The Effect of Operating Method and Configuration of Soil Trench System on NH_3-N and NO_3-N Nitrogen Removal: Computer Simulation Results

Xiaohui Lei[1], Norio Sugiura[2] and Takaaki Maekawa[2]
[1]Doctor's Program in Life and Environmental Science, University of Tsukuba, 3050006, 31-503 Ichinoya, 2-1 Tennodai, Tsukuba, Ibaraki, Japan,
Phone: +818054121741, Fax: +81298537496, Email: rain_fields@hotmail.com
[2] Graduate School of Life and Environmental Science, University of Tsukuba, Japan

ABSTRACT

Many studies have confirmed the efficiency of soil trench systems; however, few studies have focused systematically on finding the optimal operating condition and configuration of these systems. In this study, a computer simulation was performed to find the optimal operating condition and configuration of a soil trench, based on the efficiency of ammonium and nitrate nitrogen removal. To achieve this goal, CHAIN_2D—a previous version of Hydrus-2D—was modified to incorporate the effect of soil moisture content and temperature on the nitrification and denitrification reaction rates; it was then used to simulate the dynamics of nitrogen in the soil trench system under 12 different operating conditions and configurations. Based on the result, daily intermittent wastewater application method, configuration with 100 cm depth and 100 cm influent pipe distance and fine-textured soil such as clay loam should be the relative optimal, respectively. This result will be used to design, construct, and operate an improved soil trench system set in a closed container.

Keywords: computer simulation, soil trench, nitrification, denitrification, soil moisture response, septic tank effluent, onsite wastewater

1. INTRODUCTION

Rural and suburban communities are confronted with problems that are unique to their size and population density; they are often unable to apply solutions that are typically applicable to larger urban areas. Untreated wastewater from rural and suburban communities or failed on-site wastewater treatment systems is one of the main factors that result in eutrophication of rivers and lakes. Studies have demonstrated that on-site systems (Attanandana et al. 2000; Yifeng et al. 2004), if constructed and maintained properly, can provide a reliable and efficient means of wastewater treatment and disposal at a relatively low cost.

Generally, an anaerobic septic tank is selected as the first step in the treatment of wastewater; this tank has a hydraulic retention time of 2~5 days. Hence, nitrogen in the effluent of the septic tank is mainly in the form of ammonium nitrogen and organic nitrogen compounds that readily mineralize into ammonium nitrogen. Systems or filters for aerobic treatment can convert all or a portion of the ammonium nitrogen to nitrate. However, once applied to soil, nitrogen can be either denitrified by facultative bacteria or taken by plants (Beggs et al. 2004). Therefore, a soil trench system is generally used to treat the effluent of a septic tank.

A modified soil trench system that possesses a watertight layer to prevent the leakage of nitrates into groundwater and collect the treated wastewater for reuse has been widely used in Japan, China, etc. Many studies (Kong et al. 2002; Yifeng et al. 2004) have confirmed the efficiency of soil trench systems; however, few studies have focused systematically on finding the optimal operating condition and configuration of these system.

To evaluate a soil trench system, many factors can be employed as references; one of the most important factors is the efficiency of nitrogen removal. Due to the worldwide attention on environmental problems, the discharge of water containing ammonium nitrogen into aquatic environments becomes a major concern. Unionized ammonia in water at a concentration range of 0.1 to 10 mg/L causes acute toxicity to fish species (Ukropec et al. 1999). Furthermore, ammonia leads to eutrophication (Cowell and Apsimon 1998) due to a decrease in the amount of oxygen and functions as a source of nitrite and nitrate ions in water. Therefore, the removal of ammonia from wastewater is important. On the other hand nitrates, the product obtained from the nitrification, is also toxic; nitrates ingested by infants may cause methemoglobinemia because of their conversion to nitrites (under anaerobic conditions in the gut) and the subsequent reduction in the oxygen-carrying capacity of hemoglobin (Sandstedt 1990; Wolfe and Patz 2002).

Various mathematical models have been developed to serve as design and research tools. There are many general models (e.g., BioF&T, VS2D, Hydrus-2D, CHAIN_2D, and SUTRA) that can be used for multidimensional analysis of water, solute, and temperature in soil. On the other hand, many specific models (e.g., SOILN, CoupModel, RZWQM, ANIMO, DAISY, and SUNDIAL) focus mainly on carbon and nitrogen dynamics in the soil (Beggs et al. 2004). Hydrus-2D (Simunek et al. 1999) is a model that can be used for simulating two-dimensional variably saturated water flow, heat transport, and the movement of solutes involved in sequential first-order decay reactions that are very important to simulate the nitrogen removal process in soil. This model has been used to model the transport and fate of chemicals from landfills, drainage, and wastewater irrigation.

In this study, a computer simulation was performed to find the optimal operating condition and configuration of a soil trench, based on the efficiency of ammonium and nitrate nitrogen removal. To achieve this goal, CHAIN_2D (Simunek and Van Genuchten 1994), a previous version of Hydrus-2D, was modified to incorporate the effect of soil moisture content (θ) and temperature on the nitrification and denitrification reaction rates. It was then used to simulate the dynamics of nitrogen in a soil trench system under 12 different operating conditions and configurations. Based on the result, the relative optimal operating condition and configuration are described.

2. METHOD

2.1 Modification of CHAIN_2D

During the initial stage of research, we selected Hydrus-2D as the tool to simulate the fate of nitrogen in the soil trench system. However, Hydrus-2D uses only the constant reaction rate coefficients, unlike specific carbon-nitrogen models. Hence, Hydrus-2D needs to be modified; however, it is not an open source software. Therefore, CHAIN_2D was selected as the base for modification because it is an open source software and possesses almost the same features as Hydrus-2D, except for the lack of a Windows interface for pre- and post-processing.

Theoretically, with regard to stable functioning microflora, the nitrification and denitrification reaction rates are affected by many factors such as oxygen, temperature, pH, substrate, and product; oxygen availability can be modeled as a function of the soil moisture content. Hence, the reaction rate can be expressed as follows:

$$f = K_{\max} \cdot f(\theta) \cdot f(T) \cdot f(pH) \cdot f(substrate, product) \tag{1}$$

Here, $K_{\max}$ denotes the maximum nitrification/denitrification rate at the ideal soil moisture content and temperature; $f(\theta)$, $f(T)$, $f(pH)$, and $f(substrate, product)$ represent the response functions of the soil moisture content, temperature, pH, and substrate and product, respectively.

In these response functions, the pH of the soil profile is difficult to measure; hence, the pH response is omitted in this study. The soil moisture and temperature are relatively easy to measure and change quickly, and their responses are always emphasized by different specific carbon-nitrogen models; hence, the widely applied soil moisture and temperature response functions were adopted in the modification of the CHAIN_2D model.

2.1.1 Substrate and Product Response

The growth of functioning microflora was considered in many models; however, it was not adopted for the modification of CHAIN_2D because of the difficulty and complexity in measuring and estimating the required parameters. In order to simplify the model, $f(substrate, product)$ was generally assumed to be first order (Misa et al. 1974a; Misa et al. 1974b; Wagenet et al. 1977) or zero order (Shaffer et al. 2001). In modified CHAIN_2D, these two methods were both realized for nitrification and denitrification. In order to reflect the spatial distribution of the functioning microflora activities, the reaction constant $K_{\max}$ can be represented as the initial condition at any node of the domain.

2.1.2 Moisture Content Response

According to the CoupModel (Jansson and Karlberg 2004), the soil moisture content response function for nitrification can be expressed as follows:

$$f(\theta) = \begin{cases} p_{\theta satact} & \text{when } \theta = \theta_s \\ \min\left(\left(\frac{\theta_s - \theta}{\theta_{Up}}\right)^{p_{\theta p}} (1 - p_{\theta satact}) + p_{\theta satact}, \left(\frac{\theta - \theta_{wilt}}{\theta_{Low}}\right)^{p_{\theta p}}, 1\right) & \text{when } \theta_{wilt} \le \theta < \theta_s \\ 0 & \text{when } \theta < \theta_{wilt} \end{cases} \tag{2}$$

Here, θ, θ_s, and θ_{wilt} denote the soil moisture content (%), saturated moisture content (%), and wilt moisture content (%), respectively; θ_{Up} and θ_{Low} represent the upper and lower moisture content (%), respectively, between which $f(\theta) = 1$, $P_{\theta p}$ and $p_{\theta satact}$ represent the form coefficient (-) and saturation activity (-), respectively.

The soil moisture content response function for denitrification can be expressed as follows:

$$f(\theta)=\begin{cases} 1 \quad \text{when} \quad \theta_s=\theta \\ \left(\dfrac{\theta-\theta_s-p_{\theta DRange}}{p_{\theta DRange}}\right)^{P_{\theta Dp}} \quad \text{when} \quad \theta_s-\theta<P_{\theta DRange} \\ 0 \quad \text{when} \quad \theta_s-\theta>P_{\theta DRange} \end{cases} \tag{3}$$

Here, $p_{\theta DRange}$ denotes the soil moisture content (%) range from saturation and $P_{\theta Dp}$ denotes the form coefficient (-). The schematic figure of the soil moisture content response of nitrification and denitrification is depicted in Figure 1; the parameters used are illustrated in the figure. The relationships between denitrification versus moisture content used in other models show similar trends, but vary in steepness of response near field capacity moisture content.

2.1.3 Temperature Response

In addition to the Arrhenius equation realized by CHAIN_2D, the Q_{10} function (Wu and McGechan 1998) used in the SOILN model was selected and realized. For nitrification and denitrification, the temperature response function can be used with the same or different parameters.

$$f(T)=\begin{cases} t_{Q10}{}^{(T-t_{Q10bas})/10} \quad \text{when} \quad (T\geq t_{Q10threshold}) \\ \dfrac{T}{t_{Q10threshold}}t_{Q10}{}^{(T-t_{Q10bas})/10} \quad \text{when} \quad (T<t_{Q10threshold}) \end{cases} \tag{4}$$

Here, t_{Q10} denotes the response to a 10℃ soil temperature change (-); t_{Q10bas}, the base temperature (℃) at which $f(T)=1$; $t_{Q10threshold}$, the threshold temperature (℃) below which the temperature response is a linear function of temperature; and T, the soil temperature (℃). Further, the schematic diagram of the temperature response of nitrification and denitrification is also depicted in Figure 1 with same parameters.

2.2 Reference Soil Trench System

In order to find the relative optimal operating condition and configuration, an existing soil trench system, located 100 m from the Dianchi Lake in Kunming, China, was used as a reference. This system was constructed in Jan. 2003; it has a septic tank with a capacity of 12.5 m^3. The effluent from the septic tank was fed to a modified soil trench system with two similar parallel trenches, each with a bottom area of 250 m^2. The designed hydraulic loading was 2 cm/day and

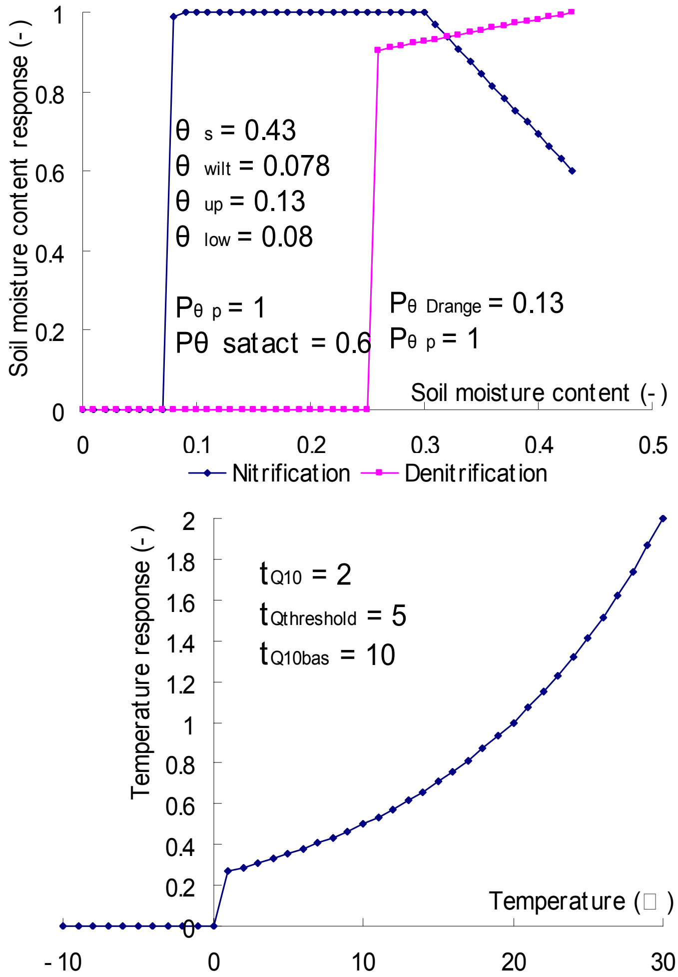

Figure 1. Soil moisture content and temperature response of nitrification/denitrification for loam

the ammonium nitrogen concentration was 40~80 mg/L. The influent concentration of nitrate for the soil trench system, which is the effluent of septic tank, can be regarded as 0 mg/L. The depth of the soil trench system is 60 cm and the distance between the influent pipes is 200 cm. There are three layers in the soil trench system: the 10-cm-thick top layer was filled with raw soil (loam) on which ryegrass was planted; the 40-cm-thick middle layer was backfilled with mixed soil (loam 60%, slag 30% and humus soil 10% etc.) in which the influent pipes at a depth of 25 cm are located; and the 10-cm-thick third layer was composed of gravel. The effluent pipes were located in the bottom layer. In order to collect the treated water effectively and prevent leakage into the deep groundwater, a waterproof material was laid at the bottom of the soil trench system.

2.3 Numerical Experiment

The result obtained from this study will be used to design a new soil trench system set in a large closed container and with higher nitrogen removal efficiency; hence, precipitation and evapotranspiration from the top layer was not considered in the computer simulation. Further, because of the insignificant effect of gravel on the effluent quality and flux, the bottom layer was also omitted.

Table 1. Configuration of the schemes for the computer simulation

Scheme	Size (Depth × Width)	Soil	Wastewater application
1-1	50 × 100 cm	loam	Daily intermittent
1-2	50 × 100 cm	loam	Weekly intermittent
1-3	50 × 100 cm	loam	Continuous
1-4	50 × 100 cm	loam	Continuous with half loading
2-1	100 × 100 cm	loam	Daily intermittent
2-2	100 × 100 cm	loam	Weekly intermittent
2-3	100 × 100 cm	loam	Continuous
2-4	100 × 100 cm	loam	Continuous with half loading
3-1	100 × 100 cm with impermeable layers	loam	Daily intermittent
4-1	100 × 50 cm	loam	Daily intermittent
4-2	100 × 50 cm	clay loam	Daily intermittent
4-3	100 × 50 cm	sandy loam	Daily intermittent

The relative optimal operating condition and configuration were evaluated using 12 schemes that comprised 4 configurations, 3 soil types, and 4 wastewater application methods. Because the cross section of the soil trench was axial symmetrical, half of the soil trench was considered for the numerical simulation. A detailed description of these schemes is provided in Table 1, and the configuration and finite-element meshes are shown in Figure 2. In the table, daily/weekly intermittent means that the wastewater is applied intermittently to both the soil trenches on a daily/weekly basis with a loading of 2 cm/day. Continuous means that the wastewater is continuously applied to one of the soil trench systems with a loading of 2 cm/day. Continuous with half loading means that the wastewater is continuously applied to both the soil trench systems with a loading of 1 cm/day.

The basic solute chain reaction modeled in this study was $NH_4^+ \rightarrow NO_3^- \rightarrow N_2$. The influence of fast-reacting intermediate or minor reaction products such as NO_2^- and N_2O was considered together with that of the major compounds, in the same manner as Beggs, Tchobanoglous et al. (2004). The computer simulation extended for 70 days, and water flow, heat transport, and solute transport and transformation were simulated. The NH_4^+ and NO_3^- concentration of the influent into the soil trench system was assumed as 80 mg/L, 0 mg/L, respectively.

2.3.1 Soil Water and Temperature Parameters

The soil water and temperature parameters were selected from the Hydrus-2D database, and the soil water hydraulic parameters were listed in Table 2. For simplification, the temperature of the influent was set to 20℃ and the air temperature was set to 25℃.

Table 2. The soil water hydraulic parameters

	θ_r	θ_s	α	n	K_s	l
Loam	0.078	0.43	0.036	1.56	1.04	0.5
Clay loam	0.095	0.41	0.019	1.31	0.26	0.5
Sandy loam	0.065	0.41	0.075	1.89	4.42083	0.5

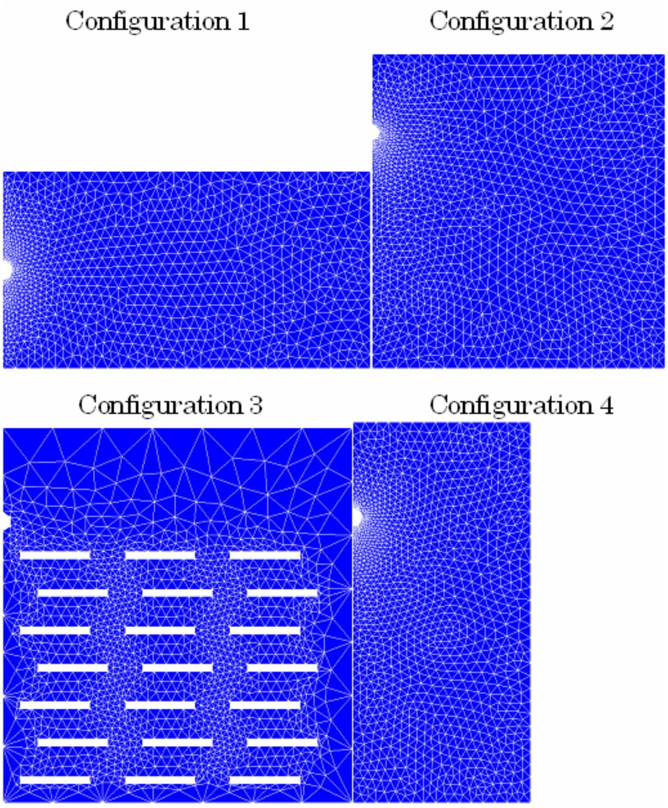

Figure 2. Configurations and finite-element meshes used in the computer simulation. Configuration 1: Depth of 50 cm and width of 100 cm. Configuration 2: Depth of 100 cm and width of 100 cm. Configuration 3: Depth of 100 cm and width of 100 cm with impermeable layers. Configuration 4: Depth of 100 cm and width of 50 cm

2.3.2 Solute Transport, Absorption, and Transform Parameters

A dispersion value of 10 cm in the longitudinal direction and 1 cm in the transverse direction, as used by Cote, Bristow et al. (2003) were selected. The ammonium and nitrate diffusivities in free water were considered to be 1.55 cm^2/day (Cote et al. 2003) and 1.63 cm^2/day (Beggs et al. 2004), respectively.

Based on the studies by Misa, Nielsen et al.(1974b), Wagenet, Biggar et al. (1977), Surprayogo, Vannoordwijk et al. (2002) and Buss, Herbert et al. (2003), ammonium absorption values of 1.0×10^{-6} cm^3/g, 3.0×10^{-6} cm^3/g, and 6.0×10^{-6} cm^3/g were used for sandy loam, loam, and clay loam, respectively; a nitrate absorption value of 1.0×10^{-7} cm^3/g was used for all the soils. The same values were used for these parameters by Beggs, Tchobanoglous et al. (2004).

For a high concentration substrate, such as an agricultural fertilizer, the nitrification and denitrification reactions rates can be simplified using zero-order reaction rates; for the low concentration range, such as the one used in this research, a first-order reaction rate may be appropriate. For nitrification and denitrification, the maximum reaction rates at the ideal soil moisture content at 20℃ were selected as 0.72 L/day and 0.072 L/day, respectively; these values were used by Misa, Nielsen et al. (1974a; 1974b).

2.3.3 Soil Moisture and Temperature Response Parameters

Parameters of soil moisture response, θ_{Up}, θ_{Low}, $P_{\theta p}$, $p_{\theta satact}$, $p_{\theta DRange}$ and $P_{\theta Dp}$ were selected as 0.13, 0.08, 1, 0.6, 0.13 and 1, respectively according Jansson and Karlberg (2004). Parameters of soil temperature response, t_{Q10}, t_{Q10bas} and $t_{Q10threshold}$ were selected as 2, 10 and 5, respectively according Wu and McGechan (1998). Graphs of these response parameters were shown in Figure 1.

2.3.4 Initial Condition

The initial conditions were set as follows: the pressure head was uniform -50 cm, temperature was uniform 20℃, and the ammonium/nitrate nitrogen concentration was uniform 0 mg/L.

2.3.5 Boundary Condition

The atmospheric boundary was set as the top boundary, the seepage boundary was set as the low boundary, and the boundary in contact with the influent pipe was set as the variable flux condition.

3. RESULTS AND DISCUSSION

3.1 Optimal Wastewater Application Method

The results obtained from the 12 schemes are shown in Table 3 and Figure 3. From the results, we can find that for configurations 1 and 2, the ammonium nitrogen removal rate is in the following order: continuous with half loading > daily intermittent > weekly intermittent > continuous. However, with regard to the ammonium and nitrate nitrogen removal rate, the daily intermittent method leads to the highest values among all the wastewater application methods except for scheme 1-2. It is well known that wet-dry cycling improves the nitrogen removal performance of large-scale rapid infiltration systems (Crites and Tchobanoglous 1998) because the wetting process can increase the soil moisture content as well as the denitrification rate; on the contrary, the drying process can increase the availability of oxygen in soil as well as the nitrification rate. This can be verified by our result. Hence, for the same configuration, the daily intermittent method would be the optimal wastewater application method based on the ammonium and nitrate nitrogen removal rate.

3.2 Optimal Structure

Initially, configuration 1 was used in the simulation; however, its ammonium nitrogen removal rate is relatively low, which may caused by the low depth of the soil trench and then incomplete nitrification of ammonia in the influent. Further, by analyzing the concentration distribution of ammonium nitrogen on the 69th day (Figure 4), it was assumed that if the depth of the soil trench were increased to 100 cm, the ammonium removal rate might improve.

Therefore, configuration 2 was designed. From Table 3 and Figure 3, it can be found that the ammonium nitrogen removal rate improved significantly. Further, from Figure 4, it can be found that the concentration of the ammonium nitrogen in the effluent decreases to almost zero with an increase in the soil depth from 50 to 100 cm.

Table 3. Simulation result of the 12 schemes

Scheme	NH_4^+-N **removal rate (%)**	NH_4^+-N + NO_3^--N **removal rate (%)**	**Influent** NH_4^+-N **(mg/cm)**	**Effluent** NH_4^+-N **(mg/cm)**	**Effluent** NO_3^--N **(mg/cm)**	**Nitrified** NH_4^+-N **(mg/cm)**	**Denitrified** NO_3^--N **(mg/cm)**
1-1	74.46	21.96	560.00	143.00	294.00	409.00	54.90
1-2	68.04	23.21	560.00	179.00	251.00	318.00	52.60
1-3	59.64	13.57	1120.00	452.00	516.00	650.00	72.70
1-4	75.71	21.61	560.00	136.00	303.00	413.00	55.30
2-1	99.15	45.85	560.00	4.76	299.00	546.00	78.60
2-2	96.93	43.28	560.00	17.20	301.00	541.00	83.40
2-3	95.25	31.59	1120.00	53.20	713.00	1040.00	145.00
2-4	99.25	45.32	560.00	4.21	302.00	541.00	75.60
3-1	98.66	54.45	560.00	7.52	248.00	519.00	105.00
4-1	99.93	46.71	280.00	0.20	149.00	276.00	48.50
4-2	99.91	82.95	280.00	0.24	47.50	273.00	173.00
4-3	99.80	31.23	280.00	0.56	192.00	277.00	24.60

Note: the difference of influent volume were caused by wastewater application method and width of the soil trench system

It was considered that the ammonium nitrogen removal rate would decrease insignificantly for the 50-cm-wide configuration. And with a decrease in the width, the loading of wastewater would be also decreased, and then ammonium, nitrate nitrogen removal rate would also improve. Hence, configuration 4 was designed, and the above assumption was verified from the result.

For configuration 4, the ammonium nitrogen concentration was almost 0 mg/l in the lower one-third of the domain (Figure 4); further, for scheme 4-1, the ammonium and nitrate nitrogen removal rate improved as compared with scheme 2-1.

Hence, a soil trench system with a width of 50 cm (distance between the influent pipes: 100 cm) and a depth of 100 cm is adequate for sufficient nitrification of the influent ammonium nitrogen. This distance is considerably less than most design recommendations, which suggest a distance of 200 cm (USEPA 2002) based entirely on the infiltrative capacity of clay; however, this distance is unnecessarily large for clay loam, loam, sandy loam, etc. Hence, with the narrow width, the required land area can be significantly decreased. In addition, under the same conditions, a shorter width would increase the soil moisture content of the domain along with an increase in the global denitrification activity of the domain without considerably affecting global nitrification. This is because there is sufficient space for nitrification; even under the saturated condition, a relatively high nitrification rate can be maintained as compared with the denitrification rate.

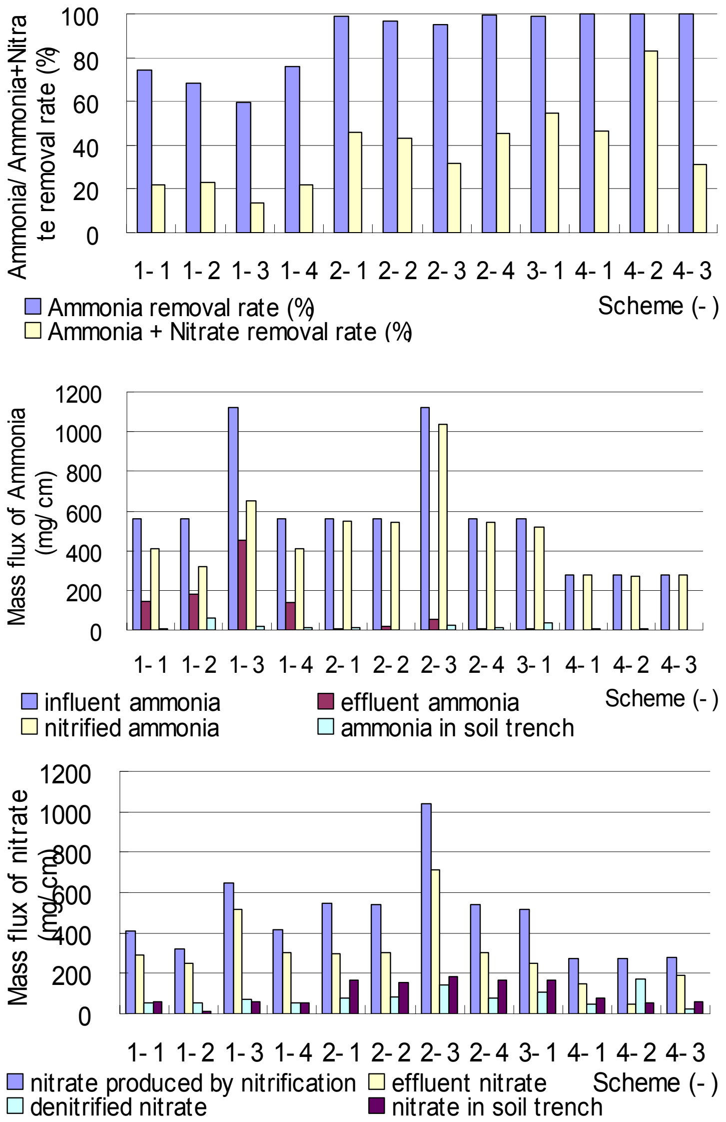

Figure 3. Ammonium, ammonium and nitrate removal rate; mass balance of ammonium and nitrate

3.3 Optimal Soil

For configuration 4, the ammonium and nitrate nitrogen removal rate was only 46.71% for the daily intermittent wastewater application method. Hence, different soils such as sandy loam and clay loam, instead of loam, were used to evaluate the ammonium and nitrate nitrogen removal rate. From Table 3 and Figure 3, it can be found that the ammonium and nitrate nitrogen removal rate increased significantly for the configuration with clay loam soil; the ammonium nitrogen removal rate was still maintained at a high level (close to 100%). Hence, for the configuration with a depth of 100 cm and width of 50 cm, clay loam is theoretically the optimal soil for ammonium and nitrate nitrogen removal.

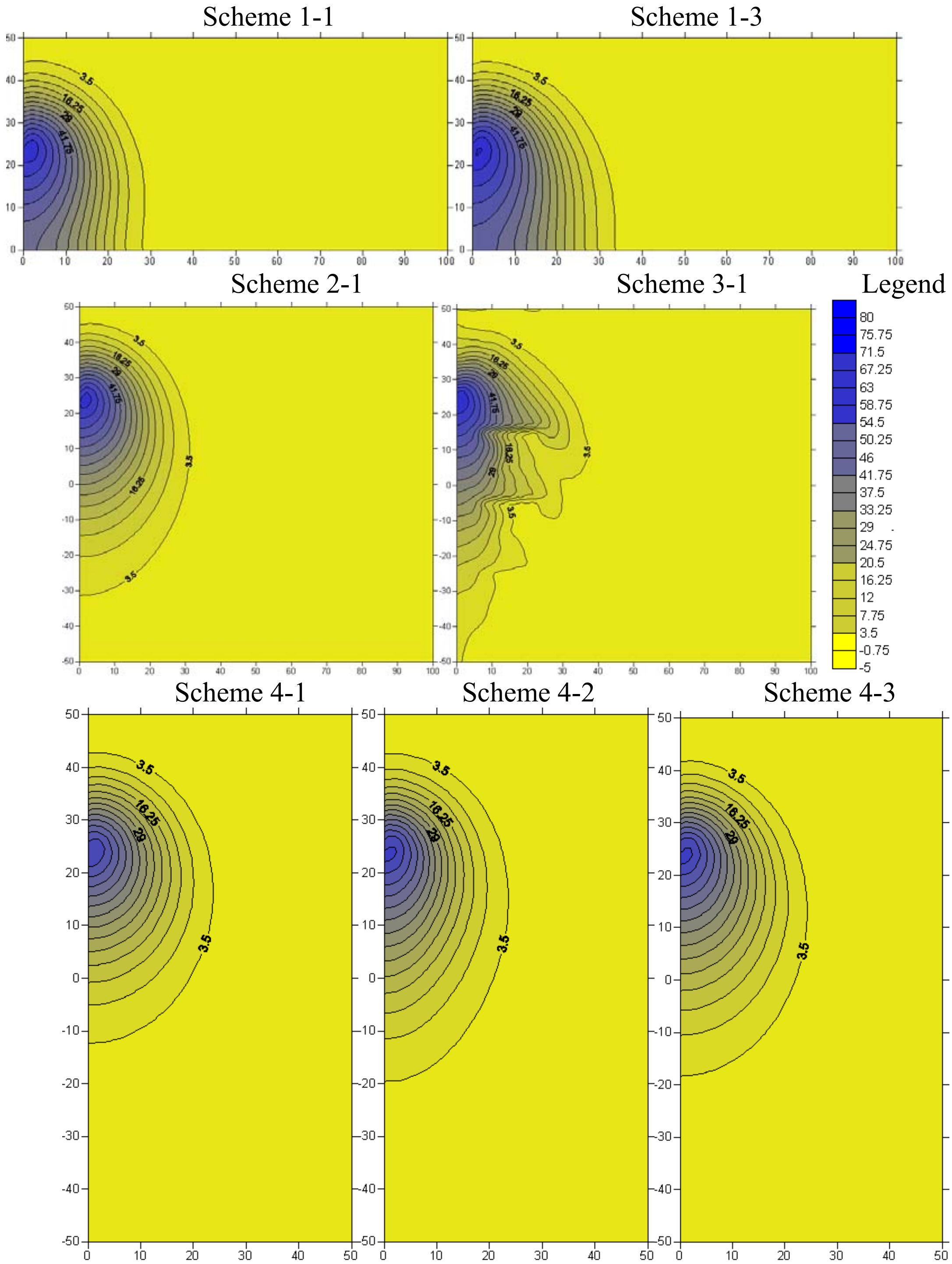

Figure 4. Distribution of the ammonium concentration in the soil trench on the 69th day (mg/L)

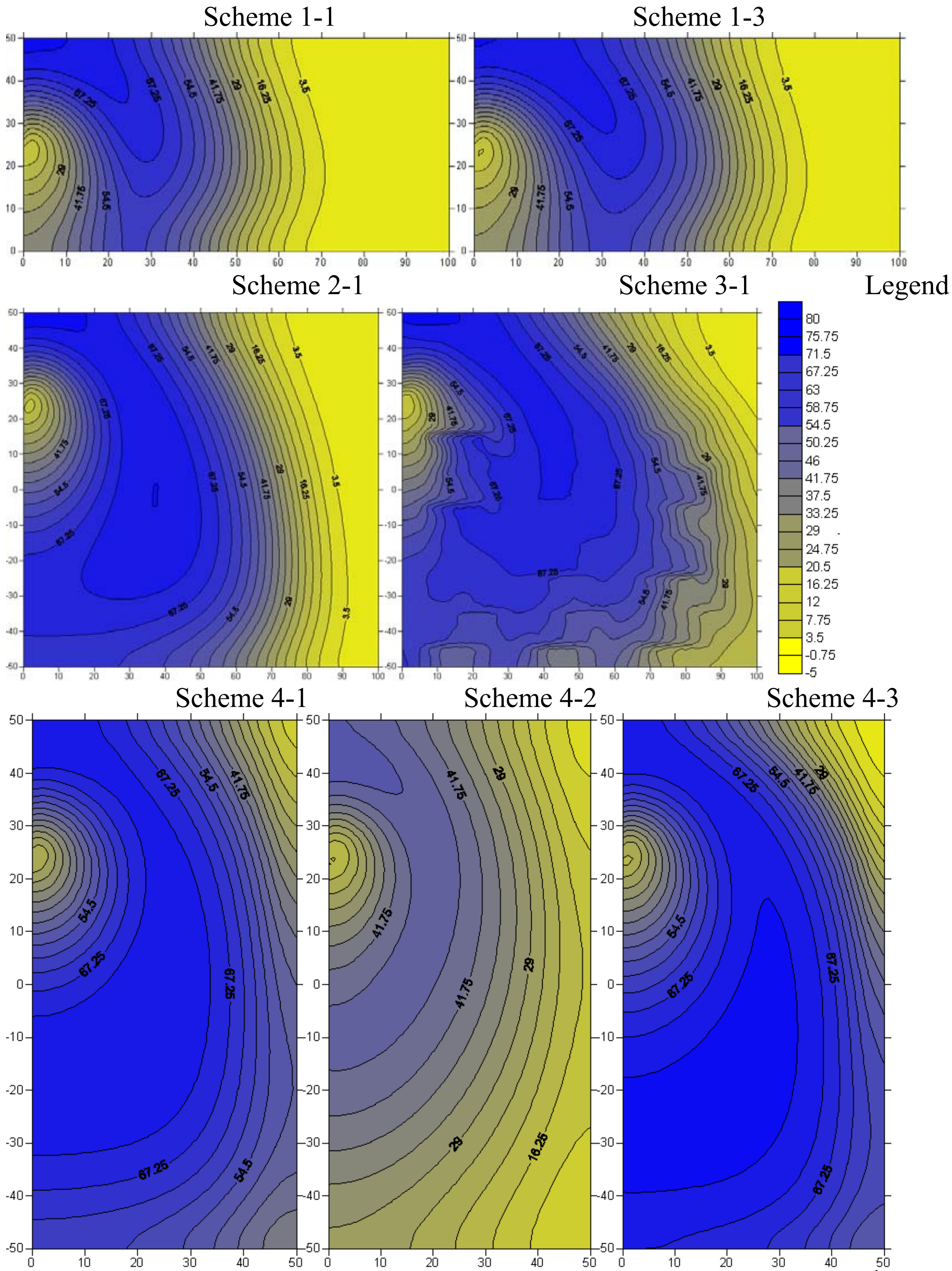

Figure 5. Distribution of the nitrate concentration in the soil trench on the 69th day (mg/L)

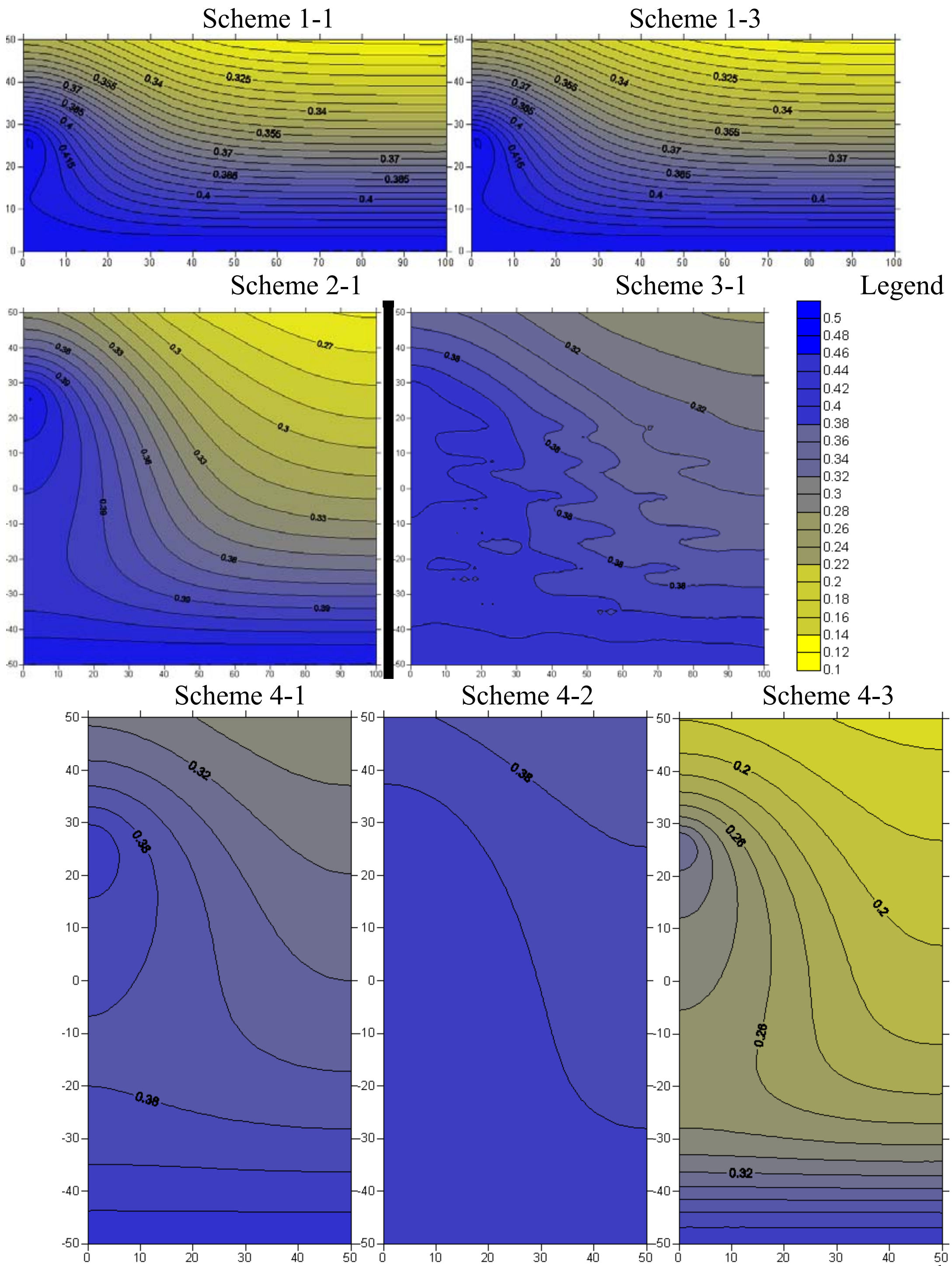

Figure 6. Distribution of the soil moisture content in the soil trench on the 69th day

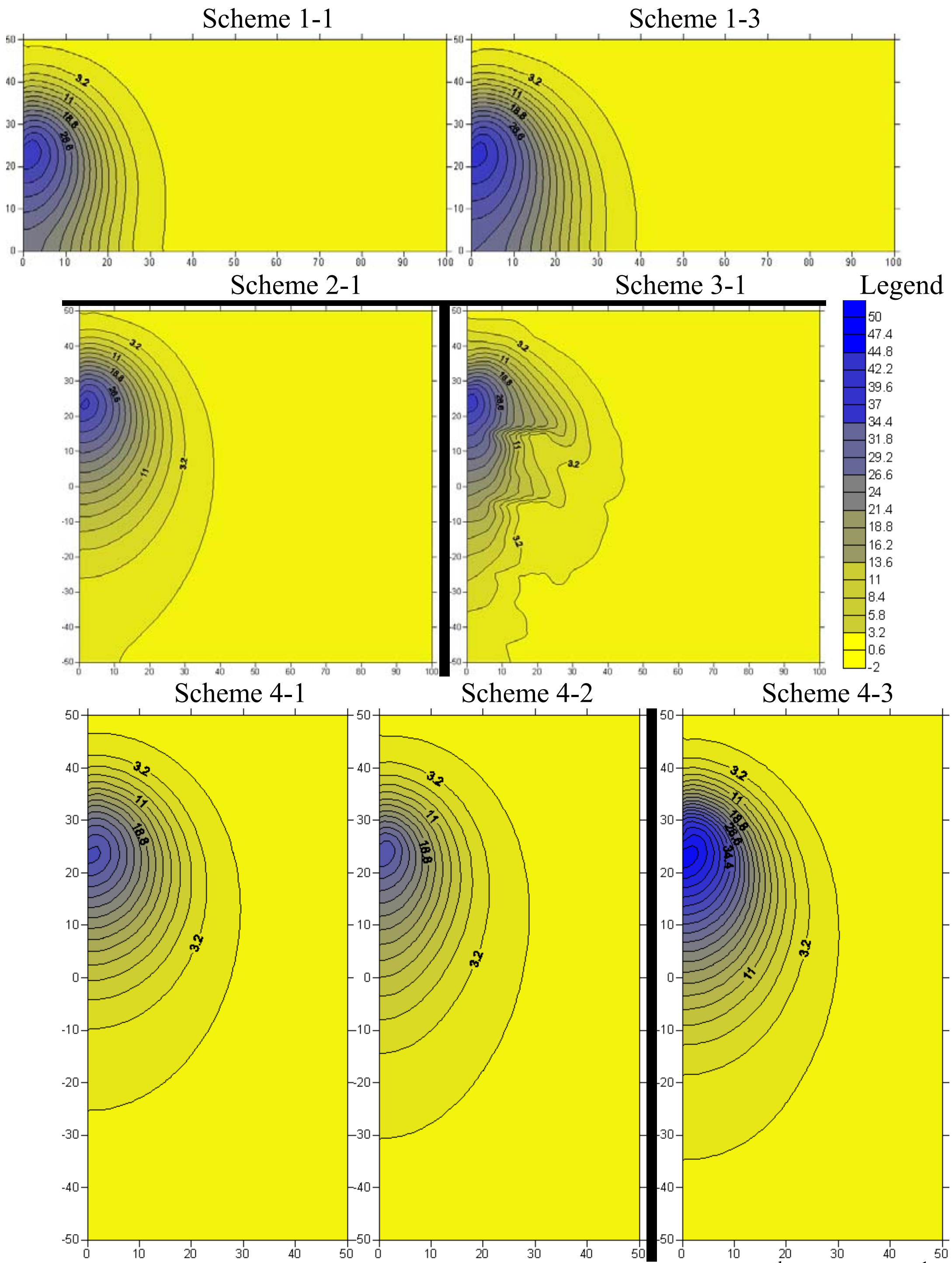

Figure 7. Distribution of nitrification rate in the soil trench on the 69th day (mg L^{-1} day^{-1})

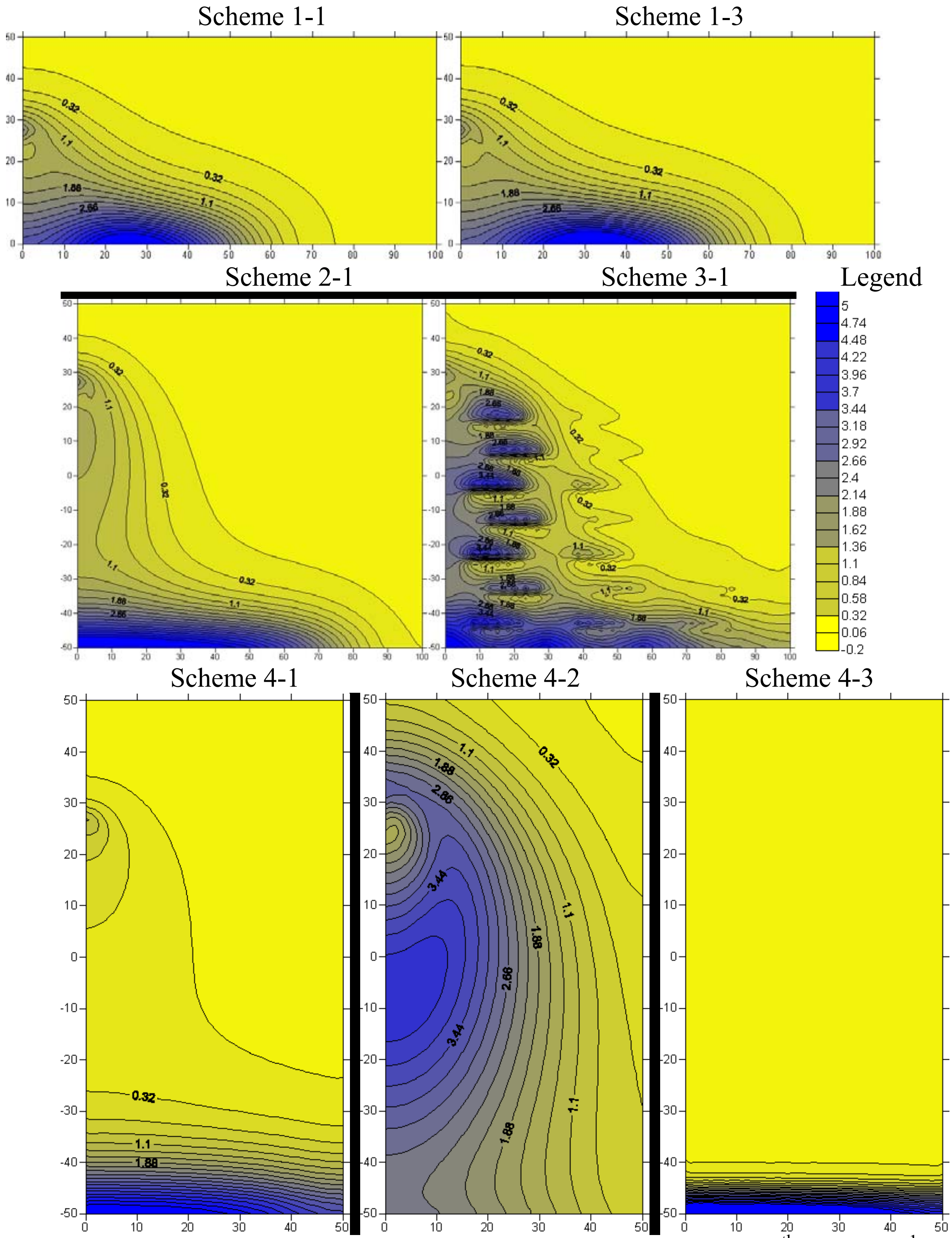

Figure 8. Distribution of denitrification rate in the soil trench on the 69th day (mg $^{-1}$ day^{-1})

3.4 Distribution of Nitrification and Denitrification Rates

The distribution of the nitrification and denitrification rates is illustrated in Figures 7 and 8, respectively. And the different patterns of the nitrification/denitrification distribution were mainly caused by that of the soil moisture content in different schemes (Figure 6).

For configuration 1, the region with a relatively high nitrification rate was very small; the size of this region was comparatively larger for configurations 2, 3, and 4. For configuration 4, sandy loam exhibited the highest nitrification rate. On the other hand, clay loam exhibited the lowest nitrification rate; however, it was sufficient to nitrify the influent ammonium nitrogen to nitrate nitrogen.

The denitrification rate of scheme 4-2 was very high when compared with the other schemes, which was the reason for the very high ammonium and nitrate nitrogen removal rate. The denitrification rate in scheme 4-3 was the lowest among all the schemes. For scheme 3-1, the impermeable layers improved the denitrification rate in the vicinity of these layers as compared with that exhibited by scheme 2-1.

4. CONCLUSION

Based on the results, daily intermittent wastewater application method, configuration with 100 cm depth and 100 cm influent pipe distance and fine-textured soil such as clay loam were found to provide the theoretical relative optimal conditions for overall nitrogen removal.

The abovementioned result will be used in the design and operation of a new soil trench system that will be set in a closed container; hence, the precipitation and evapotranspiration were not considered in the numerical simulation. However, these should be incorporated for other soil trenches that are subjected to precipitation and evapotranspiration. This can be achieved by adding some comparatively complex and precise plant growth and uptake models to CHAIN_2D, which is oversimplified in CHAIN_2D.

It is important that the computer simulation results meet those of the field experiment; moreover, a field experiment should be conducted to validate the result of the computer simulation. Currently, the design and the construction of a new soil trench system were completed by mid Nov. 2005; and the results obtained in this study will be validated in the future experiments. Other factors, such as the long term hydraulic reliability of the soil trench system, also need to be evaluated in the field experiment.

In a model envisaged for the future, the substrate/product response to the nitrification and denitrification rates should be taken into account in much more realizable form, such as the Monod model; further, directly modeling oxygen diffusion and the growth and decay of microflora should also be considered.

5. ACKNOWLEDGEMENT

This research was supported by the Strategic International Cooperative Program, JST.

6. REFERENCES

Attanandana, T., B. Saitthiti, S. Thongpae, S. Kritapirom, S. Luanmanee and T. Wakatsuki 2000. Multi-media-layering system for food service wastewater treatment. *Ecological Engineering* 15: 133-138.

Beggs, R. A., G. Tchobanoglous, D. Hills and R. W. Crites Year. Modeling subsurface drip application of onsite wastewater treatment system effluent. In *On-Site Wastewater Treatment X*, 92-103. Sacramento, California USA, 21-24 March.

Buss, S. R., A. W. Herbert, P. Morgan and S. F. Thornton 2003. *Environment Agency Review of Ammonium Attenuation in Soil and Groundwater*. Almondsbury, Bristol, England, Environment Agency.

Cote, C. M., K. L. Bristow, P. B. Charlesworth, F. J. Cook and P. J. Thorburn 2003. Analysis of soil wetting and solute transport in subsurface trickle irrigation. *Irrigation Science* (22): 143-156.

Cowell, D. A. and H. M. Apsimon 1998. Cost-effective strategies for the abatement of ammonia emissions from European agriculture. *Atmospheric Environment* 32(3): 573-580.

Crites, R. W. and G. T. Tchobanoglous 1998. *Small and Decentralized Wastewater Management Systems*. New York: WCB/McGraw-Hill.

Harte, J., C. Holdren, R. Schneider and C. Shirley 1991. *Toxics A to Z: A Guide to Everyday Pollution Hazards*. Berkeley: University of California Press.

Jansson, P.-E. and L. Karlberg 2004. *Coupled heat and mass transfer model for soil-plant-atmosphere systems*. Stockholm, Royal Institute of Technology, Department of Civil and Environmental Engineering.

Kong, H. N., Y. Kimochi, M. Mizuochi, R. Inamori and Y. Inamori 2002. Study of the characteristics of CH_4 and N_2O emission and methods of controlling their emission in the soil-trench wastewater treatment process. *The Science of the Total Environment* 290(1-3): 59-67.

Misa, C., D. R. Nielsen and J. W. Biggar 1974a. Nitrogen transformations in soil during leaching: II. Steady state nitrification and nitrate reduction. *Soil Science Society of America Proceedings* 38: 294-299.

Misa, C., D. R. Nielsen and J. W. Biggar 1974b. Nitrogen transformations in soil during leaching: III. Nitrate reduction in soil columns. *Soil Science Society of America Proceedings* 38: 300-304.

Nash, L. 1993. *Water quality and health*. New York: Oxford Univerity Press.

Sandstedt, C. A. 1990. *Nitrates: sources and their effects upon humans and livestock*. Washington, DC: American University.

Shaffer, M. J., L. Ma and S. Hansen 2001. *Modeling Carbon and Nitrogen Dynamics for Soil Management*. Boca Raton, FL: CRC Press.

Simunek, J., M. Sejna and M. T. van Genuchten 1999. *HYDRUS-2D / MESHGEN-2D: Simulating water flow and solute transport in two-dimensional variably saturated media*. Golden, Colorado, International Groundwater Modeling Centre, Colorado School of Mines.

Simunek, J. and M. T. Van Genuchten 1994. *The CHAIN_2D code for simulating two-dimensional movement of water, heat, and multiple solutes in variably-saturated porous media*. Riverside, California, U.S. Salinity laboratory.

Surprayogo, D., M. Vannoordwijk, K. Hariah and G. Cadisch 2002. The inherent 'safety net' of an Acrisol: measuring and modeling retarded leaching of mineral nitrogen. *European Journal of Soil Science* 53(2): 185-194.

Ukropec, R., B. F. M. Kuster, J. C. Schouten and R. A. van Santen 1999. Low temperature oxidation of ammonia to nitrogen in liquid phase. *Applied Catalysis B: Environmental* 23(1): 45-57.

USEPA 2002. *Onsite wastewater treatment systems manual*, U.S. Environmental Protection Agency.

Wagenet, R. J., J. W. Biggar and D. R. Nielsen 1977. Tracing the transformations of urea fertilizer during leaching. *Soil Sci. Soc. Am. Journal* 41: 896-902.

Wolfe, A. H. and J. A. Patz 2002. Reactive nitrogen and human health: Acute and long-term implications. *Ambio: A Journal of the Human Environment* 31(2): 120-125.

Wu, L. and M. B. McGechan 1998. A review of carbon and nitrogen processes in four soil nitrogen dynamics models. *Journal of Agricultural Engineering Research* 69(4): 279-305.

Yifeng, Lu., W. Donghui, T. Xiaoyan, M. Takaaki, W. Weizhong, S. Norio, Z. Zhenya and Y. Jifu 2004. Treatment of fecal sewage by the land infiltration system in Haigeng Park in the Dianchi Lake catchment. *Biosystem Studies (ISSN:1344-7432)* 7: 1-12.