation water content by weight} = 22.3\%$$

$$\begin{aligned} \therefore \text{percent water content by vol.} &= 37 \times 19 / 22.3 \\ &= \underline{32\%} \end{aligned}$$

- 2) Obtain air-filled porosity for the above sample:

$$\text{air-filled porosity} = \left(1 - \frac{\text{percent saturation (\%)}}{100}\right) \times \text{porosity}$$

$$\text{now, percent saturation (\%)} = 32 \times 100 / 37 = 85\%$$

$$\begin{aligned} \therefore \text{air-filled porosity (\%)} &= (1 - 0.85) \times 37 \\ &= \underline{5.6\%} \end{aligned}$$

APPENDIX B

CALIBRATION CURVES FOR VARIOUS PARAMETERS

Table B1. Calibration for Ammonia Using Ammonia Electrode
(Orion Model 95-10)

Standard Ammonia Nitrogen Concentration (moles/L)	Electrode Potential Reading (mv)
5×10^{-5}	17.9
1×10^{-4}	4.1
5×10^{-4}	-34.8
1×10^{-3}	-52.8
5×10^{-3}	-94.0

Table B2. Calibration for Nitrate Nitrogen Using Nitrate
Ion Electrode (Orion Model 93-07)

Amount of Nitrate Nitrogen in the Standard Solution (mg/L)	Electrode Potential Reading (mv)
0.28	-7.1
1.40	-43.9
5.00	-74.0
10.00	-93.0
14.00	-101.2

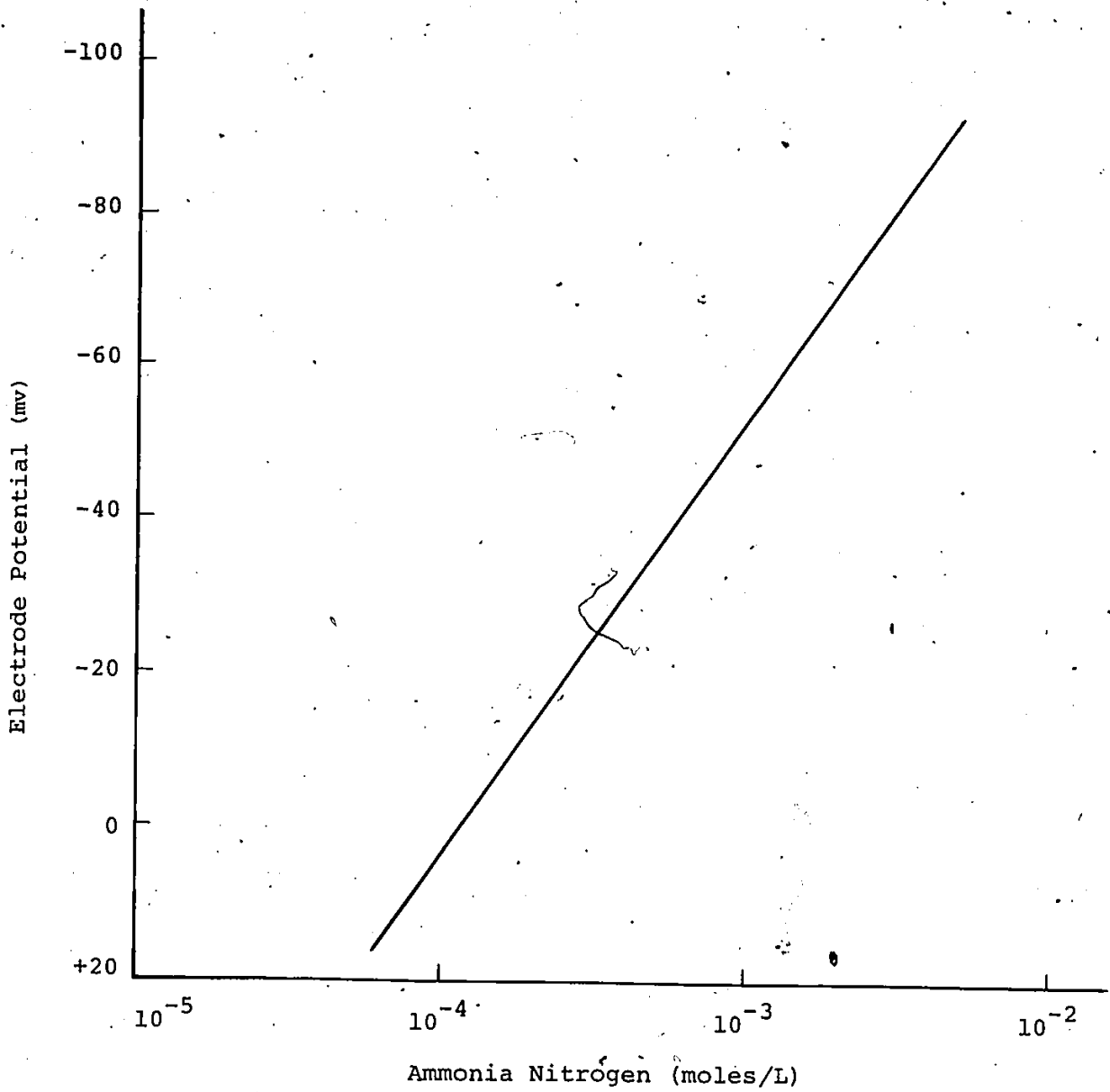


Fig. B1. Calibration Curve for Ammonia Nitrogen

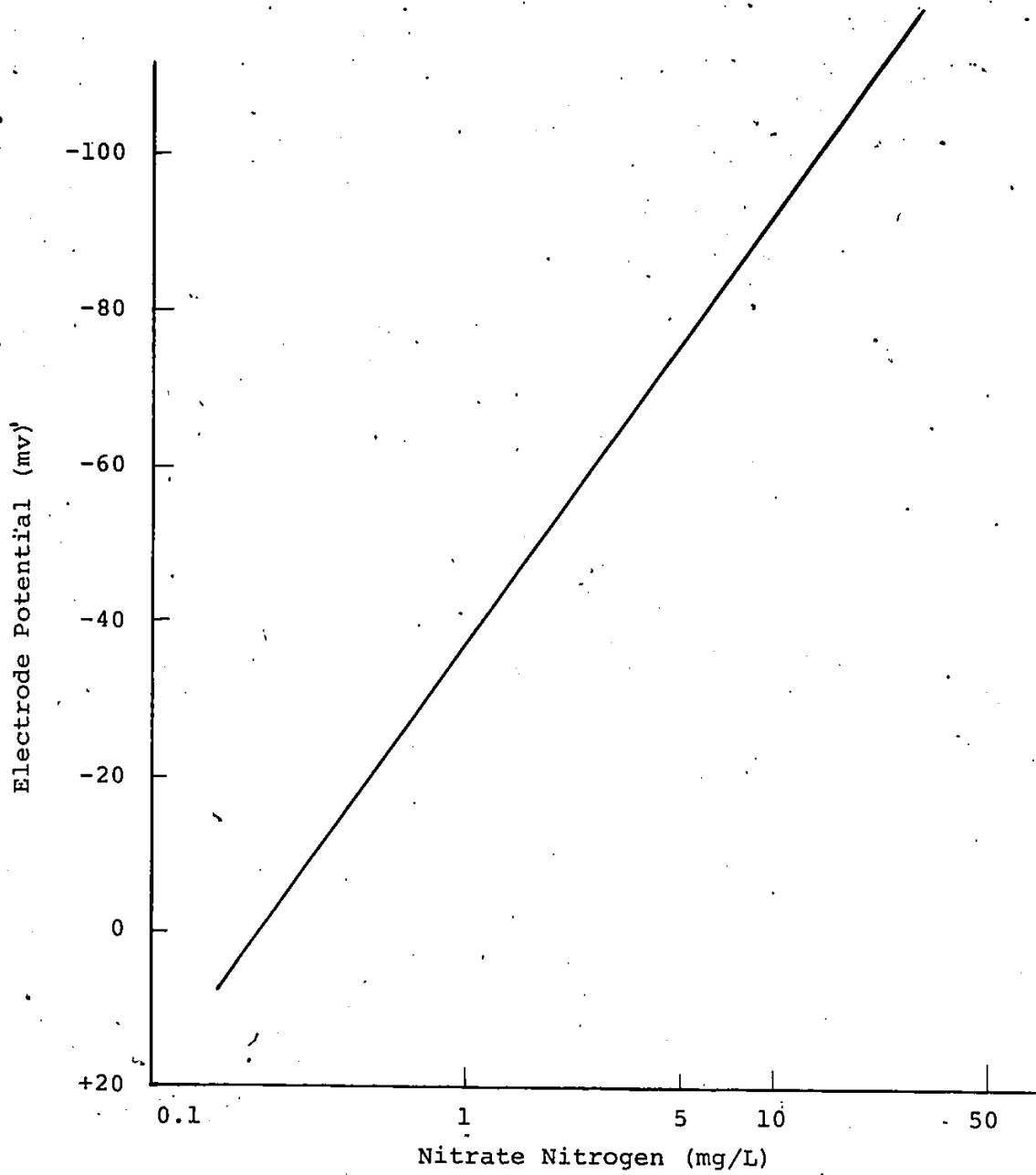


Fig. B2. Calibration Curve for Nitrate Nitrogen Using Nitrate Ion-Electrode (Orion Model 93-07)

Table B3. Calibration for Nitrate Nitrogen by Brucine Method

Amount of Nitrate Nitrogen in the Standard Solution (mg/L)	Absorbance
0.2	0.11
0.4	0.18
0.6	0.26
0.8	0.32
1.0	0.40
1.6	0.56
2.0	0.74

Table B4. Calibration for Total Carbon Analysis

Total Carbon in Standard Solution (mg/L)	Peak Heights
10	8
20	16
50	39
80	61

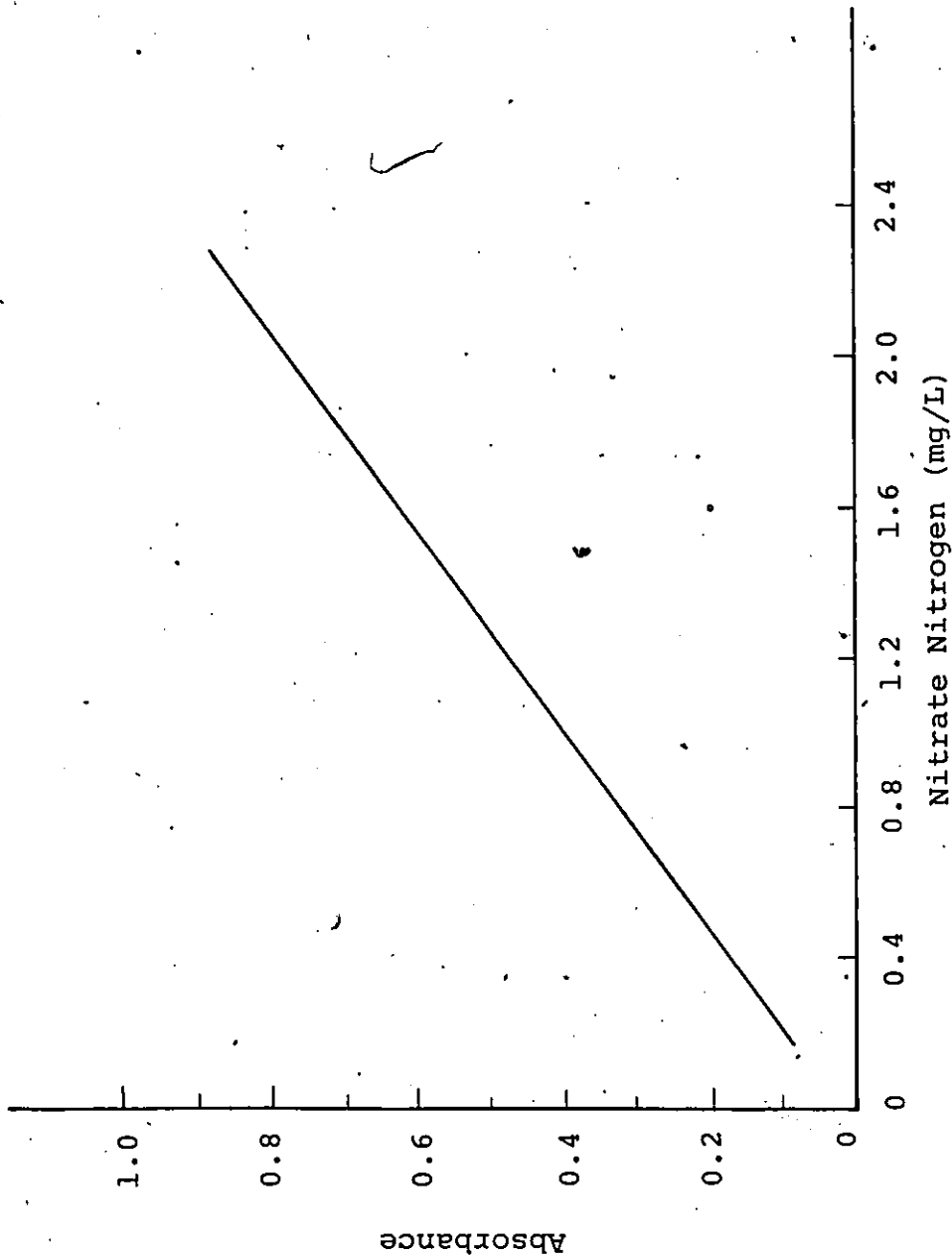


Fig. B3. Calibration Curve for Nitrate Nitrogen by Brucine Method

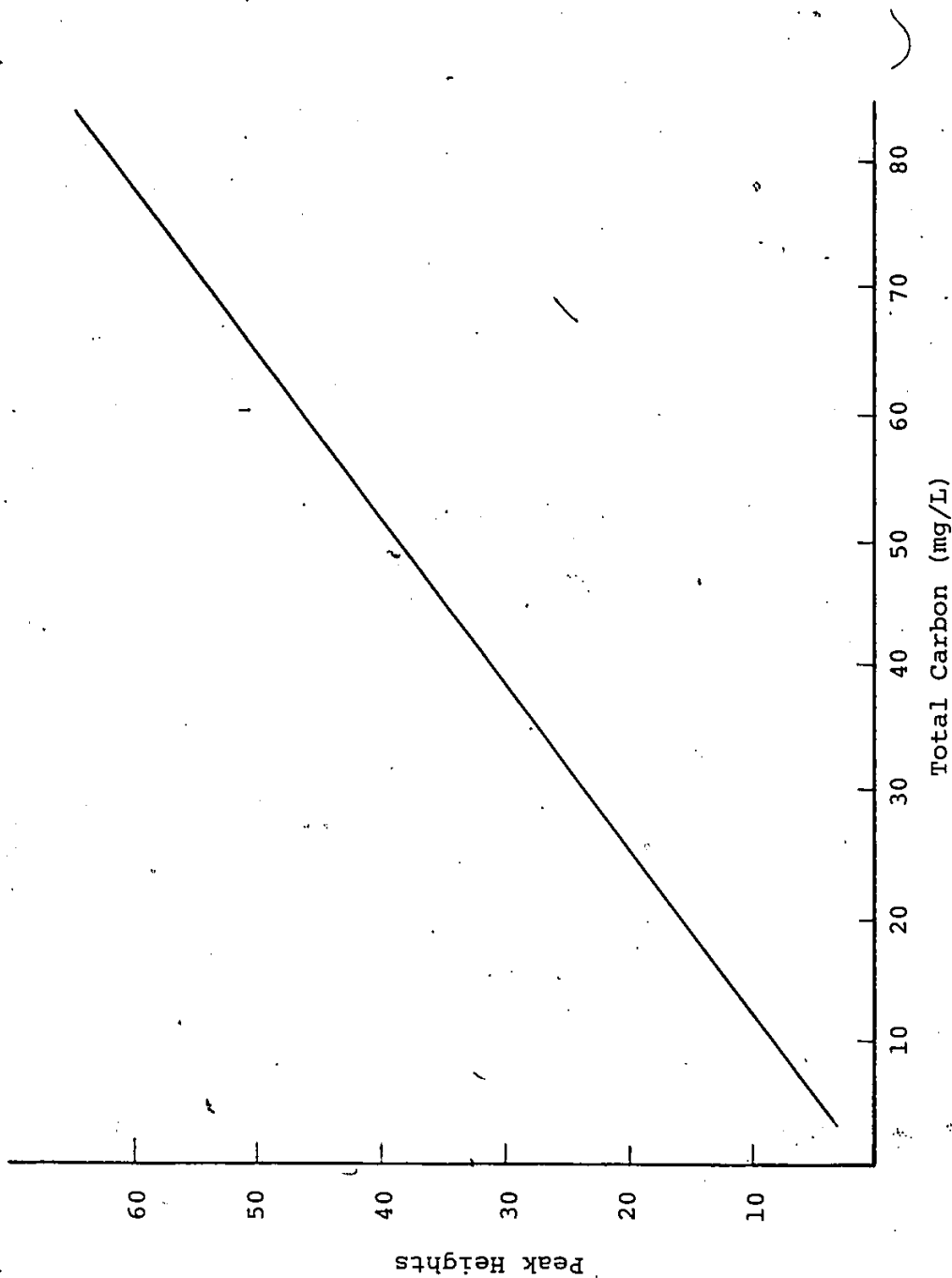


Fig. B4. Calibration Curve for Total Carbon Analysis

Table B5. Calibration for Inorganic Carbon Analysis

Inorganic Carbon in Standard Solution (mg/L)	Peak Heights
10	8
20	17
50	41
80	64

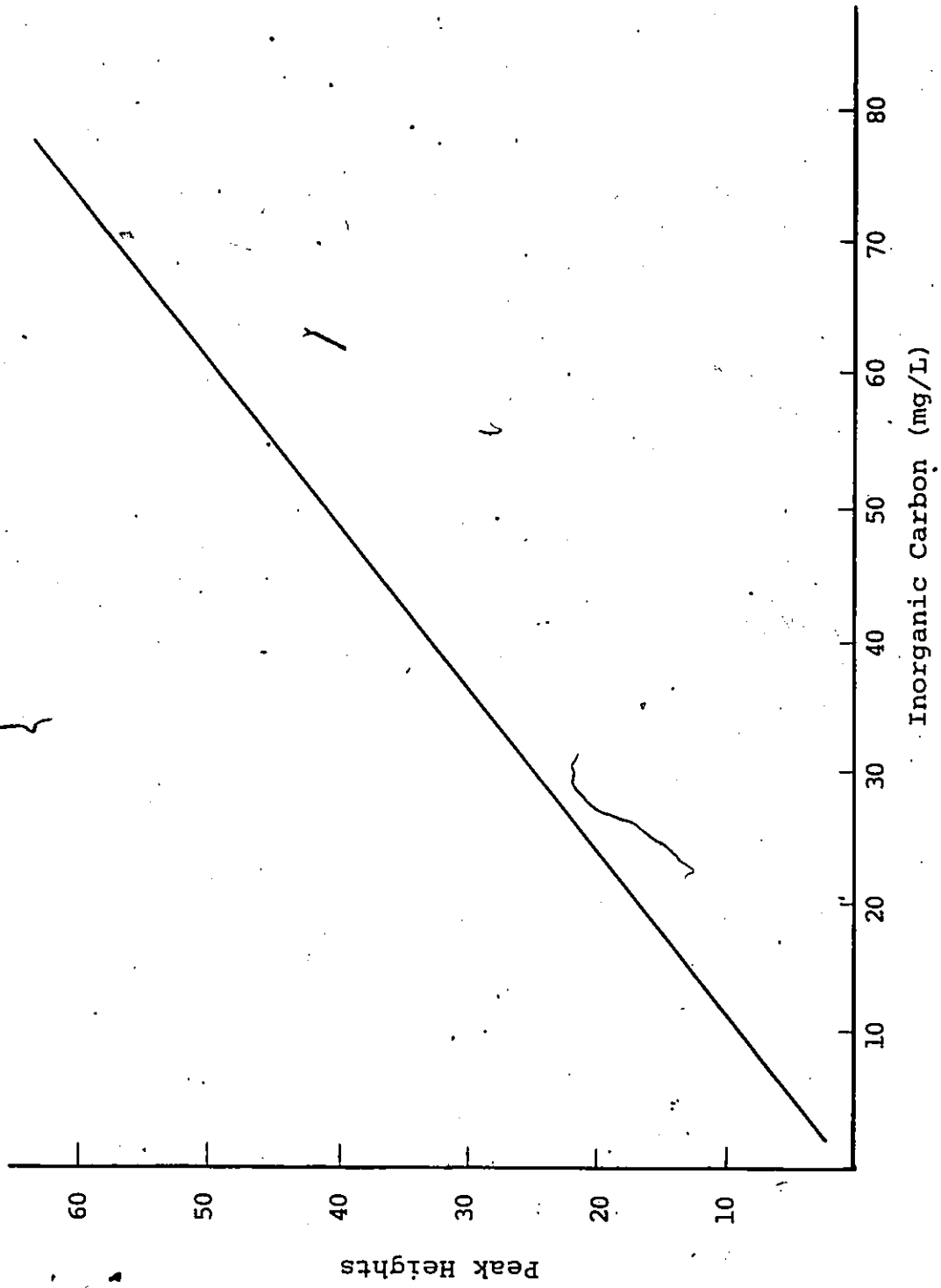


Fig. B5: Calibration Curve for Inorganic Carbon Analysis

APPENDIX C

CHARACTERISTICS OF FEED SOLUTIONS AND TREATED
EFFLUENTS BOTH FOR SOIL COLUMNS
AND TILE FIELD

Table C1. Characteristics of Feed Solutions Used In Soil Columns

Date	No.	C:N	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
30/06/80	1	2:1	6.7	-	90	0.0	0.0	25.0	-	7.9	-	-
	2	3:1	6.7	-	130	0.0	0.0	25.0	-	7.9	-	-
	3	4:1	6.7	-	180	0.0	0.0	25.0	-	7.9	-	-
	4	5:1	6.7	-	230	0.2	0.0	25.0	-	7.9	-	-
	5	6:1	6.7	-	270	0.3	0.0	25.0	-	7.9	-	-
07/07/80	1	2:1	6.8	-	40	0.0	-	25.0	-	8.0	-	-
	2	3:1	6.8	-	50	0.0	-	25.0	-	8.0	-	-
	3	4:1	6.8	-	70	0.0	-	25.0	-	8.0	-	-
	4	5:1	6.7	-	85	0.0	-	25.0	-	8.0	-	-
	5	6:1	6.7	-	100	0.0	-	25.0	-	8.1	-	-

- Tests were not done

K

Table C1. Characteristics of Feed Solutions Used In Soil Columns

Date	No.	C:N	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
15/07/80	1	2:1	6.8	60	65	0.0	-	25.0	2.8	7.8	22	10
	2	3:1	6.8	55	100	0.0	-	25.0	4.9	7.9	25	16
	3	4:1	6.8	60	120	0.0	-	25.0	6.3	7.9	36	25
	4	5:1	6.8	65	165	0.0	-	25.0	7.0	7.9	30	16
	5	6:1	6.8	65	195	0.0	-	25.0	9.1	7.9	35	24
23/07/80	1	2:1	6.7	50	65	0.0	-	25.0	3.5	8.0	-	-
	2	3:1	6.7	50	90	0.0	-	25.0	5.6	7.9	-	-
	3	4:1	6.7	50	130	0.0	-	25.0	7.7	7.9	-	-
	4	5:1	6.7	55	165	0.8	-	25.0	9.1	7.8	-	-
	5	6:1	6.8	55	200	1.0	-	25.0	10.5	8.0	-	-

'-' Tests were not done

Table Cl. Characteristics of Feed Solutions Used In Soil Columns

Date	No.	C:N	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
29/07/80	1	2:1	6.8	60	30	-	-	25.0	1.4	7.6	-	-
	2	3:1	6.8	60	40	-	-	25.0	1.4	7.7	-	-
	3	4:1	6.8	65	55	-	-	25.0	3.5	7.7	-	-
	4	5:1	6.8	65	70	-	-	25.0	3.5	7.7	-	-
	5	6:1	6.8	65	80	-	-	25.0	4.2	7.7	-	-
05/08/80	1	2:1	6.8	55	60	-	-	25.0	2.8	7.9	-	-
	2	3:1	6.7	55	80	-	-	25.0	4.2	7.8	-	-
	3	4:1	6.7	55	130	-	-	25.0	5.6	7.8	-	-
	4	5:1	6.7	60	150	-	-	25.0	6.3	7.9	-	-
	5	6:1	6.7	60	200	-	-	25.0	6.3	7.9	-	-

'-' Tests were not done

Table C1. Characteristics of Feed Solutions Used in Soil Columns

Date	No.	C:N	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
12/08/80	1	2:1	6.7	50	50	-	-	25.0	-	7.9	-	-
	2	3:1	6.7	50	70	-	-	25.0	-	7.9	-	-
	3	4:1	6.7	50	90	-	-	25.0	-	7.8	-	-
	4	5:1	6.7	50	115	-	-	25.0	-	7.6	-	-
	5	6:1	6.7	55	150	-	-	25.0	-	7.8	-	-
19/08/80	1	2:1	6.8	55	45	-	-	25.0	1.4	8.1	-	-
	2	3:1	6.8	55	70	-	-	25.0	3.5	8.0	-	-
	3	4:1	6.8	50	85	-	-	25.0	5.6	8.1	-	-
	4	5:1	6.8	55	110	-	-	25.0	5.6	8.0	-	-
	5	6:1	6.8	55	140	-	-	25.0	8.4	8.0	-	-

'-' Tests were not done

Table Cl. Characteristics of Feed Solutions Used in Soil Columns

Date	No.	C:N	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
26/08/80	1	2:1	6.8	50	40	-	-	25.0	2.1	7.5	-	-
	2	3:1	6.8	50	50	-	-	25.0	3.5	7.7	-	-
	3	4:1	6.8	50	80	-	-	25.0	4.9	7.7	-	-
	4	5:1	6.8	50	85	-	-	25.0	6.3	7.7	-	-
	5	6:1	6.7	55	130	-	-	25.0	7.0	7.7	-	-
02/09/80	1	2:1	6.8	65	120	-	-	25.0	3.5	7.8	-	-
	2	3:1	6.8	65	175	-	-	25.0	4.2	7.8	-	-
	3	4:1	6.8	65	230	-	-	25.0	6.3	7.8	-	-
	4	5:1	6.8	65	250	-	-	25.0	10.5	7.8	-	-
	5	6:1	6.8	70	340	-	-	25.0	11.2	7.7	-	-

Tests were not done

Table Cl. Characteristics of Feed Solutions Used In Soil Columns.

Date	No.	C:N	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
10/09/80	1	2:1	6.8	-	100	-	-	25.0	3.5	7.9	30	18
	2	3:1	6.9	-	135	-	-	25.0	6.3	7.8	32	16
	3	4:1	6.8	70	185	-	-	25.0	7.0	7.8	36	26
	4	5:1	6.8	70	260	-	-	25.0	9.1	7.9	40	24
	5	6:1	6.8	70	285	-	-	25.0	12.6	7.7	48	24
16/09/80	1	2:1	6.7	60	65	-	-	25.0	4.2	7.9	20	10
	2	3:1	6.7	60	110	-	-	25.0	5.6	7.9	26	18
	3	4:1	6.7	60	145	-	-	25.0	8.4	7.9	22	12
	4	5:1	6.7	65	170	-	-	25.0	9.1	7.8	30	20
	5	6:1	6.7	65	210	-	-	25.0	11.2	7.8	35	22

-' Tests were not done

Table C1. Characteristics of Feed Solutions Used In Soil Columns

Date	No.	C:N	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
23/09/80	1	2:1	6.8	65	75	-	-	25.0	4.2	7.9	-	-
	2	3:1	6.8	65	130	-	-	25.0	6.3	8.1	-	-
	3	4:1	6.8	65	155	-	-	25.0	8.4	8.0	-	-
	4	5:1	6.7	70	200	-	-	25.0	9.1	8.0	-	-
	5	6:1	6.7	70	260	-	-	25.0	12.6	8.0	-	-
30/09/80	1	2:1	6.9	70	65	0.0	-	25.0	2.8	7.9	-	-
	2	3:1	6.9	70	85	0.0	-	25.0	3.5	7.9	-	-
	3	4:1	6.9	70	135	0.5	-	25.0	4.2	7.8	-	-
	4	5:1	6.9	70	160	1.0	-	25.0	6.3	7.8	-	-
	5	6:1	7.0	75	200	1.0	-	25.0	7.0	7.7	-	-

- Tests were not done

Table C1. Characteristics of Feed Solutions Used In Soil Columns

Date	No.	C:N	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
08/10/80	1	2:1	6.9	55	65	-	-	25.0	-	7.8	-	-
	2	3:1	6.9	55	95	-	-	25.0	-	7.8	-	-
	3	4:1	6.9	55	120	-	-	25.0	-	7.8	-	-
	4	5:1	6.9	50	140	-	-	25.0	-	7.7	-	-
	5	6:1	6.9	60	190	-	-	25.0	-	7.8	-	-
15/10/80	1	2:1	7.0	60	60	-	-	25.0	2.8	7.8	-	-
	2	3:1	7.0	60	65	-	-	25.0	3.5	7.9	-	-
	3	4:1	7.0	60	120	-	-	25.0	6.3	7.9	-	-
	4	5:1	7.0	65	140	-	-	25.0	6.3	7.9	-	-
	5	6:1	7.0	65	180	-	-	25.0	8.4	7.9	-	-

'-' Tests were not done

Table C1. Characteristics of Feed Solutions Used In Soil Columns

Date	No.	C:N	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
22/10/80	1	2:1	6.9	60	45	-	-	25.0	1.4	-	-	-
	2	3:1	6.9	60	95	-	-	25.0	3.5	-	-	-
	3	4:1	6.9	60	115	-	-	25.0	5.6	-	-	-
	4	5:1	6.9	60	160	-	-	25.0	5.6	-	-	-
	5	6:1	6.9	65	175	-	-	25.0	7.7	-	-	-
28/10/80	1	2:1	7.1	65	80	-	-	25.0	2.8	-	-	-
	2	3:1	7.1	65	105	-	-	25.0	4.2	-	-	-
	3	4:1	7.1	65	145	-	-	25.0	5.6	-	-	-
	4	5:1	7.1	65	180	-	-	25.0	6.3	-	-	-
	5	6:1	7.1	70	200	-	-	25.0	7.7	-	-	-

Tests were not done

Table C1. Characteristics of Feed Solutions Used In Soil Columns

Date	No.	C:N	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
04/11/80	1	2:1	7.0	70	80	-	-	25.0	1.4	-	18	12
	2	3:1	7.0	70	85	-	-	25.0	3.5	-	32	18
	3	4:1	7.0	70	135	-	-	25.0	4.2	-	22	14
	4	5:1	7.1	70	155	-	-	25.0	4.9	-	28	22
	5	6:1	7.1	75	200	-	-	25.0	5.6	-	44	24
11/11/80	1	2:1	6.9	70	105	0.0	-	25.0	2.1	8.2	-	-
	2	3:1	6.9	75	135	0.0	-	25.0	2.8	8.0	-	-
	3	4:1	7.0	75	180	0.5	-	25.0	3.5	8.1	-	-
	4	5:1	7.0	75	185	1.0	-	25.0	6.3	8.1	-	-
	5	6:1	7.0	75	245	1.0	-	25.0	6.3	8.1	-	-

Tests were not done

Table C1. Characteristics of Feed Solutions Used In Soil Columns

Date	No.	C:N	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
18/11/80	1	2:1	7.1	65	70	-	-	25.0	3.5	7.9	-	-
	2	3:1	7.1	65	140	-	-	25.0	4.2	7.9	-	-
	3	4:1	7.1	65	165	-	-	25.0	4.9	8.9	-	-
	4	5:1	7.1	65	190	-	-	25.0	5.6	7.8	-	-
	5	6:1	7.1	65	265	-	-	25.0	6.3	7.8	-	-
25/11/80	1	2:1	6.8	60	50	-	-	25.0	1.4	7.6	-	-
	2	3:1	6.8	60	100	-	-	25.0	2.1	7.7	-	-
	3	4:1	6.8	60	130	-	-	25.0	2.8	7.7	-	-
	4	5:1	6.8	60	160	-	-	25.0	3.5	7.7	-	-
	5	6:1	6.7	60	185	-	-	25.0	3.5	7.7	-	-

Tests were not done

Table C1. Characteristics of Feed Solutions Used In Soil Columns

Date	No.	C:N	pH	Alkalinity as CaCO ₃ (mg/L) ³	COD (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
02/12/80	1	2:1	6.7	55	55	-	-	25.0	2.8	7.8	-	-
	2	3:1	6.7	55	80	-	-	25.0	3.5	7.8	-	-
	3	4:1	6.7	55	125	-	-	25.0	3.5	7.8	-	-
	4	5:1	6.7	55	155	-	-	25.0	4.9	7.8	-	-
	5	6:1	6.7	60	160	-	-	25.0	5.6	7.8	-	-
09/12/80	1	2:1	6.8	60	55	-	-	25.0	2.1	7.8	-	-
	2	3:1	6.8	60	85	-	-	25.0	3.5	7.7	-	-
	3	4:1	6.8	60	110	-	-	25.0	3.5	7.7	-	-
	4	5:1	6.8	60	140	-	-	25.0	5.6	7.7	-	-
	5	6:1	6.7	65	185	-	-	25.0	7.0	7.7	-	-

Tests were not done

Table C1. Characteristics of Feed Solutions Used in Soil Columns

Date	No.	C:N	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
16/12/80	1	2:1	6.8	60	55	-	-	25.0	1.4	7.6	-	-
	2	3:1	6.8	65	100	-	-	25.0	1.4	7.9	-	-
	3	4:1	6.8	60	115	-	-	25.0	2.1	7.9	-	-
	4	5:1	6.8	65	140	-	-	25.0	2.8	7.8	-	-
	5	6:1	6.7	65	170	-	-	25.0	3.5	7.8	-	-
22/12/80	1	2:1	6.8	60	80	-	-	25.0	3.5	7.7	-	-
	2	3:1	6.8	60	100	-	-	25.0	5.6	7.8	-	-
	3	4:1	6.8	60	125	-	-	25.0	7.0	7.8	-	-
	4	5:1	6.8	60	175	-	-	25.0	10.5	7.8	-	-
	5	6:1	6.8	65	205	-	-	25.0	11.2	7.8	-	-

'-' Tests were not done

Table C1. Characteristics of Feed Solutions Used In Soil Columns

Date	No.	C:N	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
30/12/80	1	2:1	6.8	55	85	-	-	25.0	2.8	7.6	26	16
	2	3:1	6.8	55	95	-	-	25.0	2.8	7.6	24	14
	3	4:1	6.8	55	170	-	-	25.0	4.2	7.6	34	18
	4	5:1	6.8	60	205	-	-	25.0	4.9	7.7	38	24
	5	6:1	6.8	60	270	-	-	25.0	5.6	7.6	50	28
05/01/81	1	2:1	6.9	55	75	-	-	25.0	2.8	7.9	-	-
	2	3:1	6.9	55	120	-	-	25.0	4.2	7.9	-	-
	3	4:1	6.9	55	165	-	-	25.0	4.9	7.9	-	-
	4	5:1	6.9	55	205	-	-	25.0	4.9	7.8	-	-
	5	6:1	6.9	60	235	-	-	25.0	6.3	7.8	-	-

'-' Tests were not done

Table C.2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 01/07/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	6.9	-	-	-	-	-	25	-	-	-	-
2	6.9	-	-	-	-	-	19	-	-	-	-
3	7.2	-	-	-	-	-	17	-	-	-	-
4	7.3	-	-	-	-	-	15	-	-	-	-
5	7.3	-	-	-	-	-	15	-	-	-	-
6	6.9	-	-	-	-	-	25	-	-	-	-
7	6.9	-	-	-	-	-	17	-	-	-	-
8	7.0	-	-	-	-	-	17	-	-	-	-
9	7.1	-	-	-	-	-	19	-	-	-	-
10	7.1	-	-	-	-	-	12	-	-	-	-
11	6.9	-	-	-	-	-	25	-	-	-	-
12	6.9	-	-	-	-	-	13	-	-	-	-
13	6.9	-	-	-	-	-	16	-	-	-	-
14	7.2	-	-	-	-	-	12	-	-	-	-
15	7.1	-	-	-	-	-	12	-	-	-	-
16	6.9	-	-	-	-	-	23	-	-	-	-
17	6.9	-	-	-	-	-	13	-	-	-	-
18	7.1	-	-	-	-	-	14	-	-	-	-
19	7.4	-	-	-	-	-	12	-	-	-	-
20	7.3	-	-	-	-	-	12	-	-	-	-

Tests were not done

Table C2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 08/07/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	6.9	-	26	-	-	0.0	25	2.1	-	-	-
2	6.9	-	30	-	-	5.0	16	3.5	-	-	-
3	7.2	-	38	-	-	7.0	16	4.9	-	-	-
4	7.3	-	40	-	-	3.5	10	4.9	-	-	-
5	7.3	-	40	-	-	1.0	7	5.6	-	-	-
6	7.0	-	18	-	-	1.0	25	1.4	-	-	-
7	6.8	-	14	-	-	5.0	9	2.1	-	-	-
8	6.9	-	26	-	-	3.5	11	2.1	-	-	-
9	7.1	-	26	-	-	1.0	7	2.8	-	-	-
10	7.1	-	22	-	-	1.0	8	4.2	-	-	-
11	6.7	-	14	-	-	2.0	24	2.1	-	-	-
12	6.9	-	12	-	-	12.5	13	3.5	-	-	-
13	7.0	-	14	-	-	7.0	7	2.1	-	-	-
14	6.9	-	14	-	-	2.0	9	4.9	-	-	-
15	7.3	-	16	-	-	0.0	5	6.3	-	-	-
16	7.0	-	16	-	-	1.0	24	2.8	-	-	-
17	7.0	-	10	-	-	3.5	17	3.5	-	-	-
18	6.9	-	16	-	-	1.0	6	2.8	-	-	-
19	7.1	-	14	-	-	1.0	10	4.2	-	-	-
20	7.1	-	12	-	-	0.0	5	3.5	-	-	-

--- Tests were not done

Table C2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 15/07/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	-	50	36	2	0.0	7.0	17.5	2.8	5.1	26	12
2	-	105	46	4	0.0	2.0	5.0	4.9	2.8	22	14
3	-	115	58	9	0.0	0.0	1.6	5.6	1.9	24	12
4	-	100	70	11	0.0	0.0	1.8	5.6	1.5	24	16
5	-	135	74	15	0.0	0.0	1.2	7.7	1.3	22	12
6	-	55	22	2	0.0	5.0	17.5	2.1	4.5	18	8
7	-	100	30	1	0.0	3.5	5.3	3.5	2.7	18	12
8	-	110	32	4	0.0	0.0	2.3	4.2	1.8	22	12
9	-	115	42	12	0.0	0.0	2.5	4.2	1.3	16	10
10	-	115	42	12	0.0	0.0	2.0	4.9	1.0	18	10
11	-	50	8	1	0.0	5.0	18.3	2.1	3.2	20	12
12	-	95	10	2	0.0	2.0	4.5	4.9	2.2	12	10
13	-	115	8	3	0.0	0.0	2.0	2.8	1.4	18	8
14	-	110	10	5	0.0	0.0	1.3	3.5	1.1	16	10
15	-	120	14	10	0.0	0.0	1.5	3.5	1.1	12	8
16	-	50	78	1	0.0	8.5	17.0	1.4	2.4	14	8
17	-	100	10	1	0.0	1.0	3.5	2.8	1.4	10	8
18	-	120	8	1	0.0	0.0	1.0	2.1	1.4	12	10
19	-	110	10	5	0.0	0.0	1.0	3.5	1.0	17	8
20	-	125	14	7	0.0	0.0	1.0	4.2	0.7	16	8

Tests were not done

Table C2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 22/07/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	7.0	55	42	3	-	3.5	8.5	4.2	6.1	-	-
2	7.4	85	44	2	-	3.5	6.6	4.9	3.3	-	-
3	7.1	100	54	8	-	0.0	3.0	4.2	2.4	-	-
4	7.3	110	78	12	-	0.0	2.2	6.3	1.6	-	-
5	7.4	110	80	13	-	0.0	2.4	11.9	1.3	-	-
6	7.1	50	30	2	-	5.0	19.3	2.8	4.8	-	-
7	7.0	85	30	1	-	3.5	0.8	4.2	3.1	-	-
8	7.3	110	32	4	-	0.0	2.5	4.2	1.7	-	-
9	7.4	110*	34	11	-	0.0	1.8	4.2	1.4	-	-
10	7.4	120	34	10	-	0.0	1.5	5.6	1.3	-	-
11	7.1	40	14	1	-	7.0	19.0	2.8	3.3	-	-
12	7.1	90	16	2	-	3.5	5.8	3.5	2.4	-	-
13	7.4	115	26	2	-	0.0	1.3	4.2	1.6	-	-
14	7.3	115	28	6	-	0.0	1.8	3.5	1.3	-	-
15	7.4	125	38	7	-	0.0	1.5	4.9	1.0	-	-
16	7.2	50	12	0	-	0.0	3.5	18.8	1.4	-	-
17	7.2	95	8	1	-	2.0	5.3	2.8	1.6	-	-
18	7.4	110	24	2	-	0.0	1.3	2.8	1.2	-	-
19	7.6	105	32	3	-	0.0	1.0	4.2	0.6	-	-
20	7.3	125	34	8	-	0.0	0.5	3.5	1.0	-	-

* Tests were not done

Table C2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 29/07/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	7.0	70	18	2	-	3.5	19.0	2.8	6.0	-	-
2	7.0	95	26	4	-	3.5	9.0	4.2	3.0	-	-
3	7.2	115	34	5	-	0.0	2.0	5.6	2.1	-	-
4	7.2	115	36	10	-	0.0	2.0	2.8	1.7	-	-
5	7.5	130	48	13	-	0.0	1.8	4.9	1.5	-	-
6	7.3	60	12	1	-	2.0	19.0	2.1	5.1	-	-
7	7.1	100	20	2	-	3.5	7.0	3.5	2.8	-	-
8	7.0	125	18	3	-	0.0	1.8	2.1	1.8	-	-
9	7.4	130	24	9	-	0.0	1.0	2.1	1.1	-	-
10	7.4	130	22	11	-	0.0	2.0	5.6	1.1	-	-
11	7.0	60	10	1	-	5.0	19.0	1.4	3.0	-	-
12	7.0	100	12	1	-	2.0	4.3	2.8	2.4	-	-
13	7.3	130	10	3	-	0.0	1.3	2.8	1.7	-	-
14	7.2	125	10	6	-	0.0	0.8	4.2	1.0	-	-
15	7.6	135	6	6	-	0.0	0.5	2.8	0.9	-	-
16	7.0	55	6	1	-	2.0	18.5	1.4	2.5	-	-
17	7.1	105	6	2	-	1.0	3.8	2.8	1.6	-	-
18	7.1	110	6	2	-	0.0	1.0	2.1	1.3	-	-
19	7.3	115	8	3	-	0.0	0.8	2.8	0.6	-	-
20	7.3	130	8	7	-	0.0	0.8	4.2	0.6	-	-

'-' Tests were not done

Table C2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 05/08/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	7.2	60	38	1	-	2.0	19.0	1.4	5.7	-	-
2	7.2	95	34	4	-	2.0	5.0	5.6	3.2	-	-
3	7.2	120	58	9	-	0.0	2.6	4.9	2.3	-	-
4	7.3	125	80	10	-	0.0	2.0	4.9	1.9	-	-
5	7.4	125	102	10	-	0.0	1.3	5.6	1.2	-	-
6	7.2	60	24	2	-	3.5	20.0	1.4	4.9	-	-
7	7.3	95	30	2	-	3.5	7.0	3.5	2.6	-	-
8	7.2	120	32	1	-	0.0	2.0	2.8	2.0	-	-
9	7.4	125	38	7	-	0.0	1.3	3.5	1.2	-	-
10	7.4	135	40	10	-	0.0	1.5	3.5	1.1	-	-
11	7.2	60	18	1	-	7.0	19.5	1.4	3.6	-	-
12	7.2	115	16	1	-	1.0	4.8	3.5	2.3	-	-
13	7.4	125	24	3	-	0.0	1.5	3.5	1.6	-	-
14	7.4	130	22	4	-	0.0	0.8	2.8	1.1	-	-
15	7.4	130	18	7	-	0.0	0.8	3.5	0.7	-	-
16	7.1	65	12	0	-	1.0	19.8	2.8	2.6	-	-
17	7.3	105	12	1	-	1.0	4.0	1.4	1.5	-	-
18	7.3	130	16	1	-	0.0	1.3	6.3	1.4	-	-
19	7.5	135	22	5	-	0.0	0.8	2.8	0.5	-	-
20	7.5	140	20	5	-	0.0	0.5	4.2	0.5	-	-

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Tests were not done

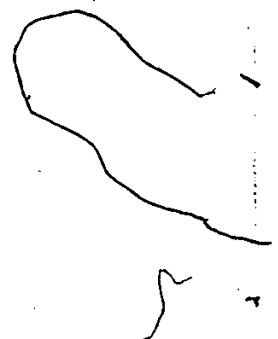


Table C2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 12/08/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	-	50	30	1	-	-	22.0	-	5.9	-	-
2	-	85	40	3	-	-	6.0	-	2.9	-	-
3	-	115	45	10	-	-	2.6	-	2.0	-	-
4	-	120	68	11	-	-	1.6	-	1.3	-	-
5	-	125	86	13	-	-	1.0	-	1.2	-	-
6	-	55	20	1	-	-	19.8	-	4.7	-	-
7	-	90	26	3	-	-	6.5	-	2.9	-	-
8	-	120	28	4	-	-	1.5	-	1.7	-	-
9	-	120	32	9	-	-	2.0	-	1.1	-	-
10	-	125	38	12	-	-	1.8	-	1.2	-	-
11	-	50	12	1	-	-	19.3	-	3.1	-	-
12	-	95	16	2	-	-	7.0	-	2.6	-	-
13	-	120	14	2	-	-	1.8	-	1.5	-	-
14	-	120	12	7	-	-	2.0	-	0.8	-	-
15	-	130	14	9	-	-	0.8	-	0.8	-	-
16	-	60	8	0	-	-	18.5	-	2.2	-	-
17	-	100	8	1	-	-	4.0	-	1.3	-	-
18	-	130	10	3	-	-	1.3	-	1.4	-	-
19	-	130	10	6	-	-	1.3	-	0.9	-	-
20	-	130	12	5	-	-	1.0	-	0.7	-	-

'-' Tests were not done

Table C2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 19/08/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	6.9	45	26	3	-	2.5	19.0	2.1	5.9	-	-
2	7.1	90	38	4	-	2.0	7.6	3.5	3.1	-	-
3	7.1	115	50	5	-	-	3.0	4.2	2.2	-	-
4	7.3	120	60	12	-	-	2.0	4.2	1.5	-	-
5	7.4	120	72	15	-	-	2.0	7.7	1.3	-	-
6	7.1	60	18	1	-	2.0	19.3	2.1	4.9	-	-
7	7.0	85	24	1	-	2.0	7.3	2.8	2.8	-	-
8	7.4	115	40	5	-	-	2.5	4.2	1.8	-	-
9	7.5	120	44	11	-	-	2.0	4.9	1.0	-	-
10	7.4	130	52	12	-	-	1.0	5.6	1.0	-	-
11	7.0	50	18	1	-	2.0	18.5	2.1	3.3	-	-
12	7.3	95	24	3	-	2.0	5.3	2.8	2.1	-	-
13	7.1	120	10	3	-	-	1.5	4.2	1.7	-	-
14	7.4	120	8	5	-	-	1.3	3.5	1.2	-	-
15	7.4	125	10	8	-	-	1.3	5.6	0.8	-	-
16	7.1	50	6	1	-	2.0	18.3	1.4	2.9	-	-
17	7.3	100	8	1	-	1.0	4.5	2.8	1.5	-	-
18	7.5	130	6	2	-	-	1.0	2.8	1.1	-	-
19	7.6	125	8	3	-	-	1.0	3.5	1.1	-	-
20	7.5	130	16	9	-	-	0.5	3.5	0.6	-	-

Tests were not done

Table C2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 26/08/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	-	50	28	1	-	5.0	22.0	2.1	6.0	-	-
2	-	95	28	2	-	3.5	6.0	2.8	3.3	-	-
3	-	105	44	7	-	-	2.3	3.5	2.4	-	-
4	-	110	52	11	-	-	1.4	5.6	1.6	-	-
5	-	115	72	15	-	-	1.4	2.1	1.2	-	-
6	-	50	14	1	-	3.5	20.5	1.4	4.9	-	-
7	-	100	20	2	-	2.0	6.3	2.1	3.0	-	-
8	-	100	36	6	-	-	2.3	5.6	1.8	-	-
9	-	100	32	9	-	-	2.0	4.9	1.3	-	-
10	-	115	50	10	-	-	1.3	6.3	1.0	-	-
11	-	45	14	1	-	2.0	19.5	2.1	3.5	-	-
12	-	100	18	2	-	2.0	5.8	4.2	2.4	-	-
13	-	115	18	3	-	-	1.5	2.8	1.7	-	-
14	-	115	18	6	-	-	1.0	2.1	1.1	-	-
15	-	120	28	8	-	-	1.0	2.1	0.9	-	-
16	-	75	10	1	-	2.0	18.0	0	2.3	-	-
17	-	105	12	1	-	0.5	4.3	0	1.7	-	-
18	-	115	16	1	-	-	1.8	2.8	1.1	-	-
19	-	115	14	5	-	-	1.3	2.8	0.8	-	-
20	-	120	14	9	-	-	0.8	2.1	0.4	-	-

'-' Tests were not done

Table C2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 03/09/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	-	70	64	3	-	2.0	19.0	2.8	5.7	-	-
2	-	95	54	5	-	2.0	7.6	3.5	3.0	-	-
3	-	120	62	7	-	-	2.7	4.9	2.1	-	-
4	-	115	52	10	-	-	2.2	6.3	1.7	-	-
5	-	135	64	14	-	-	1.6	9.1	1.3	-	-
6	-	45	50	1	-	3.5	20.0	2.8	4.6	-	-
7	-	100	36	2	-	2.0	6.8	3.5	3.1	-	-
8	-	120	52	6	-	-	1.8	3.5	1.7	-	-
9	-	120	42	10	-	-	1.8	2.1	1.2	-	-
10	-	135	48	11	-	-	2.0	4.9	1.1	-	-
11	-	60	22	1	-	2.0	19.8	2.1	3.5	-	-
12	-	100	28	1	-	1.0	5.8	5.6	2.3	-	-
13	-	125	24	3	-	-	2.0	3.5	1.5	-	-
14	-	120	20	5	-	-	1.0	6.3	1.1	-	-
15	-	130	28	9	-	-	2.0	5.6	1.0	-	-
16	-	55	12	0	-	1.0	19.0	4.9	2.5	-	-
17	-	105	14	1	-	1.0	4.3	2.8	2.0	-	-
18	-	130	18	3	-	-	1.5	2.1	1.3	-	-
19	-	140	24	5	-	-	0.8	3.5	0.8	-	-
20	-	140	28	8	-	-	0.5	1.4	1.0	-	-

Tests were not done

Table C2. Characteristics of Column Effluents (Application rate = .200 mm/wk) Date: 09/09/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	7.1	-	-	2	-	5.0	20.0	4.2	5.8	28	16
2	7.3	-	56	4	-	3.5	0.0	5.6	3.2	32	22
3	7.8	125	62	10	-	-	3.0	5.6	2.3	26	22
4	7.6	125	78	13	-	-	2.0	8.4	1.8	36	28
5	7.6	130	48	13	-	-	2.6	6.3	1.4	46	34
6	7.2	-	28	3	-	2.0	19.5	3.5	4.9	38	16
7	7.4	-	36	3	-	3.5	6.5	3.5	2.6	40	26
8	7.6	130	42	3	-	-	1.8	3.5	1.9	38	26
9	7.6	130	42	9	-	-	1.5	4.9	1.1	28	22
10	7.7	135	44	12	-	-	1.3	5.6	1.0	40	28
11	7.2	-	16	1	-	-	1.3	4.2	3.2	22	14
12	7.2	-	18	2	-	2.0	19.3	2.8	2.2	26	16
13	7.5	125	24	3	-	2.0	4.5	3.5	1.5	30	22
14	7.6	130	34	4	-	-	1.3	3.5	1.0	24	18
15	7.6	140	22	4	-	-	1.0	2.8	1.1	34	24
16	7.2	-	14	10	-	3.5	18.8	2.1	2.5	26	20
17	7.3	-	24	1	-	1.0	4.8	1.4	1.3	20	14
18	7.6	130	16	2	-	-	1.3	4.2	1.4	22	12
19	7.6	135	26	5	-	-	0.8	2.8	0.7	20	14
20	7.7	140	22	7	-	-	1.0	2.8	0.8	20	16

'-' Tests were not done

Table C2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 16/09/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	-	65	24	2	-	5.0	20.0	4.9	5.9	32	24
2	-	100	46	3	-	3.5	6.5	4.9	2.9	44	34
3	-	115	60	6	-	-	2.0	4.9	2.0	36	22
4	-	120	46	11	-	-	1.6	5.6	1.7	48	36
5	-	130	52	16	-	-	2.4	4.2	1.2	58	38
6	-	60	24	2	-	2.0	19.3	5.6	4.9	28	22
7	-	105	32	2	-	3.5	7.0	3.5	2.9	28	20
8	-	125	40	4	-	-	2.5	3.5	1.9	44	32
9	-	125	36	11	-	-	2.3	4.9	1.4	36	28
10	-	130	36	12	-	-	1.3	5.6	0.8	46	30
11	-	60	16	1	-	3.5	19.5	2.8	3.2	32	24
12	-	100	20	1	-	2.0	5.0	3.5	2.2	36	24
13	-	130	24	3	-	-	1.5	3.5	1.4	36	28
14	-	125	20	5	-	-	1.0	4.2	0.8	42	32
15	-	135	26	9	-	-	0.8	4.2	0.6	44	30
16	-	70	12	1	-	2.0	18.3	2.8	2.7	30	22
17	-	105	18	1	-	1.0	4.0	4.2	1.3	26	22
18	-	130	18	2	-	-	1.3	3.5	1.3	34	26
19	-	135	18	5	-	-	0.8	2.8	0.6	38	32
20	-	135	18	8	-	-	0.5	3.5	0.9	36	32

Tests were not done

Table C2. Characteristics of Column Effluents, (Application rate = 200 mm/wk) Date: 23/09/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	-	60	44	1	-	7.0	19.0	3.5	6.2	-	-
2	-	90	56	3	-	5.0	8.0	5.6	2.9	-	-
3	-	120	58	9	-	-	2.0	7.7	2.0	-	-
4	-	120	68	10	-	-	2.4	7.0	1.6	-	-
5	-	130	76	14	-	-	1.8	11.2	1.3	-	-
6	-	70	30	1	-	2.0	19.3	3.5	4.8	-	-
7	-	90	32	2	-	3.5	6.0	4.9	2.7	-	-
8	-	125	34	3	-	-	2.0	4.2	2.0	-	-
9	-	125	48	11	-	-	2.0	7.0	1.1	-	-
10	-	130	50	10	-	-	2.3	6.3	1.0	-	-
11	-	60	18	1	-	2.0	19.5	3.5	3.1	-	-
12	-	100	24	3	-	2.0	4.3	4.9	2.2	-	-
13	-	130	24	3	-	-	1.3	3.5	1.7	-	-
14	-	130	18	6	-	-	1.3	4.2	1.3	-	-
15	-	140	20	7	-	-	1.0	5.6	1.1	-	-
16	-	70	12	1	-	3.5	17.8	2.8	2.7	-	-
17	-	100	14	2	-	2.0	5.3	4.2	1.4	-	-
18	-	130	12	4	-	-	1.0	3.5	1.4	-	-
19	-	130	20	4	-	-	0.8	3.5	0.7	-	-
20	-	130	20	7	-	-	1.3	3.5	1.0	-	-

'-' Tests were not done

Table C2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 30/09/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1 ^e	6.9	70	36	2	-	3.5	20.0	2.8	6.1	-	-
2	7.1	100	40	2	-	3.5	7.0	2.8	3.1	-	-
3	7.4	130	62	7	-	-	1.0	3.5	2.2	-	-
4	7.3	125	66	10	-	-	1.6	5.6	1.6	-	-
5	7.5	135	66	13	-	-	2.0	6.3	1.3	-	-
6	7.2	70	24	2	-	5.0	20.0	2.8	4.7	-	-
7	7.3	105	24	1	-	3.5	6.0	2.8	2.7	-	-
8	7.3	130	44	3	-	-	2.0	2.8	1.8	-	-
9	7.5	135	36	11	-	-	1.5	0	1.2	-	-
10	7.6	140	46	12	-	-	1.3	4.9	1.1	-	-
11	7.1	65	14	2	-	2.0	19.3	1.4	3.0	-	-
12	7.3	105	20	2	-	1.0	4.8	2.8	2.1	-	-
13	7.3	130	14	1	-	-	2.5	2.1	1.7	-	-
14	7.5	135	12	6	-	-	1.8	2.1	1.1	-	-
15	7.5	145	14	11	-	-	1.3	2.8	1.0	-	-
16	7.2	90	8	1	-	2.0	19.3	1.4	2.3	-	-
17	7.4	110	8	1	-	1.0	5.0	2.8	1.5	-	-
18	7.4	145	12	3	-	-	1.3	2.8	1.3	-	-
19	7.5	140	12	3	-	-	1.3	3.5	1.1	-	-
20	7.4	145	18	9	-	-	1.5	3.5	0.6	-	-

'-' Tests were not done

Table C2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 08/10/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	-	60	38	1	-	3.5	22.0	-	5.7	-	-
2	-	105	50	2	-	3.5	8.2	-	3.0	-	-
3	-	120	54	6	-	-	3.0	-	2.3	-	-
4	-	115	60	11	-	-	2.0	-	1.8	-	-
5	-	125	74	12	-	-	2.0	-	1.4	-	-
6	-	65	20	1	-	3.5	20.3	-	5.0	-	-
7	-	115	32	3	-	3.5	6.8	-	2.9	-	-
8	-	120	44	5	-	-	2.5	-	1.7	-	-
9	-	125	38	9	-	-	1.8	-	1.2	-	-
10	-	130	40	14	-	-	1.5	-	1.2	-	-
11	-	60	18	1	-	3.5	18.8	-	3.3	-	-
12	-	115	20	1	-	2.0	5.3	-	2.3	-	-
13	-	130	20	3	-	-	1.0	-	1.6	-	-
14	-	125	12	7	-	-	1.0	-	1.3	-	-
15	-	130	18	8	-	-	1.0	-	1.0	-	-
16	-	50	10	0	-	2.0	18.5	-	2.5	-	-
17	-	110	8	2	-	1.0	4.8	-	1.6	-	-
18	-	110	12	2	-	-	1.5	-	1.2	-	-
19	-	125	12	6	-	-	0.8	-	1.1	-	-
20	-	130	16	7	-	-	0.8	-	0.6	-	-

Tests were not done

Table C2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 15/10/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	-	50	38	3	-	3.5	18.6	3.5	5.9	-	-
2	-	115	32	1	-	3.5	5.8	2.8	3.6	-	-
3	-	120	58	5	-	-	3.0	2.8	2.1	-	-
4	-	115	62	12	-	-	3.0	4.2	1.7	-	-
5	-	130	66	16	-	-	1.6	4.9	1.4	-	-
6	-	50	26	2	-	5.0	19.8	2.8	4.9	-	-
7	-	115	18	2	-	2.0	6.3	3.5	2.7	-	-
8	-	120	32	5	-	-	1.8	2.8	1.9	-	-
9	-	125	28	7	-	-	1.5	4.2	1.1	-	-
10	-	130	28	9	-	-	1.3	4.2	0.9	-	-
11	-	55	12	1	-	3.5	18.8	2.8	3.3	-	-
12	-	115	10	1	-	2.0	5.0	2.8	2.1	-	-
13	-	120	22	3	-	-	1.3	2.8	1.6	-	-
14	-	120	24	4	-	-	1.5	3.5	1.2	-	-
15	-	125	20	11	-	-	0.8	3.5	0.9	-	-
16	-	55	10	0	-	2.0	18.8	1.4	2.5	-	-
17	-	120	12	1	-	2.0	5.0	0	1.6	-	-
18	-	130	14	3	-	-	1.0	0	1.6	-	-
19	-	130	16	3	-	-	1.0	0	1.0	-	-
20	-	130	14	5	-	-	0.5	2.8	0.5	-	-

'-' Tests were not done

Table C2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 22/10/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	-	75	28	2	-	2.0	20.0	2.1	5.8	-	-
2	-	115	56	4	-	3.5	7.0	2.1	3.1	-	-
3	-	120	58	9	-	-	2.4	3.5	2.1	-	-
4	-	120	68	9	-	-	2.6	3.5	1.6	-	-
5	-	130	80	14	-	-	1.0	4.2	1.2	-	-
6	-	70	18	1	-	3.5	19.5	1.4	4.6	-	-
7	-	120	38	2	-	3.5	6.5	1.4	2.8	-	-
8	-	120	40	5	-	-	1.8	2.8	1.8	-	-
9	-	120	44	10	-	-	1.5	3.5	1.0	-	-
10	-	135	34	12	-	-	1.5	3.5	0.9	-	-
11	-	70	12	1	-	3.5	20.0	0.7	3.4	-	-
12	-	120	18	1	-	1.0	4.8	1.4	2.3	-	-
13	-	130	18	3	-	-	1.5	1.4	1.4	-	-
14	-	135	14	4	-	-	1.3	2.8	1.1	-	-
15	-	130	18	10	-	-	1.3	2.8	1.0	-	-
16	-	80	6	1	-	3.5	18.3	0	2.4	-	-
17	-	125	14	1	-	2.0	5.3	0	1.7	-	-
18	-	130	12	1	-	-	1.3	0	1.2	-	-
19	-	130	14	7	-	-	1.3	0	0.7	-	-
20	-	140	16	11	-	-	0.5	2.1	0.7	-	-

!-! Tests were not done

Table C2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 28/10/80

Col. NO.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	7.0	70	44	1	-	5.0	20.0	2.1	5.8	-	-
2	7.2	110	50	3	-	3.5	8.0	2.1	3.0	-	-
3	7.3	125	66	6	-	-	2.2	3.5	2.0	-	-
4	7.2	125	66	11	-	-	2.0	4.2	1.9	-	-
5	7.4	140	70	16	-	-	1.0	4.2	1.3	-	-
6	7.1	80	30	1	-	3.5	19.0	2.1	4.7	-	-
7	7.2	110	34	3	-	3.5	6.0	2.1	2.7	-	-
8	7.2	130	40	4	-	-	2.0	2.8	1.7	-	-
9	7.3	130	54	9	-	-	1.5	2.1	1.3	-	-
10	7.4	140	46	11	-	-	1.5	4.9	1.3	-	-
11	7.1	80	24	1	-	3.5	19.8	1.4	3.4	-	-
12	7.3	120	24	3	-	2.0	5.5	2.1	2.5	-	-
13	7.3	135	30	3	-	-	1.8	2.1	1.4	-	-
14	7.5	140	16	4	-	-	1.3	1.4	1.0	-	-
15	7.5	145	18	9	-	-	0.8	4.2	1.1	-	-
16	7.0	80	16	1	-	3.5	18.3	1.4	2.4	-	-
17	7.3	115	10	2	-	1.0	4.3	0.7	1.3	-	-
18	7.2	130	14	2	-	-	2.0	2.1	1.1	-	-
19	7.5	130	18	6	-	-	1.0	2.1	0.7	-	-
20	7.5	140	16	5	-	-	1.0	4.9	0.7	-	-

!-! Tests were not done

Table C2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 04/11/80

Col. No.	PH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	-	75	40	2	-	2.0	20.0	2.8	6.2	30	22
2	-	100	40	2	-	5.0	8.0	2.8	3.3	44	30
3	-	120	64	5	-	-	2.3	3.5	2.4	48	30
4	-	130	52	12	-	-	2.0	4.9	2.0	42	32
5	-	140	58	12	-	-	1.8	4.9	1.4	56	38
6	-	80	26	1	-	3.5	19.8	2.1	4.6	28	22
7	-	110	24	2	-	3.5	8.0	2.1	2.7	28	20
8	-	130	40	4	-	-	2.0	2.1	2.1	38	28
9	-	135	38	9	-	-	2.0	3.5	1.3	36	30
10	-	135	34	13	-	-	1.3	2.8	1.1	42	32
11	-	80	20	1	-	2.0	19.3	2.1	3.2	34	28
12	-	115	14	2	-	2.0	5.5	1.4	2.3	36	32
13	-	135	14	3	-	-	1.3	3.5	1.6	44	36
14	-	135	32	7	-	-	1.3	2.8	1.0	38	34
15	-	140	16	11	-	-	0.8	2.8	0.8	40	30
16	-	75	8	1	-	2.0	18.5	1.4	2.4	26	18
17	-	115	18	2	-	1.0	4.3	1.4	1.5	32	26
18	-	140	10	1	-	-	0.8	3.5	1.7	32	24
19	-	145	12	5	-	-	0.8	2.8	0.9	40	28
20	-	145	16	9	-	-	1.0	2.8	0.8	44	34

Tests were not done

Table C2. Characteristics of Column Effluents (Application rate = 200 mm/wk) Date: 11/11/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	-	75	62	2	-	2.0	19.6	2.8	6.0	-	-
2	-	110	68	3	-	2.0	6.6	2.8	3.2	-	-
3	-	130	68	7	-	-	3.0	3.5	2.0	-	-
4	-	130	58	11	-	-	2.0	3.5	1.5	-	-
5	-	140	74	12	-	-	2.8	4.2	1.3	-	-
6	-	80	42	1	-	2.0	19.8	2.1	5.0	-	-
7	-	110	36	2	-	3.5	7.8	2.1	2.8	-	-
8	-	135	48	5	-	-	2.3	2.1	1.7	-	-
9	-	135	36	9	-	-	1.8	4.2	1.2	-	-
10	-	145	32	11	-	-	1.0	3.5	1.2	-	-
11	-	85	18	1	-	3.5	18.8	1.4	3.3	-	-
12	-	115	18	2	-	2.0	4.5	1.4	2.1	-	-
13	-	135	28	3	-	-	1.5	3.5	1.7	-	-
14	-	135	20	7	-	-	1.0	3.5	1.0	-	-
15	-	145	24	9	-	-	1.0	3.5	0.8	-	-
16	-	85	16	1	-	3.5	18.8	1.4	2.7	-	-
17	-	120	18	1	-	1.0	4.0	2.8	1.4	-	-
18	-	140	18	2	-	-	0.8	1.4	1.5	-	-
19	-	145	14	5	-	-	1.0	3.5	0.6	-	-
20	-	150	30	8	-	-	0.8	2.8	0.9	-	-

'-' Tests were not done

Table C3. Characteristics of Column Effluents (Application rate = 420 mm/wk) Date: 18/11/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	-	75	44	1	-	3.5	19.0	2.8	6.0	-	-
2	-	110	54	1	-	5.0	6.0	3.5	3.3	-	-
3	-	120	66	5	-	0.0	2.2	4.9	2.3	-	-
4	-	120	56	9	-	0.0	2.0	7.7	1.6	-	-
5	-	130	46	11	-	0.0	1.4	5.6	1.2	-	-
6	-	80	32	1	-	2.0	19.5	2.8	4.9	-	-
7	-	105	32	1	-	5.0	6.8	3.5	2.9	-	-
8	-	120	52	4	-	0.0	2.0	3.5	1.6	-	-
9	-	130	54	7	-	0.0	1.8	3.5	1.3	-	-
10	-	135	76	13	-	0.0	1.5	4.2	1.1	-	-
11	-	80	20	1	-	3.5	19.5	2.1	3.3	-	-
12	-	115	38	2	-	5.0	5.0	2.8	2.2	-	-
13	-	120	24	2	-	0.0	1.8	2.8	1.7	-	-
14	-	125	24	5	-	0.0	1.3	3.5	0.9	-	-
15	-	135	32	10	-	0.0	1.0	2.8	0.8	-	-
16	-	80	10	0	-	2.0	18.3	2.1	2.5	-	-
17	-	115	18	2	-	3.5	5.3	2.1	1.5	-	-
18	-	120	20	3	-	0.0	1.8	1.4	1.2	-	-
19	-	120	22	5	-	0.0	2.0	2.1	0.9	-	-
20	-	135	24	8	-	0.0	0.5	3.5	1.0	-	-

'-' Tests were not done

Table C3. Characteristics of Column Effluents (Application rate = 420 mm/wk) Date: 25/11/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	7.1	70	32	2	-	-	-	1.4	-	-	-
2	7.2	95	38	2	-	7.0	7.2	4.2	2.9	-	-
3	7.4	120	64	7	-	-	2.0	2.8	2.2	-	-
4	7.4	125	68	12	-	-	1.8	4.9	1.3	-	-
5	7.5	130	68	14	-	-	1.8	4.2	1.2	-	-
6	7.2	75	22	1	-	2.0	19.5	1.4	4.8	-	-
7	7.2	100	22	1	-	5.0	6.3	2.8	3.0	-	-
8	7.3	130	38	5	-	-	1.8	2.8	1.8	-	-
9	7.4	125	40	9	-	-	2.5	2.1	1.2	-	-
10	7.4	130	38	12	-	-	1.3	0	1.0	-	-
11	7.2	75	12	1	-	3.5	19.3	0	3.1	-	-
12	7.4	100	22	2	-	5.0	5.3	1.4	2.2	-	-
13	7.4	125	28	3	-	-	1.8	2.1	1.9	-	-
14	7.4	130	44	5	-	-	1.5	2.1	1.1	-	-
15	7.4	130	20	10	-	-	0.8	0	1.1	-	-
16	7.3	75	10	1	-	2.0	18.0	0	2.6	-	-
17	7.2	100	28	2	-	3.5	4.0	0	1.3	-	-
18	7.4	120	14	2	-	-	2.0	0.7	1.3	-	-
19	7.4	130	14	5	-	-	1.0	2.1	1.0	-	-
20	7.4	130	14	9	-	-	1.0	0	0.7	-	-

Tests were not done

Table C3. Characteristics of Column Effluents (Application rate = 420 mm/wk) Date: 02/12/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	-	60	36	2	-	2.0	24.0	2.1	5.3	-	-
2	-	85	38	2	-	7.0	6.6	2.1	3.2	-	-
3	-	120	64	6	-	-	2.6	2.1	2.1	-	-
4	-	125	70	9	-	-	2.0	3.5	1.6	-	-
5	-	130	60	15	-	-	1.4	4.9	1.5	-	-
6	-	70	28	1	-	3.5	19.3	1.4	4.8	-	-
7	-	90	24	2	-	7.0	6.0	2.8	2.6	-	-
8	-	125	48	3	-	-	1.8	4.2	1.9	-	-
9	-	130	48	9	-	-	1.3	3.5	1.1	-	-
10	-	130	36	11	-	-	1.8	3.5	1.1	-	-
11	-	75	17	1	-	3.5	19.5	1.4	3.0	-	-
12	-	95	18	2	-	5.0	5.0	2.1	2.5	-	-
13	-	120	26	3	-	-	1.3	2.1	1.3	-	-
14	-	130	24	5	-	-	2.0	2.1	1.1	-	-
15	-	135	14	7	-	-	0.8	3.5	1.0	-	-
16	-	70	12	0	-	2.0	18.5	0.7	2.6	-	-
17	-	100	12	2	-	5.0	4.3	1.4	1.5	-	-
18	-	125	12	2	-	-	1.5	1.4	1.3	-	-
19	-	130	14	3	-	-	1.3	3.5	0.8	-	-
20	-	130	12	7	-	-	1.0	2.8	0.8	-	-

- Tests were not done

Table C3. Characteristics of Column Effluents (Application rate = 420 mm/wk) Date: 09/12/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	-	70	32	2	-	3.5	22.0	2.8	5.7	-	-
2	-	90	44	2	-	7.0	7.2	2.8	3.1	-	-
3	-	115	58	5	-	-	3.2	3.5	2.2	-	-
4	-	120	70	12	-	-	2.4	2.8	1.7	-	-
5	-	125	80	14	-	-	2.0	4.9	1.3	-	-
6	-	75	20	2	-	2.0	18.8	-	4.6	-	-
7	-	100	30	2	-	5.0	7.0	-	2.8	-	-
8	-	120	38	5	-	-	2.0	-	1.8	-	-
9	-	130	40	9	-	-	1.8	-	1.4	-	-
10	-	135	44	14	-	-	1.3	-	0.9	-	-
11	-	75	16	1	-	5.0	19.0	1.4	3.4	-	-
12	-	115	18	2	-	5.0	4.3	3.5	2.4	-	-
13	-	130	16	4	-	-	1.3	2.1	1.6	-	-
14	-	135	16	1	-	-	1.0	2.1	1.3	-	-
15	-	135	14	9	-	-	1.3	2.8	0.9	-	-
16	-	75	8	0	-	3.5	18.3	1.4	2.1	-	-
17	-	120	10	2	-	3.5	4.5	1.4	1.6	-	-
18	-	130	8	3	-	-	1.0	2.1	1.4	-	-
19	-	140	14	2	-	-	0.8	1.4	0.8	-	-
20	-	140	14	6	-	-	0.5	2.8	0.6	-	-

Tests were not done

Table C3. Characteristics of Column Effluents (Application rate = 420 mm/wk) Date: 16/12/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	-	70	32	1	-	5.0	24.0	2.1	6.4	-	-
2	-	95	54	4	-	5.0	7.0	2.1	3.0	-	-
3	-	120	64	4	-	-	3.4	2.1	2.3	-	-
4	-	120	68	13	-	-	1.8	1.4	1.7	-	-
5	-	130	80	17	-	-	1.6	2.8	1.4	-	-
6	-	75	18	2	-	5.0	19.0	1.4	4.7	-	-
7	-	100	34	2	-	5.0	7.3	0	2.7	-	-
8	-	120	42	3	-	-	2.5	0	1.7	-	-
9	-	130	42	9	-	-	2.0	1.4	1.1	-	-
10	-	135	42	11	-	-	1.5	1.4	1.1	-	-
11	-	80	20	1	-	3.5	19.5	0	3.5	-	-
12	-	100	26	1	-	5.0	4.8	0	2.5	-	-
13	-	130	14	3	-	-	1.5	0	1.6	-	-
14	-	120	10	7	-	-	1.0	2.1	1.2	-	-
15	-	135	14	11	-	-	1.0	0	0.9	-	-
16	-	80	6	0	-	5.0	18.8	0	2.4	-	-
17	-	115	8	2	-	3.5	5.0	0	1.5	-	-
18	-	130	10	3	-	-	1.3	2.1	1.5	-	-
19	-	130	12	5	-	-	0.8	0.7	0.6	-	-
20	-	140	16	9	-	-	0.5	0.5	0.6	-	-

'-' Tests were not done

Table C3. Characteristics of Column Effluents (Application rate = 420 mm/wk) Date: 22/12/80

Col. NO.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	7.2	60	50	2	-	2.0	24.0	2.8	5.3	-	-
2	7.2	90	48	2	-	5.0	-	2.8	3.4	-	-
3	7.4	120	60	5	-	-	3.0	5.6	2.2	-	-
4	7.4	120	76	11	-	-	3.2	6.3	1.6	-	-
5	7.4	125	74	15	-	-	1.5	6.3	1.4	-	-
6	7.2	70	28	1	-	3.5	20.0	2.8	4.7	-	-
7	7.2	100	36	1	-	5.0	6.0	3.5	2.7	-	-
8	7.3	115	36	3	-	-	1.5	3.5	1.7	-	-
9	7.3	125	50	11	-	-	1.5	5.6	1.0	-	-
10	7.4	130	48	12	-	-	2.3	7.7	1.0	-	-
11	7.1	70	24	1	-	5.0	18.5	1.4	3.4	-	-
12	7.3	95	26	1	-	7.0	5.3	3.5	2.6	-	-
13	7.2	125	24	2	-	-	1.5	2.8	1.5	-	-
14	7.4	130	24	4	-	-	1.3	5.6	1.1	-	-
15	7.4	130	28	10	-	-	1.3	4.9	1.1	-	-
16	7.2	75	16	0	-	3.5	18.5	1.4	2.6	-	-
17	7.2	110	14	1	-	3.5	5.3	2.8	1.7	-	-
18	7.4	125	18	2	-	-	1.0	5.6	1.6	-	-
19	7.4	140	18	5	-	-	0.6	3.5	1.0	-	-
20	7.3	140	20	8	-	-	0.8	6.3	0.9	-	-

- Tests were not done

Table C3. Characteristics of Column Effluents (Application rate = 420 mm/wk) Date: 30/12/80

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	-	55	52	2	-	2.0	23.0	2.8	5.9	26	20
2	-	90	54	4	-	5.0	8.0	2.8	3.1	32	18
3	-	125	66	9	-	-	2.0	2.8	2.3	32	24
4	-	120	70	11	-	-	2.0	2.8	1.7	34	28
5	-	130	78	13	-	-	1.6	4.2	1.3	40	30
6	-	70	34	1	-	5.0	20.5	1.4	4.8	22	18
7	-	95	36	2	-	5.0	6.5	1.4	2.8	42	26
8	-	120	42	4	-	-	1.8	3.5	1.9	36	24
9	-	125	44	9	-	-	1.8	2.1	1.1	38	30
10	-	130	46	11	-	-	1.5	4.9	0.9	42	32
11	-	70	24	1	-	3.5	19.5	1.4	3.1	18	14
12	-	95	22	2	-	5.0	4.8	1.4	2.1	22	16
13	-	125	34	2	-	-	1.3	-	1.5	30	24
14	-	130	40	7	-	-	1.3	-	1.1	36	28
15	-	135	36	11	-	-	0.8	-	1.1	36	30
16	-	75	18	0	-	5.0	17.8	0	2.9	26	22
17	-	105	20	1	-	5.0	4.8	0	1.7	32	22
18	-	125	22	2	-	-	1.5	1.4	1.3	36	24
19	-	125	18	4	-	-	1.5	1.4	0.7	34	22
20	-	130	24	9	-	-	1.0	2.8	0.8	30	26

Tests were not done

Table C3. Characteristics of Column Effluents (Application rate = 420 mm/wk) Date: 05/01/81

Col. No.	pH	Alkalinity as CaCO ₃ (mg/L)	COD (mg/L)	SOC (mg/L)	NH ₃ -N (mg/L)	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	TKN (mg/L)	DO (mg/L)	TSS (mg/L)	VSS (mg/L)
1	-	50	48	1	-	3.5	23.0	2.8	6.1	-	-
2	-	90	54	3	-	3.5	8.2	3.5	3.0	-	-
3	-	125	70	9	-	-	2.4	2.8	2.2	-	-
4	-	120	70	9	-	-	3.0	4.2	1.6	-	-
5	-	130	68	15	-	-	1.2	3.5	1.2	-	-
6	-	65	30	2	-	5.0	19.3	1.4	4.9	-	-
7	-	85	38	1	-	3.5	6.0	2.1	2.8	-	-
8	-	125	50	4	-	-	1.8	2.1	1.9	-	-
9	-	125	56	9	-	-	1.8	2.8	1.2	-	-
10	-	135	44	11	-	-	1.5	2.8	1.1	-	-
11	-	65	16	1	-	5.0	19.8	1.4	3.1	-	-
12	-	90	14	2	-	3.5	4.3	2.1	2.5	-	-
13	-	125	24	2	-	-	1.3	1.4	1.4	-	-
14	-	130	16	7	-	-	1.3	2.8	1.0	-	-
15	-	140	24	6	-	-	0.8	2.1	1.0	-	-
16	-	70	12	0	-	5.0	19.0	1.4	2.0	-	-
17	-	85	10	1	-	2.0	7.8	1.4	1.6	-	-
18	-	125	16	2	-	-	1.3	2.1	1.1	-	-
19	-	130	16	3	-	-	1.5	1.4	1.1	-	-
20	-	135	18	5	-	-	1.0	2.1	1.0	-	-

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Tests were not done

Table C4. Reduction Of COD In Soil Columns (Depth = 150 mm)

Applica- tion Rate (mm/wk)	Time (week)	Percentage Reduction of COD (%)				
		C:N=2:1	C:N=3:1	C:N=4:1	C:N=5:1	C:N=6:1
200	1	-	-	-	-	-
	2	37	40	46	52	59
	3	45	55	51	58	62
	4	35	51	59	53	60
	5	39	33	37	50	40
	6	37	44	55	47	49
	7	40	42	50	41	43
	8	43	47	41	46	49
	9	32	43	44	39	45
	10	46	69	73	79	81
	11	-	59	66	70	83
	12	38	58	59	73	75
	13	42	57	62	66	71
	14	45	53	54	59	67
	15	41	47	55	57	61
	16	37	50	51	56	63
	17	39	41	49	57	64
	18	44	49	54	63	65
	19	51	53	52	66	71
	20	40	50	62	69	70
420	21	20	30	37	45	49
	22	23	34	39	47	53
	23	22	32	45	43	57
	24	29	39	41	54	42
	25	33	37	46	49	59
	26	28	42	49	57	53
	27	35	35	45	46	49
	28	30	43	42	49	52

- Tests were not done

Table C4. Reduction Of COD In Soil Columns (Depth = 250 mm)

Applica- tion Rate (mm/wk)	Time (week)	Percentage Reduction of COD (%)				
		C:N=2:1	C:N=3:1	C:N=4:1	C:N=5:1	C:N=6:1
	1	-	-	-	-	-
	2	67	77	80	83	85
	3	77	81	89	92	94
	4	79	83	80	83	81
	5	69	74	82	89	92
	6	70	80	81	86	91
	7	75	76	85	90	91
	8	62	65	88	93	94
	9	63	64	77	79	79
200	10	82	84	90	92	92
	11	84	87	87	87	92
	12	75	82	83	88	88
	13	76	81	85	91	92
	14	78	77	89	93	93
	15	73	79	84	91	91
	16	80	84	82	83	89
	17	72	82	85	91	90
	18	70	77	79	91	91
	19	75	83	90	80	92
	20	82	86	84	89	90
	21	72	73	85	87	88
	22	75	78	78	73	89
420	23	69	77	79	85	91
	24	72	78	85	89	92
	25	63	74	88	93	92
	26	70	75	81	86	86
	27	71	77	80	80	87
	28	79	83	85	92	90

Tests were not done

Table C4. Reduction Of COD In Soil Columns (Depth = 350 mm)

Applica- tion Rate (mm/wk)	Time (week)	Percentage Reduction of COD (%)				
		C:N=2:1	C:N=3:1	C:N=4:1	C:N=5:1	C:N=6:1
	1	-	-	-	-	-
	2	57	63	64	69	78
	3	65	70	73	75	78
	4	54	67	76	79	83
	5	57	49	66	67	72
	6	59	62	75	75	80
	7	60	64	68	72	75
	8	62	67	53	60	63
	9	67	59	56	63	62
200	10	58	79	77	83	86
	11	72	74	77	84	85
	12	62	71	73	79	83
	13	59	75	78	76	81
	14	64	72	68	78	77
	15	69	67	64	73	79
	16	58	72	74	80	84
	17	60	60	65	72	81
	18	62	67	72	70	77
	19	67	73	70	75	83
	20	60	74	73	81	87
	21	40	47	60	68	70
	22	43	49	64	74	71
	23	50	55	69	73	76
	24	47	60	65	67	75
420	25	43	58	66	65	73
	26	49	58	59	67	77
	27	43	63	67	71	71
	28	44	57	68	73	76

'-' Tests were not done

Table C4: Reduction Of COD In Soil Columns (Depth = 450 mm)

Applica- tion Rate (mm/wk)	Time (week)	Percentage Reduction of COD (%)				
		C:N=2:1	C:N=3:1	C:N=4:1	C:N=5:1	C:N=6:1
	1	-	-	-	-	-
	2	81	82	80	83	88
	3	88	90	93	94	93
	4	81	81	82	80	83
	5	81	87	89	89	91
	6	80	86	88	85	90
	7	86	88	90	91	92
	8	89	90	92	92	88
200	9	76	77	79	83	89
	10	90	92	92	90	92
	11	87	83	91	90	92
	12	83	83	88	89	91
	13	85	90	92	90	92
	14	89	91	91	92	91
	15	84	91	90	92	92
	16	82	82	88	88	92
	17	85	86	90	91	91
	18	79	91	91	90	92
	19	90	78	92	92	92
	20	84	87	90	92	88
	21	85	87	88	88	91
	22	78	72	89	91	92
	23	79	85	91	92	92
420	24	85	89	92	90	92
	25	88	93	92	92	91
	26	81	86	86	90	90
	27	80	80	87	91	91
	28	85	92	90	92	92

'-' Tests were not done

Table C5. Feed Solution Characteristics For The Tile-Field (C:N=4:1)

Date	Characteristics										
	pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	
3/2/81	6.9	0.0	25.0	0.0	7.7	60	34	16	210	7.8	
9/2/81	7.0	0.0	25.0	0.0	5.6	60	40	34	130	7.9	
16/2/81	6.9	-	25.0	-	6.3	65	22	10	180	7.9	
23/2/81	6.7	-	25.0	-	9.1	60	28	24	150	7.8	
2/3/81	6.7	-	25.0	-	5.6	65	44	30	210	7.8	
9/3/81	6.8	-	25.0	-	7.0	65	32	22	250	7.8	
16/3/81	6.8	-	25.0	-	7.7	70	-	-	170	7.9	
23/3/81	6.9	-	25.0	-	6.3	65	-	-	180	7.9	
1/4/81	7.0	-	25.0	-	6.3	65	-	-	130	7.7	
6/4/81	6.8	-	25.0	-	9.1	70	-	-	200	7.9	
13/4/81	6.7	-	25.0	-	8.4	75	-	-	260	7.9	
20/4/81	6.9	-	25.0	-	7.0	65	-	-	210	7.8	
1/6/81	6.7	-	25.0	-	5.6	60	28	22	165	7.6	
8/6/81	6.8	-	25.0	-	8.4	60	-	-	250	7.8	
15/6/81	6.7	-	25.0	-	7.7	65	-	-	130	7.8	
22/6/81	6.9	-	25.0	-	6.3	65	-	-	180	7.9	
30/6/81	6.7	-	25.0	-	7.0	60	44	18	200	7.7	
6/7/81	6.7	-	25.0	-	9.1	60	28	14	210	7.8	
12/7/81	6.8	-	25.0	-	7.7	65	34	26	170	7.8	
20/7/81	6.8	-	25.0	-	7.0	60	26	16	150	7.8	

- Tests were not done

Table C6. Characteristics of Percolates Collected In The Tile-Field (Date: 5/2/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)
1,2,3 & 4	1000	7.3	3.5	18.5	0.0	5.6	65	74	36	78	5.2	-
5 & 6	900	7.1	1.0	21.2	0.0	6.3	60	44	20	84	5.6	-
7 & 8	800	7.0	0.0	24.6	0.0	5.6	65	26	12	80	6.0	-
9 & 10	700	7.3	1.0	22.5	0.0	4.9	65	20	10	100	5.8	-
11 & 12	600	7.4	0.0	23.4	0.0	5.6	70	42	18	120	5.9	-
13 & 14	500	7.3	0.0	24.2	0.0	3.5	60	30	14	106	6.4	-
15 & 16	400	7.1	0.0	24.0	0.0	4.9	65	36	12	150	6.3	-

1-1 Tests were not done

Table C6. Characteristics of Percolates Collected In The Tile-Field (Date: 12/2/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)
1,2,3 & 4	1000	7.4	5.0	17.5	0.0	3.5	70	62	48	32	5.0	-
5 & 6	900	7.3	3.5	21.2	0.0	4.2	70	40	26	40	5.0	-
7 & 8	800	7.3	3.5	21.4	0.0	3.5	70	24	18	38	4.8	-
9 & 10	700	7.3	1.0	22.3	0.0	4.9	70	26	14	52	5.2	-
11 & 12	600	7.4	1.0	24.0	0.0	2.8	70	36	14	54	5.6	-
13 & 14	500	7.3	1.0	23.4	0.0	4.2	65	38	28	68	5.7	-
15 & 16	400	7.3	1.0	23.6	0.0	4.9	65	36	24	60	5.6	-

1-1 Tests were not done

Table C6. Characteristics of Percolates Collected In The Tile-Field (Date: 19/2/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)
1,2,3 & 4	1000	7.4	5.0	11.2	-	3.5	90	58	42	46	4.2	7.0
5 & 6	900	7.3	7.0	13.7	-	3.5	80	38	30	56	4.7	8.4
7 & 8	800	7.2	7.0	12.2	-	4.2	75	32	12	48	4.5	11.2
9 & 10	700	7.3	5.0	16.4	-	4.9	75	20	8	58	5.1	13.4
11 & 12	600	7.3	7.0	12.3	-	5.6	80	34	14	68	4.9	15.2
13 & 14	500	7.4	3.5	19.4	-	4.9	75	28	12	82	5.0	14.6
15 & 16	400	7.3	3.5	18.6	-	4.9	70	32	12	80	5.0	15.8

Tests were not done

Table C6. Characteristics Of Percolates Collected In The Tile-Field (Date: 26/2/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L) ³	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)
1,2,3 & 4	1000	7.5	0.0	7.3	-	4.9	100	64	44	44	2.8	5.2
5 & 6	900	7.5	0.0	6.4	-	5.6	100	40	32	56	3.1	6.8
7 & 8	800	7.4	0.0	7.7	-	6.3	95	28	22	60	2.9	7.2
9 & 10	700	7.4	0.0	9.4	-	6.3	90	34	22	68	3.2	7.0
11 & 12	600	7.4	0.0	13.2	-	7.0	90	30	14	78	4.8	8.4
13 & 14	500	7.3	0.0	17.4	-	7.7	85	36	14	86	4.9	10.2
15 & 16	400	7.4	0.0	19.2	-	7.7	85	26	18	96	4.9	10.6

'-' Tests were not done

Table C6. Characteristics of Percolates Collected In The Tile-Field (Date: 5/3/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)
1,2,3 & 4	1000	7.5	0.0	4.0	-	2.1	115	48	28	34	1.7	4.0
5 & 6	900	7.4	0.0	4.5	-	2.8	110	36	26	42	1.7	6.6
7 & 8	800	7.5	0.0	4.8	-	3.5	110	28	18	50	2.0	8.2
9 & 10	700	7.5	1.0	6.2	-	3.5	110	24	16	64	2.3	8.4
11 & 12	600	7.5	0.0	14.3	-	4.2	100	36	22	74	3.0	11.0
13 & 14	500	7.5	0.0	19.4	-	4.9	90	34	14	76	5.1	10.8
15 & 16	400	7.5	1.0	21.6	-	4.2	85	40	12	72	5.0	11.6

1. Tests were not done

Table C6. Characteristics of Percolates Collected In The Tile-Field (Date:13/3/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)
1,2,3 & 4	1000	7.4	0.0	4.8	-	3.5	120	44	36	38	2.0	5.4
5 & 6	900	7.3	0.0	5.2	-	3.5	115	24	16	52	1.9	5.0
7 & 8	800	7.4	0.0	5.8	-	3.9	115	26	18	48	2.3	7.2
9 & 10	700	7.3	0.0	7.4	-	5.6	105	22	14	72	2.4	7.6
11 & 12	600	7.3	0.0	13.6	-	4.9	95	24	12	94	3.8	8.0
13 & 14	500	7.4	0.0	18.4	-	4.9	80	20	16	56	3.8	8.2
15 & 16	400	7.4	0.0	19.8	-	5.6	80	20	18	78	4.6	10.8

'-' Tests were not done

Table C6. Characteristics Of Percolates Collected In The Tile-Field (Date: 19/3/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	OOD (mg/L)	DO (mg/L)	SOC (mg/L)
1,2,3 & 4	1000	7.4	-	4.2	-	4.2	120	-	-	48	1.8	4.2
5 & 6	900	7.4	-	5.1	-	3.5	125	-	-	64	2.4	5.6
7 & 8	800	7.5	-	5.4	-	4.9	115	-	-	52	2.4	6.8
9 & 10	700	7.3	-	5.6	-	4.9	115	-	-	76	2.5	6.8
11 & 12	600	7.3	-	15.3	-	5.6	95	-	-	66	3.6	7.6
13 & 14	500	7.4	-	17.8	-	5.6	90	-	-	92	4.7	9.4
15 & 16	400	7.3	-	18.2	-	4.9	90	-	-	100	3.9	8.0

Tests were not done

Table C6. Characteristics Of Percolates Collected In The Tile-Field (Date: 26/3/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)
1, 2, 3 & 4	1000	7.4	-	3.8	-	1.4	120	-	-	44	1.6	5.0
5 & 6	900	7.5	-	4.4	-	3.5	115	-	-	40	2.1	6.0
7 & 8	800	7.5	-	4.0	-	2.8	115	-	-	58	2.2	5.8
9 & 10	700	7.4	-	6.2	-	2.8	105	-	-	46	2.4	7.6
11 & 12	600	7.4	-	12.8	-	4.2	100	-	-	72	2.9	8.2
13 & 14	500	7.4	-	17.6	-	3.5	80	-	-	64	3.9	8.6
15 & 16	400	7.4	-	19.4	-	4.2	90	-	-	78	4.2	10.4

- Tests were not done

Table C6. Characteristics Of Percolates Collected In The Tile-Field (Date: 2/4/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	OOD (mg/L)	DO (mg/L)	SOC (mg/L)
1,2,3 & 4	1000	7.5	-	4.4	-	2.8	115	-	-	32	1.8	3.4
5 & 6	900	7.5	-	4.2	-	3.5	115	-	-	30	2.1	4.2
7 & 8	800	7.5	-	5.3	-	3.5	110	-	-	46	2.6	4.8
9 & 10	700	7.4	-	7.2	-	4.2	110	-	-	52	3.5	6.2
11 & 12	600	7.4	-	8.1	-	4.2	100	-	-	68	4.8	6.6

'-' Tests were not done

Table C6. Characteristics of Percolates Collected In The Tile-Field (Date: 9/4/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	%COD (mg/L)	DO (mg/L)	SOC (mg/L)
1, 2, 3 & 4	1000	7.5	-	4.8	-	4.2	125	-	-	60	2.2	4.0
5 & 6	900	7.5	-	5.0	-	4.9	120	-	-	56	2.1	5.2
7 & 8	800	7.5	-	5.6	-	5.6	120	-	-	88	3.0	5.8
9 & 10	700	7.4	-	8.4	-	5.6	115	-	-	100	3.7	7.4
11 & 12	600	7.4	-	9.4	-	5.6	105	-	-	86	4.1	8.2

'-' Tests were not done

Table C6. Characteristics Of Percolates Collected In The Tile-Field (Date: 16/4/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DQ (mg/L)	SOC (mg/L)
1,2,3 & 4	1000	7.4	0.0	5.6	-	3.5	120	-	-	38	2.0	4.6
5 & 6	900	7.4	0.0	5.8	-	4.2	120	-	44	44	2.3	6.2
7 & 8	800	7.4	0.0	6.0	-	4.2	115	-	74	74	3.5	5.8
9 & 10	700	7.5	0.0	9.0	-	5.6	115	-	96	96	4.2	7.0
11 & 12	600	7.5	0.0	21.2	-	4.9	90	-	90	90	4.4	8.2

'-' Tests were not done

Table C6. Characteristics of Percolates Collected In The Tile-Field (Date: 23/4/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)
1, 2, 3 & 4	1000	7.3	0.0	5.4	-	4.2	115	-	-	60	2.3	5.2
5 & 6	900	7.2	0.0	6.1	-	3.5	105	-	-	58	2.7	5.4
7 & 8	800	7.2	0.0	9.4	-	4.9	100	-	-	76	3.1	6.4
9 & 10	700	7.3	0.0	11.1	-	4.2	100	-	-	56	3.3	6.8
11 & 12	600	7.4	0.0	22.0	-	4.9	80	-	-	60	3.8	8.0

Tests were not done

Table C6. Characteristics of Percolates Collected In The Tile-Field (Date: 30/4/81)

Sample Port No.	Soil Depth (mm)	Characteristics												
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)		
1,2,3 & 4	1000	-	-	24.3	-	-	-	-	-	-	-	-	-	-
5 & 6	900	-	-	24.0	-	-	-	-	-	-	-	-	-	-
7 & 8	800	-	-	25.4	-	-	-	-	-	-	-	-	-	-
9 & 10	700	-	-	23.6	-	-	-	-	-	-	-	-	-	-
11 & 12	600	-	-	23.2	-	-	-	-	-	-	-	-	-	-

-! Tests were not done

Table C6. Characteristics Of Percolates Collected In The Tile-Field (Date: 7/5/81)

Sample Port No.	Soil Depth (mm)	Characteristics											
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)	
1, 2, 3 & 4	1000	-	-	24.2	-	-	-	-	-	-	-	-	-
5 & 6	900	-	-	23.0	-	-	-	-	-	-	-	-	-
7 & 8	800	-	-	24.6	-	-	-	-	-	-	-	-	-
9 & 10	700	-	-	22.4	-	-	-	-	-	-	-	-	-
11 & 12	600	-	-	24.2	-	-	-	-	-	-	-	-	-

'-' Tests were not done

Table C6. Characteristics of Percolates Collected In The Tile-Field (Date: 14/5/81)

Sample Port No.	Soil Depth (mm)	Characteristics												
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)		
1,2,3 & 4	1000	-	-	21.2	-	-	-	-	-	-	-	-	-	-
5 & 6	900	-	-	19.5	-	-	-	-	-	-	-	-	-	-
7 & 8	800	-	-	22.7	-	-	-	-	-	-	-	-	-	-
9 & 10	700	-	-	21.5	-	-	-	-	-	-	-	-	-	-
11 & 12	600	-	-	24.2	-	-	-	-	-	-	-	-	-	-

246

- Tests were not done

Table C6. Characteristics Of Percolates Collected In The Tile-Field (Date: 21/5/81).

Sample Port No.	Soil Depth (mm)	Characteristics											
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)	
1, 2, 3 & 4	1000	-	-	11.1	-	-	-	-	-	-	-	-	-
5 & 6	900	-	-	10.2	-	-	-	-	-	-	-	-	-
7 & 8	800	-	-	13.5	-	-	-	-	-	-	-	-	-
9 & 10	700	-	-	19.4	-	-	-	-	-	-	-	-	-
11 & 12	600	-	-	21.2	-	-	-	-	-	-	-	-	-

'-' Tests were not done

Table C6. Characteristics Of Percolates Collected In The Tile-Field (Date: 4/6/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)
1, 2, 3 & 4	1000	7.2	0.0	7.0	-	7.7	105	90	84	130	2.7	10.0
5 & 6	900	7.4	0.0	7.3	-	5.6	100	58	48	90	2.7	8.2
7 & 8	800	7.3	0.0	9.8	-	7.0	90	30	26	90	2.8	8.4

!-! Tests were not done

Table C6. Characteristics Of Percolates Collected In The Tile-Field (Date: 11/6/81)

Sample Port. No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)
1,2,3 & 4	1000	7.4	-	6.5	-	4.2	105	-	-	60	2.6	4.8
5 & 6	900	7.4	-	5.3	-	4.9	105	-	-	72	2.7	5.2
7 & 8	800	7.3	-	7.1	-	5.6	100	-	-	84	3.1	5.6

- Tests were not done

Table C6. Characteristics Of Percolates Collected In The Tile-Field (Date: 18/6/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)
1,2,3 & 4	1000	7.5	-	5.4	-	5.6	110	-	-	36	2.1	4.4
5 & 6	900	7.4	-	6.2	-	4.9	105	-	-	40	2.4	5.0
7 & 8	800	7.4	-	6.4	-	4.9	105	-	-	48	2.9	5.2

'-' Tests were not done

Table C6. Characteristics of Percolates Collected In The Tile-Field (Date: 25/6/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SO ₄ (mg/L)
1,2,3 & 4	1000	7.5	0.0	4.8	-	2.8	120	-	-	38	2.1	4.0
5 & 6	900	7.5	0.0	5.1	-	4.2	115	-	-	34	2.1	4.2
7 & 8	800	7.4	0.0	5.7	-	3.5	110	-	-	40	2.9	4.8
9 & 10	700	7.4	0.0	7.4	-	4.2	105	-	-	60	3.1	5.4

1-1 Tests were not done

Table C6. Characteristics of Percolates Collected In The Tile-Field (Date: 2/7/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)
1,2,3 & 4	1000	7.5	0.0	5.0	-	3.5	115	40	26	40	1.9	4.0
5 & 6	900	7.4	0.0	6.2	-	4.2	105	28	22	48	2.2	4.0
7 & 8	800	7.4	0.0	6.5	-	4.2	100	24	18	56	2.7	5.2

Tests were not done

5

Table C6. Characteristics Of Percolates Collected In The Tile-Field (Date: 9/7/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)
1, 2, 3 & 4	1000	7.5	-	4.4	-	5.6	110	26	18	38	2.0	3.8
5 & 6	900	7.5	-	4.6	-	5.6	110	32	22	34	2.0	4.2
7 & 8	800	7.5	-	5.1	-	6.3	105	24	16	52	3.1	4.6
9 & 10	700	7.4	-	10.1	-	6.3	110	26	18	36	3.0	5.0

Tests were not done

Table C6. Characteristics Of Percolates Collected In The Tile-Field (Date: 16/7/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)
1, 2, 3 & 4	1000	7.5	-	5.1	-	4.2	110	46	30	40	2.1	4.2
5 & 6	900	7.5	-	5.0	-	4.9	115	32	24	40	2.3	4.2
7 & 8	800	7.4	-	6.3	-	4.9	110	28	16	44	2.7	4.8
9 & 10	700	7.4	-	9.5	-	5.6	110	20	14	46	2.9	5.0

!-! Tests were not done.

Table C6. Characteristics of Percolates Collected In The Tile-Field (Date: 23/7/81)

Sample Port No.	Soil Depth (mm)	Characteristics										
		pH	NO ₂ -N (mg/L)	NO ₃ -N (mg/L)	NH ₃ -N (mg/L)	TKN (mg/L)	Alkalinity as CaCO ₃ (mg/L)	TSS (mg/L)	VSS (mg/L)	COD (mg/L)	DO (mg/L)	SOC (mg/L)
1, 2, 3 & 4	1000	7.5	0.0	4.7	-	3.5	115	30	24	52	2.4	3.8
5 & 6	900	7.4	0.0	4.5	-	4.2	115	22	18	38	2.3	4.0
7 & 8	800	7.5	0.0	5.4	-	4.2	100	18	12	44	2.7	4.2
9 & 10	700	7.4	0.0	9.0	-	4.9	105	24	12	40	3.0	4.2

-: Tests were not done

APPENDIX D

MEAN VARIATIONS OF VARIOUS PARAMETERS
WITH SOIL DEPTH & TIME IN THE
SOIL COLUMN STUDY

Table D1. Variation of Percent Nitrate Removal (two weeks mean) With Time in 150 mm Soil Columns

Time (Week)	Mean Percent Nitrate Removal (%)					
	C:N = 2:1	C:N = 3:1	C:N = 4:1	C:N = 5:1	C:N = 6:1	
1	0	30	34	50	56	
3	28	77	91	92	93	
5	24	72	91	92	94	
7	18	73	89	93	94	
9	18	73	90	92.5	94	
11	20	74	90	93	90	
13	22	70	94	92	93	
15	18.5	72	88	90	93	

Table D2. Variation of Percent Removal of Nitrate (two weeks mean) With Time in 250 mm Column

Time (Week)	Mean Percent Nitrate Removal (%)				
	C:N = 2:1	C:N = 3:1	C:N = 4:1	C:N = 5:1	C:N = 6:1
1	0	48	44	48	60
3	27	76	91	92	93
5	22	72	93	96	93
7	22	73	92	92	95
9	19	74	92	93	94
11	23	73	92	93	95
13	22	76	92	93	92
15	20	74	92	94	95

Table D3. Variation of Percent Nitrate Removal (two weeks mean) With Time in 350 mm Soil Columns

Time (Week)	Mean Percent Nitrate Removal (%)				
	C:N = 2:1	C:N = 3:1	C:N = 4:1	C:N = 5:1	C:N = 6:1
1	2	48	54	58	66
3	26	80	94	94	94
5	22	82	95	97	98
7	25	76	94	94	96
9	22	77	93	96	94
11	23	81	95	96	97
13	23	82	93	94	96
15	25	80	96	95	97

Table D4. Variation of Percent Nitrate Removal (two weeks mean) With Time
in 450 mm Soil Columns

Time (Week)	Mean Percent Nitrate Removal (%)				
	C:N = 2:1	C:N = 3:1	C:N = 4:1	C:N = 5:1	C:N = 6:1
1	6	40	60	56	66
3	29	83	96	96	97
5	24	85	96	97	98
7	27	83	96	96	97
9	26	83	94	96	98
11	26	83	95	97	97
13	26	80	96	96	95
15	26	81	95	97	98

Table D5. Mean Reduction of Nitrate With Soil Depth and C:N Ratios Over 20 Weeks of Operation - Application Rate = 200 mm/wk

C:N Ratio	Mean Percent Nitrate Removal (%)		
	150 mm soil depth	250 mm soil depth	350 mm soil depth
2:1	21	22	23
3:1	72	73	80
4:1	90	92	94
5:1	92	93	95
6:1	93	94	96

450 mm soil depth

26
82
95
96
97

Table D6. Mean Reduction of Nitrate With Soil Depth and C:N Ratios Over Final 8 Weeks of Operation - Application Rate = 420 mm/wk

C:N Ratio	Mean Percent Nitrate Removal (%)					
	150 mm soil depth	250 mm soil depth	350 mm soil depth	450 mm soil depth	250 mm soil depth	350 mm soil depth
2:1	9	22	23	26		
3:1	72	74	81	81		
4:1	89	92	94	94		
5:1	91	93	95	95		
6:1	94	94	96	97		

Table D7. Mean COD Removal Over 20 Weeks - Application Rate 200 mm/wk

Depth of Soil (mm)	Reduction of COD (%)				
	C:N = 2:1	C:N = 3:1	C:N = 4:1	C:N = 5:1	C:N = 6:1
150	41	50	54	58	62
250	62	69	70	74	79
350	74	79	84	88	90
450	84	86	89	89	90

Table D8. Mean COD Removal Over 8 Weeks - Application Rate 420-mm/wk

Depth of Soil (mm)	Reduction of COD (%)				
	C:N = 2:1	C:N = 3:1	C:N = 4:1	C:N = 5:1	C:N = 6:1
150	28	37	43	49	52
250	45	56	65	70	74
350	71	77	83	86	89
450	82	85	89	91	91

Table D9. Mean Values of Dissolved Oxygen Concentration in Treated Effluents Over 28 Weeks

Organic Carbon Applied (mg/L)	Levels of DO Concentration (mg/l)		
	150 mm depth	250 mm depth	350 mm depth
50	5.9	4.8	3.3
75	3.1	2.8	2.3
100	2.2	1.8	1.6
125	1.6	1.2	1.1
150	1.3	1.1	0.9

Table D10. Levels of Residual SOC for Various Soil Columns During 28 Weeks of Operation

Soluble Organic Carbon Applied (mg/L)	Residual Soluble Organic Carbon			
	150 mm depth (mg/L)	250 mm depth (mg/L)	350 mm depth (mg/L)	450 mm depth (mg/L)
50	2	1.5	1.0	0.5
75	3	2.0	2.0	1.5
100	7	4.0	2.5	2.0
125	11	10.0	5.0	4.0
150	14	12.0	9.0	8.0

Table D11. Nitrate Reduction and Dissolved Oxygen Concentration at Various Depths for Different Levels of Ground-water.

Time period	Depth to water table (mm)	Sampling Points		Mean nitrate removal (%)	Mean Dissolved Oxygen Conc. (mg/L)	Remarks
		No.	Depth from top of the ground (mm)			
26/2/81 to 26/3/81	450	1,2,3,4	1000	81	2.0	All the sampling points were in saturated zone.
		5,6	900	79	2.2	
		7,8	800	78	2.4	
		9,10	700	71	2.6	
		11,12	600	45	2.9	
		13,14	500	29	4.5	
2/4/81 to 23/4/81	650	1,2,3,4	1000	80	2.1	All the sampling points were in saturated zone.
		5,6	900	79	2.3	
		7,8	800	74	2.8	
		9,10	700	64	3.0	
		11,12	600	39	4.1	
4/6/81 to 23/7/81	800	1,2,3,4	1000	79	2.2	All the sampling points were in saturated zone except 9 & 10.
		5,6	900	78	2.3	
		7,8	800	74	2.9	
		9,10	700	64	3.2	

Table D12. Total Nitrogen Removal in Soil Columns - Application Rate = 200 mm/wk

C:N	Soil Depths											
	150 mm	250 mm	350 mm	450 mm	Total 'N' in influent (mg/L)	Total 'N' in removal (%)	Total 'N' in influent (mg/L)	Total 'N' in removal (%)	Total 'N' in influent (mg/L)	Total 'N' in removal (%)	Total 'N' in influent (mg/L)	Total 'N' in removal (%)
2:1	27.6	22.4	19	27.6	21.7	27.6	20.9	24	27.6	20.4	26	26
3:1	28.6	10.4	64	28.6	8.5	28.6	8.0	72	28.6	9.4	67	67
4:1	30.3	6.5	79	30.3	5.0	30.3	4.4	85	30.3	4.1	86	86
5:1	31.4	6.7	79	31.4	5.2	31.4	4.9	84	31.4	3.7	88	88
6:1	32.7	7.2	78	32.7	5.8	32.7	4.9	85	32.7	4.0	87	87

APPENDIX E

AMBIENT WEEKLY TEMPERATURE VARIATION
DURING THE SOIL COLUMN STUDY

Table E1. Ambient Weekly Temperature Variation During the Soil Column Study.

Date	Temperature °C
30/6/80	25
7/7/80	25
15/7/80	24
22/7/80	25
29/7/80	24
5/8/80	25
12/8/80	25
19/8/80	24
26/8/80	25
2/9/80	24
10/9/80	24
16/9/80	25
23/9/80	24
30/9/80	24
8/10/80	24
15/10/80	23
22/10/80	24
28/10/80	25
4/11/80	24
11/11/80	23
18/11/80	23
25/11/80	24
2/12/80	24
9/12/80	23
16/12/80	24
22/12/80	25
30/12/80	25
5/01/81	25
12/01/81	23

APPENDIX F
STATISTICAL ANALYSIS

Table F1. Statistical Analysis of Nitrate Removal Using Depth, DO & SOC as Independent Variables

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: NO3		SUM OF SQUARES		MEAN SQUARE	F VALUE	PR > F	R-SQUARE
SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	
MODEL	3	524.64899492	174.88299831	20.63	0.0006	0.93449%	
ERROR	6	36.65600508	6.10933410				
CORRECTED TOTAL	9	561.30500000					
		TYPE I SS	PR > F	DF	TYPE IV SS	F VALUE	
DEPTH	1	17.13879310	0.1450	1	17.57119441	2.88	
DO	1	31.99223400	3.24	1	0.01756236	0.00	
SOC	1	475.51796782	77.83	1	475.51796782	77.83	
		TYPE III	PR > F	STD ERROR OF ESTIMATE			
PARAMETER	ESTIMATE	T FOR HO: PARAMETER=0	PR > F	STD ERROR OF ESTIMATE			
INTERCEPT	43.65695431	0.73	0.4905	59.46035087			
DEPTH	-0.01320508	-1.70	0.1408	0.00778641			
DO	-0.39441824	-0.05	0.9590	7.35433576			
SOC	-0.33792081	-0.02	0.0001	0.04170305			

Table F2. Statistical Analysis of Nitrate Removal Using Depth, DO & COD as Independent Variables

GENERAL LINEAR MODELS PROCEDURE									
DEPENDENT VARIABLE: NH3									
SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	K-SQUARE			
MODEL	3	308.90796078	102.30265359	2.41	0.1651	0.546776			
ERROR	6	254.39703922	42.39750654						
CORRECTED TOTAL	9	561.30500000							
SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F	STD DEV
DEPTH	1	17.13879310	0.40	0.5484	1	6.20526711	0.15		
DO	1	31.99223400	0.75	0.4184	1	21.48613301	0.51		
COD	1	257.77693368	6.00	0.0487	1	257.77693368	6.00		
PARAMETER	ESTIMATE	T FOR HO: PARAMETER=0	PR > T	STD ERROR OF ESTIMATE					
INTERCEPT	154.70150168			0.4382					
DEPTH	-0.00791963	0.83		0.7152					
DO	-16.31045502	-0.71		0.5033					
COD	-0.15646738	-2.17		0.0487					