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Experimental analysis of a nitrogen removal process simulation of wastewater land treatment under three different wheat planting densities

WANG Hong-qi*[1], CHEN Jia-jun[1], TIAN Kai-ming[3], LU Yan[2]

(1. State Key Joint Laboratory of Environmental Simulation and Pollution Control, Institute of Environmental Sciences, Beijing Normal University, Beijing 100875, China. E-mail: whongqi @ public. bta. net. cn; 2 Plant of Water and Electricity Supply, Huabei Oil-Field, Renqiu 062552, China; 3. Department of Water Resources and Environmental Science, China University of Geoscience, Beijing 100873, China)

Abstract: Nitrogen contaminant transport, transformation and uptake simulation experiments were conducted in green house under three different planting density of winter wheat. They were Group A, planting density of 0.0208 plants/cm^2, Group B, 0.1042 plants /cm^2, and Group C, 0.1415 plants/cm^2. The capacity and ratio of nitrogen removal were different on three kinds of conditions of wastewater land treatment. From analysis of wastewater treatment capacity, wastewater concentration and irrigation intensity for Group C were suitable and nitrogen quantity added was 2 times of that for Group B, 2.6 times for Group A while nitrogen residue was only 7.06%. Hence, wastewater irrigation and treatment design with purpose of waste water treatment should select the design with maximum capacity, optimal removal ratio and least residue in soil, which was closely related to crop planting density, crop growth status and also background nitrogen quantity in soil.

Keywords: wastewater land treatment; planting density; winter wheat; nitrogen removal; soil

Introduction

Wastewater land treatment eco-engineering system is a system based on the complicated physical, chemical and biological process and self adjustment mechanism, as well as dilution capacity of contaminant, to treat municipal domestic wastewater as well as some industrial wastewater so that organic contaminants and inorganic nutrients in wastewater can be transformed and removed and meanwhile the growth of green plant can be promoted and production yield can be increased through bio-geochemical circulation of nutrients and water to realize wastewater recovery and nonhazardization. This is tertiary treatment of waste water that many developed countries in the world adopted (Avoogadro, 1994). In last few years, much research work had been done in the country on mechanisms of wastewater land treatment and design in natural wastewater cleaning up system. Since the Seventh Five-year Plan of China, large scale (with big area) municipal wastewater land treatment have been conducted and demonstration system has been setup, in which there are different land treatment systems, such as slow rate infiltration (Gao, 1991), rapid infiltration (Wang, 1994), overland flow, artificial or natural wet land, underground seepage as well as some composite system. Musharrafeh, Ghassan R., Richard C. Peralta, Lynn. M. Dudley *et al*. (Musharrafeh, 1995) made sophisticated analysis of optimal irrigation management with pollution control in wastewater irrigation. Wang Hongqi and Ju Jianhua (Wang, 1998) introduced typical designing parameter and system specification of different kind of land treatment, Kurt Roth (Kurt, 1999) made a comprehensive analysis of contaminant migration pattern and process in aerated zone. Groot (Groot, 1991), Mengel (Mengel, 1992) conducted simulation analysis of crop growth mass circulation process based on crop ecological process. Wang Hongqi and Li Yunzhu (Wang, 1997) made integrated simulation analysis of the performance and patterns of nitrogen in crop growth and in migration process in consideration of crop growth, uptake by root and water, solute circulation process in SPAC system. Jiang Cuiling *et al*. (Jiang, 1997), Fatta *et al*. (Fatta, 1999) analyzed soil and ground water pollution by wastewater irrigation through in-situ investigation. This is helpful for land treatment system designing in engineering aspect and for study

Foundation item: The National Natural Science Foundation of China (No. 29777001). * Corresponding author of contaminant migration pattern in soil and it is productive in research. Nevertheless since wastewater land treatment involves complicated physico-chemical and bio-chemical process, it is difficult to study the mechanism and pattern of wastewater cleaning up. In this study, it was shown that intrinsic relationship of contaminant in each component of the soil-crop system through simulation experiment of nitrogen contaminant degration, migration, chemical transformation, uptake by root and circulation process under conditions of municipal wastewater land treatment, mechanisms of self adjustment in wastewater land treatment and comprehensive cleaning up capability was discussed, and wastewater treatment capacity as well as the influence pattern on plant growth was analyzed under different planting density.

1 Materials and methods

1.1 Experiments condition

The experiment was conducted in the green house under artificial condition. There is aerodynamics adjusting system with air venting and cooling in the green house in which dried and wet bulb thermometer was installed to monitor indoor temperature and humidity. Apparatus for monitoring evaporation in the water surface, evaporation in the soil, and evapo-transporation in the soil-crop system were also installed to monitor indoor meteorological and plant growth condition.

1.2 Experiment design scheme

In this study, simulation devices for three different planting density were designed and experiments of different wastewater treatment intensity were conducted.

Group A: single row winter wheat was planted on the top, 4 experiment devices were designed. The growth period of winter wheat was divided into 4 stages. The devices were shaped as volume of 80 cm × 30 cm × 95 cm. 50 individual winter wheat were planted in single row, its average planting density is 0.0208 plants/cm^2.

Group B: winter wheat was planted on the top, 4 experiment devices were designed. The growth period of winter wheat is divided into 4 stages. 5 rows of winter wheat were planted in each device. The distance between rows is 15 cm and the distance of outer row to the edge of device is 10 cm. There is 50 winter wheat plants in each row. Total of the winter wheat plants are 250. The devices were shaped as volume of 80 cm × 30 cm × 95 cm. The average winter wheat planting density is 0.1042 plants/cm^2.

Group C: Winter wheat was planted on the top uniformly in a scatter manner with certain number of crops concentrating around each point, 5 experiment devices were designed. The growth period of winter wheat is divided into 5 stages. Devices are shaped as cylinder with diameter of 15 cm and height of 100 cm. 25 winter wheat plants were planted in each device. They were divided into 5 groups, planting uniformly on the surface of soil column. The average planting density is 0.1415 plants/cm^2.

1.3 Monitoring function of experiment devices

There are following monitoring functions designed for experiment devices:

(1) Soil maxtric potential monitoring: WM-1 type tentiometer with mercury chamber and observing panel were installed in sectional two-dimension in order to monitor water potential variation dynamics at different location in the section. Horizontal distance between tentiometer probes is 10 cm and vertical distance is 10 cm.

(2) Timed sampling of soil water content: there is small openings at locations corresponding to each tentiometer probe for timed soil water content sampling to be conducted in order to monitor water content distribution in experiment process.

(3) Sampling of nitrogen concentration in soil: timed soil sampling were conducted at locations same with soil water content sampling location, and NH_4^+, NO_3^- concentration in soil at different time were measured, in order to analyze nitrogen concentration distribution and variation dynamics.

(4) Crop roots visual system: on the other side of device there is glass window installed for view, which is covered by black plastics. Crop rooting pattern can be described by putting off the cover periodically. Root distribution can be measured by grid method. Growth speed of roots can be analyzed by taking pictures of roots at the same ratio.

(5) Crop root length and density measuring system: timed sampling in different layers were conducted in different devices by 10 × 10 × 15 grid and samples were washed sequentially. Root length was measured in different small cubes by grid overlay method in order to analyze root length and density at this point.

(6) Performance monitoring system of the upper part of crop above the surface: crop stem height, number of leaves, and the beginning time and completion percent were measured everyday. 10 crops were taken periodically to measure leaf area index, water content of crops, dried mass and nitrogen content in plant and thus the dried mass of plant and nitrogen quantity uptake etc. in all devices could be calculated. A series of crop parameters, such as weight of crop seeds, nitrogen quantity, water content, seed weight per crop, number of seeds per stem, number of non-pregnant small flowers, each section length of stems were measured when harvesting, and this could serves as basis for the follow up simulating calculation.

1.4 Property of soils in the experiment

The same type of soil was used and the same kind of treatment, such as filtering and compressing, was adopted in the experiment in order to analyze the influence of different planting patterns. The designed bulk density of soil is 1.416 g/cm^3. Soil was refilled in experiment devices with compression of soil each 5 cm thick. The soil type is loam. The results of grain analysis and the chemical property of soil are shown in Table 1 and Table 2, respectively.

Table 1 The ratio of soil grain analysis(%)

Sample	Size, mm					
	1 - 0.25	0.25 - 0.05	0.05 - 0.01	0.01 - 0.005	0.005 - 0.001	< 0.001
1	8.92	40.88	25.00	5.20	3.60	16.40
2	9.64	39.56	24.00	4.00	5.60	17.20

Notes: samples are refilled soil after sorting and filtering

Table 2 Chemical property of soil samples

Total N, %	Organic N, g/kg	NH_4^+, g/kg	NO_3^-, g/kg	Organic matter, %	pH	P_2O_5, g/kg	K_2O, g/kg
0.036	0.033	0.004	0.005	0.561	8.25	0.007	0.073

1.5 Nitrogen contaminant treatment

The simulating experiment and wastewater treatment intensity were designed based on winter wheat growth stage and its physiological characteristics to guarantee plant grow in order. Meanwhile, appropriate quantity of P and K were added into the tested soil for proper adjustment of crop growth process. High nitrogen concentration wastewater was used in early stage and middle stage of crop growth, low concentration wastewater or clean water was used in other stage. The quantity of nitrogen contaminant were used in different stages is shown in Table 3.

2 Results and discussion

2.1 Analysis of nitrogen uptake process

Wastewater land treatment process under different conditions reflects nitrogen uptake in soil by crops and nitrogen transformation by photo-synthesis and different planting density indicates that the degree of nitrogen competitive uptake by root in the soil and the intensity of wastewater land treatment. Under conditions of the same irrigation quantity and the same intensity of nitrogen adding, different planting density indicates the extent of water content and nutrient deficiency, affects water uptake by root, nitrogen

Table 3 Nitrogen quantity used in wastewater land treatment in different stages (Unit: mg/cm^2)

Date	Group A		Group B		Group C	
	Quantity	Total quantity	Quantity	Total quantity	Quantity	Total quantity
March 1	1.271	1.271	1.271	1.271	1.271	1.271
March 28	0.009	1.280	0.009	1.280	0.009	1.280
April 4	0.007	1.287	0.007	1.287	0.004	1.284
April 18	–	1.287	–	1.287	0.003	1.287
April 25	0.009	1.296	0.009	1.296	0.013	1.300
May 7	0.005	1.301	0.010	1.306	0.008	1.308
May 8	0.489	1.790	0.977	2.283	3.317	4.625
May 12	0.004	1.794	0.007	2.290	0.008	4.633
May 21	0.004	1.798	0.007	2.297	0.010	4.643
May 22	0.003	1.801	0.006	2.303	0.009	4.652
May 28	0.004	1.805	0.007	2.310	0.009	4.661
June 1	–	1.805	–	2.310	0.009	4.670
June 4	0.007	1.812	0.010	2.320	0.009	4.679
June 5	0.003	1.815	0.004	2.324	0.004	4.683
June 9	–	1.815	–	2.324	0.004	4.687
Total		1.815		2.324		4.687

uptake speed. Meanwhile it certainly reflects crop growth. Thus nitrogen uptake pattern by roots can be recognized through analysis of winter wheat growth pattern and difference under different planting density. Furthermore nitrogen removal process and designed capacity of wastewater land treatment can be determined.

Winter wheat growth pattern: From analysis of three groups of winter wheat growth process, it is shown that winter wheat growth speed is dynamic process in the whole growth period and the growth curve is in the form of "S", indicating the growth pattern of fast-slow-fast-slow. The difference between different groups is only degree of variation. Fig. 1 shows crop growth process by height under different planting density. The height of crop varies greatly due to competitive nitrogen uptake by roots and water deficit, and height of crop in Group A is two times as height of crop in Group C. This is in compliance with planting density basically. From analysis of other property of crop (Table 4), it can be noticed that there is obvious difference for dried mass of single crop and nitrogen quantity at different growth stage. The dried seed weight per crop is 1.345g for Group A, 0.587g for Group B, and 0.566g for Group C. The number of seed per crop for Group A is 33, 19 for Group B and 17 for Group C. The average dried weight per thousand seeds is 33.240g for Group A, 27.406g for Group B and 26.288g for Group C.

Table 4 Winter wheat growth status under different planting densities

Group	Dried weight of third part of crop, g/plant: Jointing stage	Heading stage	Filling stage	Mature stage	Production: Dried weight of seeds, g/plant	Seeds number per crop	Weight of 1000 seeds, g	Length of crop, cm	N quantity, mg/ind.: Jointing stage	Heading stage	Filling stage	Mature stage
A	0.432	0.971	2.253	2.478	1.345	33	33.240	7.2	13.8	26.8	31.3	45.8
B	0.346	0.653	0.955	1.100	0.587	19	27.406	6.3	11.3	15.0	19.8	25.1
C	0.230	0.407	0.770	0.983	0.566	17	26.288	5.8	6.2	9.7	16.6	18.5

Nitrogen uptake pattern: Nitrogen uptake in soil by root in different growth stages shows different stile and different quantitative variation process, which mainly relies on water yield of soil, heritage characteristic of crop growth, nitrogen quantity in soil, status of crop growth. Hence under different planting density, nitrogen uptake quantity varies dramatically even in the same growth stage with the same type of crop since water stress and nitrogen deficiency differs in extent. The maximum difference of nitrogen uptake reaches over one time

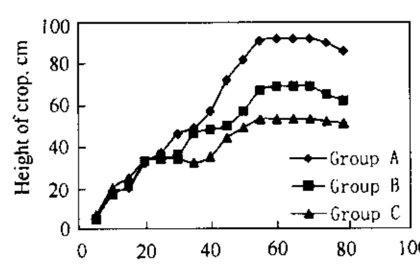

Fig.1 Growth process of winter wheat height under different planting densities

(Table 5). Inevitably competitive uptake by root results in water and nutrient deficiency, it affects crop growth and crop production. From Table 5 it is also shown that water stress is a main factor affecting crop growth, nitrogen uptake by roots, nitrogen removal in soil under the condition of adequate nutrient. Therefore not only the quantity of wastewater to be treated should be taken into account, but also the concentration of wastewater when determining wastewater land treatment intensity. From analysis of nitrogen uptake for Group A, Group B and Group C shown in Fig. 2, though nitrogen uptake quantity by per crop for Group A is nearly one time greater than that for Group B nitrogen uptake quantity per area for Group C, Group B is one time more greater than Group A. As a result, choosing appropriate planting density plays an important role in determining wastewater treatment capacity.

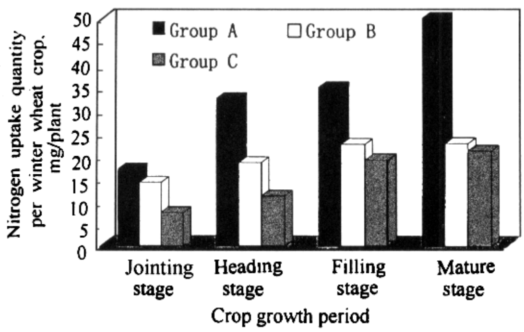

Fig. 2 Nitrogen uptake quantity per winter wheat crop in different growth stages

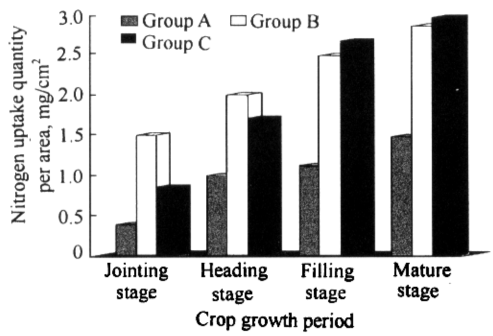

Fig. 3 Nitrogen uptake quantity per area in different growth stages

Table 5 Nitrogen uptake quantity per area in different growth stage under different planting density

Group	Growth stage	Water quality used per crop, g/plant	Crop dried weight above surface, g/plant	Root/crop ratio	Total weight of dried crop, g/plant	Number of wheat	N in crop, mg/plant	N uptake, mg/cm²
A	Jointing	846.7	0.432	0.217	0.526	53	16.77	0.37
	Heading	431.9	0.971	0.203	1.168	72	32.23	0.97
	Filling	346.8	2.253	0.112	2.505	76	34.82	1.10
	Mature	293.5	2.478	0.090	2.701	70	49.90	1.46
B	Jointing	116.6	0.078	0.224	0.424	255	13.82	1.47
	Heading	89.6	0.139	0.213	0.792	260	18.22	1.97
	Filling	130.8	0.122	0.128	1.077	265	22.29	2.46
	Mature	66.1	0.107	0.097	1.207	303	22.50	2.84
C	Jointing	89.5	0.230	0.217	0.279	20	7.31	0.83
	Heading	72.3	0.407	0.172	0.477	27	10.97	1.68
	Filling	84.6	0.770	0.128	0.869	25	18.76	2.65
	Mature	39.0	0.983	0.100	1.081	25	20.88	2.95

2.2 Nitrogen removal process analysis

Nitrogen removal process and pattern in wastewater treatment system is affected by many factors, including property of soil, water content, meteorological condition, crop type, crop growth status and method and intensity of wastewater treatment. How to maximize nitrogen uptake by crop and minimize its residue in soil, how to lead to least soil seepage and least ground water contamination, these are key issues to study and solve in setting up wastewater land treatment system. Wastewater land treatment system involves complicated physico-chemical and bio-chemical process, to understand it and to get to know the pattern a series of experiment under different conditions need to be conducted and modeling analysis needs to be made. In this paper, analysis of nitrogen removal pattern and nitrogen accumulation process was made under condition of different planting density of winter wheat in green house to seek for the optimal design for wastewater irrigation, including irrigation intensity, concentration and time span.

It is seen from Table 6 that the capacity and ratio of nitrogen removal differs on three different condition of wastewater land treatment. From the analysis of ratio of nitrogen reduction to nitrogen used, the planting density for Group B is relatively appropriate for wastewater land treatment. The capacity of nitrogen removal is almost same with nitrogen quantity in wastewater used with only slightly difference of 0.04%. The capacity for Group A is worst with difference of 20.44% and part of nitrogen residue left in soil. In about less than 5 years soil will be over saturated, nitrogen will transport reaching ground water and contaminate geological environment. From analysis of wastewater treatment capacity, wastewater concentration and irrigation intensity for Group C are suitable and nitrogen quantity added is 2 time of that for Group B, 2.6 time for Group A while nitrogen residue is only 7.06%. Hence wastewater irrigation and treatment design with purpose of waster water treatment is to select the design with maximum capacity, optimal removal ratio and least residue in soil, which is closely related to crop planting density, crop growth status and also background nitrogen quantity in soil. Once wastewater land treatment site is chosen, wastewater treatment plan in the due year should be determined by situation each year and planting condition in order to guarantee optimal effect of wastewater treatment.

Table 6 Nitrogen removal in soil in different growth stage (measuring in N)

Group	Growth stage	Time, d	Background inorganic N, mg/cm²	Accumulated organic N transform, mg/cm²	Total organic N in irrigated water, mg/cm²	Residual N in soil, mg/cm²	N reduction in soil, mg/cm²	N removal ratio, %	Ratio of N reduction/N added in soil, %
A	Jointing	39	1.211	0.240	1.296	2.420	0.327	11.90	25.23
	Heading	19		0.354	1.800	2.610	0.755	22.44	41.94
	Filling	18		0.456	1.815	2.380	1.102	31.65	60.72
	Mature	11		0.518	1.815	2.100	1.444	40.74	79.56
B	Jointing	39	1.211	0.240	1.296	1.751	0.996	36.26	76.85
	Heading	19		0.354	2.303	2.271	1.597	41.29	69.34
	Filling	18		0.456	2.324	1.931	2.060	51.62	88.64
	Mature	11		0.518	2.324	1.730	2.323	57.32	99.96
C	Jointing	39	1.211	0.240	1.300	1.680	1.071	38.93	82.38
	Heading	19		0.354	4.652	3.500	2.717	43.70	58.40
	Filling	18		0.456	4.687	2.811	3.523	55.45	75.17
	Mature	11		0.518	4.687	2.060	4.356	67.89	92.94

Notes: Mineralization rate constant $K_l = 0.00143(1/d)$; organic N concentration = 4.43 mg/cm²

3 Conclusion

Wastewater land treatment eco-engineering system is a system to treat municipal domestic sewage and industry wastewater so that organic contaminant and inorganic nutrients can be transformed and removed based on complicated physical, chemical and biological process of soil-crop system, self adjustment mechanism and contaminant removal capacity. Meanwhile the green crop growth is facilitated and production is increased through circulation of nutrients and water in bio-geochemical environment to realize wastewater recovery and nonhazardization. It is a tertiary treatment method of wastewater which many developed countries adopted.

Nitrogen contaminant transport, transformation and uptake simulation experiment were conducted in green house under three different planting density of winter wheat. Group A: planting density was 0.0208 plants/cm^2; Group B: 0.1042 plants/cm^2; Group C: 0.1415 plants/cm^2.

Winter wheat growth process was analyzed under three different planting densities. The height of crop varies greatly due to competitive nitrogen uptake by roots and water stress. Height of crop in Group A is two times as height of crop in Group C. From analysis of other property of crop, it can be noticed that there is obvious difference for dried mass of single crop and nitrogen quantity at different growth stage. The dried seed weight of single crop is 1.345 g/ind. for Group A, 0.587 g/ind. for Group B, and 0.566 g/ind. for Group C. The number of seed per crop for Group A is 33, 19 for Group B and 17 for Group C. The average dried weight per thousand seeds is 33.240g for Group A, 27.406g for Group B and 26.288g for Group C.

Nitrogen uptake in soil by root in different growth stage shows different stile and different quantitative variation process. Nitrogen uptake per stem of winter wheat for Group A reaches 49.90 mg, 22.50 mg for Group B, 20.88 mg for Group C and maximum variation is over one time. Nitrogen uptake per area for both Group B and Group C is over one time more than that for Group A. As a result, choosing suitable planting density plays an important role in determining wastewater treatment capacity.

From the analysis of ratio of nitrogen reduction to nitrogen used, the planting density for Group B is relatively suitable for wastewater land treatment. From analysis of wastewater treatment capacity, wastewater concentration and irrigation intensity for Group C are suitable and nitrogen quantity added in the waste water irrigation is 2 times of that for Group B, 2.6 times for Group A while nitrogen residue is only 7.06%.

Nitrogen removal process and pattern in wastewater treatment is affected by many factors, including property of soil, water content, meteorological condition, crop type, crop growth status and method and intensity of wastewater treatment. How to maximize uptake by crop and minimize residue in soil, how to lead to least soil seepage and least ground water contamination, these are key issues to study and solve in setting up wastewater land treatment system. Hence wastewater irrigation and treatment design with purpose of waster water treatment is to select the design with maximum capacity, optimal removal ratio and least residue in soil, which is closely related to crop planting density, crop growth status and also background nitrogen quantity in soil. Once wastewater land treatment site is chosen, wastewater treatment plan that year should be determined by situation each year and planting condition in order to guarantee optimal effect of wastewater treatment.

References:

Avogadro A, Ragalni, 1994. Technologies for environmental cleanup: Soil and groundwater[M]. The Netherlands: Kluwer Academic Publishers.

Barbar S A, 1984. Soil nutrient bio-availability——a mechanistic approach[M]. New York: John Wiley & Sons.

Fatta D, Papadopoulos A, 1999. A study on the landfill leachate and its impact on the groundwater quality of the Greater Area[J]. Environmental Geochemistry and Health, 21(2):175—190.

Gao Z M *et al*., 1991. Handbook of urban wastewater land treatment design[M]. Beijing: The Standard Press of China.

Gao Z M, 1986. Soil-crop-system pollution ecology[M]. Beijing: Chinese Science & Technology Press.

Groot J J R, 1991. Nitrogen turnover in the soil-crop system[M]. The Netherlands: Kluwer Academic Publishers.

Jiang C L, Xia Z Q, Liu Ling, 1997. Nitrogen & phosphor pollution of Kui River in its wastewater irrigation area[J]. Environmental Science, 5: 23—25.

Kurt R, 1999. Transport of dissolved contaminant through the vadose zone[M]. Transport of contaminants in vadose zone and prevention of groundwater pollution(Zhang J ed.). Nanjing: Southeast University Press. 5—22.

Lafolie F, 1991. Modeling root water potential and soil-root water transport[J]. Soil Sci Soc AM J, 55:1203—1217.

Mengel K, 1992. Nitrogen metabolism of plants[M]. USA: Oxfard Science Publications.

Musharrafieh, Ghassan R, Richard C P *et al*., 1995. Optimizing irrigation management for pollution control and sustainable crop yield[J]. Water Resource Research, 4: 1077—1086.

Shao A J, Li H C, 1997. The construction of out-door crop root sopping model[J]. Journal of Hydraulic Engineering, 2:99—102.

Wang H Q, Li Y Z, 1997. Combined soil-crop-system nitrogen migratory model[J]. Journal of Hydraulic Engineering (Supplement): 45—56.

Wang H Q, Ju J H, 1998. Modeling nitrogen pollutants transport in urban environment[M]. Beijing: The Beijing Normal University Press.

Wang M, Wu Y F *et al*., 1994. Rapid infiltration of waste water[M]. Beijing: Geological Press.

Xu M G, Zhang Y P, Zhang J C, 1997. Research progress in root-soil interface nutrient migratory research[J]. Soil Bulletin, 28(1):46—49.

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