Journal of Environmental Sciences Vol. 10, No. 1, pp. 87—97, 1998 ISSN 1001—0742

An united model and simulation of nitrogen transport, uptake and transformation in soil-crop system*

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Abstract—Based on the simulation experiments of water and nitrogen transport, transformation and uptaking, under the condition of different cropping pattern of winter wheat in the greenhouse and the condition of different wastewater irrigation plan. An united computing model of crop growth, distribution of roots, water and nitrogen uptaking by roots and transformation in soil-crop system was developed. Growth status of crops, root growth condition and water, nitrogen uptaking pattern by roots under different watering and N pollution conditions were simulated and analyzed due to the development of this mathematical model and the identification of parameters and boundary conditions in the greenhouse, so that it provided a primary computing method for selecting an efficient, productive watering and wastewater irrigating plan.

Keywords: soil-crop system; nitrogen uptaking and movement; mathematical model.

1 Introduction

It has long known that nitrogen is one of the elements of which supply is most often limiting growth. Traditionally agricultural research has focused on how to provide the crop with sufficient nitrogen to guarantee optimum yield. However, the contamination of water resources by nitrogenous compounds is becoming an increasingly serious problem, especially in areas of intensive farming. Nitrogenous compounds may pollute groundwater due to leaching. Many people have studied and developed some models of the N cycle and the leaching of nitrate (Groot, 1991; Gardener, 1991; Lafolie, 1991; Wang, 1993; Nye, 1977; Bruchler, 1991). Also, for resolving nitrogen movement, uptake and nutrient problems, all of the researches (Barber, 1986; 1984; Hatfield, 1992; Mengel, 1992; Reginato, 1991; Nye, 1977) only got the part process of nitrogen transport, transformation and uptake in soil-crop system. This paper, based on the results of previous researching, want to develop a united model that includes simulating the processes of crop growth, root growth and distribution, water, nitrogen uptaking, and nitrogen mineralization,

* The project was supported by the National Natural Science Foundation of China and Nation Climb Foundation as well as the Foundation of State Key Laboratory of Environmental Simulation and Pollution Control

nitrification and denitrification and so on. Main idea is to use the way of system, unit, and as a whole to resolve the problem of error due to parts process researching.

2 Simulating experiment of nitrogen transport, uptake and transformation in the soil column

2.1 Simulating experiment condition

The experiment was conducted in the greenhouse, at "268" Science Experiment Garden of Agricultural University of China. It includes soil column experiment and sectional two-dimensional bin-scale physical simulation experiment under bare, covered, wheat cropped (including three different kinds of cropping patterns) conditions respectively. Considerations of monitoring of soil matric potential, water content, nitrogen concentration were taken into account in the experiment designing. Besides, a root-visual window system, length and density of root measuring system and monitoring system of status of upper part of crop above ground were designed.

The experiment covers: unsaturated hydraulic dispersion of nitrogen experiment under condition of surface covering (Group E: soil column with 100 cm high, 19 cm diameter); simulating experiments of water and nitrogen movement, uptake and dispersion under bare evaporation conditions respectively (Group D: soil column with 100 cm high, 19 cm diameter); simulating experiments of water and nitrogen migration, uptaking and dispersion under evenly winter wheat cropping (Group C: soil column with 100 cm high, 19 cm diameter), winter wheat cropping in the density the same with natural case in the field (Group B: soil column with 80×30 cm^2 surface and 100 cm high), winter wheat cropping in a density of single line (Group A: soil column with 80×30 cm^2 surface and 100 cm high). Each kind of experiments was conducted respectively according to the different crop growth phase, and 9 experimenting soil columns, 8 sectional two-dimensional bin-scale experimenting soil columns and 6 observing barrels for measuring water surface evaporation, soil evaporation and evapotranspiration were designed.

2.2 Simulation experiment

The simulating experiment started on March 25, 1994 with first irrigating on March 28. On March 29, the spring-melted winter wheat was transcribed in the experimenting facilities. There were 4 experimenting devices designed in each group of Group A and Group B and the experimenting period for these two groups was divided into 4 phases representing 4 crop growth stages; 5 growth phases were taken into account for Group C. A unified fertilizing was done on May 8. Irrigation for Group A in total is 353.87 mm, for Group B 465.64 mm. Winter wheat was harvested on June 20 and the experiment ended on June 21. Group C, D, E and F were mainly for parameters identification.

In the experiment, water content, NH_4^+, NO_2^-, NO_3^- concentrations were measured, in the time of each 10 days at the point of 10 cm distance between two measuring point (Group C, D, E), and 10×10 cm^2 sectional two-dimensional measuring point (Group A, B); soil matric potential was monitored by tensiometer two times each day at the same distance point with water content; root length was measured in the each different $10 \times 10 \times 15$ cm^3 soil cube at the different crop stage.

3 The united mathematical model for nitrogen transport, uptake and transformation in soil-crop system

Study of water and nitrogen movement and uptaking pattern in soil-crop system cover crop growth, root distribution, water and nitrogen uptaking by roots, water and nitrogen movement and transformation and so on. It requires integrated iterating computation in order to accomplish this system study.

United model:
- 1-1 plant growth model
- 1-2 root growth, density and distribution model
- 2-1 water uptaking by roots model
- 2-2 nitrogen uptaking by roots model
- 3-1 water movement and uptaking in the soil model
- 3-2 NH_4^+ movement and transformation in the soil model
- 3-3 NO_3^- uptake, movement and transformation in the soil model

3.1 Assumptions and predecessors

Crop mass was classified into two categories, i.e. structure and storage, in the crop model. Structure is crop texture and storage is base for crop growth and transformation, usually considered as hydrocarbon compound or as some special content like nitrogen component. The key to simulate growth of crop growth by means of base for crop growth lies on parameter variation. Assumptions were made according to such crop growth model and other corresponding water and nitrogen movement and uptaking model respectively: (1) crop status was determined at given time t by two status variables W_G and W_S. W_G is dry weight of structural mass, W_S is dry weight of storage mass, then the total dry weight of stems should be: $W = W_G + W_S$; (2) leaf area of stems A is proportional to structural dry weight W_G, i.e. $A = F_G W_G$, where F_G is constant; (3) internal movement resistance of crop is neglected; (4) storage mass is nitrogen compound and the utilization of nitrogen-stored mass in different position of stems (e.g., root, stem) is based on the same formula; (5) structure growth relies on the quantity of storage mass at that time; (6) the most important factor affecting crop growth is assimilation ratio; (7) the relative growth rate or comparable growth rate of dry mass is $\mu = \frac{1}{W}\cdot\frac{\mathrm{d}W}{\mathrm{d}t} = \frac{1}{W}\left(\frac{\mathrm{d}W_G}{\mathrm{d}t} + \frac{\mathrm{d}W_S}{\mathrm{d}t}\right)$, then relative structural growth rate is $\mu_G = \frac{1}{W_G}\cdot\frac{\mathrm{d}W_G}{\mathrm{d}t}$, relative stored mass growth rate is $\mu_S = \frac{1}{W_S}\cdot\frac{\mathrm{d}W_S}{\mathrm{d}t}$, as a result, $\mu = \frac{1}{W}\cdot\frac{\mathrm{d}W}{\mathrm{d}t} = \frac{W_G\mu_G + W_S\mu_S}{W_G + \mu_S}$; (8) soil cation exchange capacity (CEC) is constant; (9) equilibrium cation exchange; (10) isothermal condition; (11) synergistic reaction only occurs between organic nitrogen, ammonia, nitrite and nitrate ions, but no synergistic reaction with other ions; (12) nitrogen chemical dynamics complies with first order kinetic equation; (13) all nitrogen uptaking comes from nitrate due to the extremely low concentration of ammonia, and the ammonia can be uptaken by crop only when nitrification make it become nitrate.

3.2 Expression of each individual model

$$
1\text{—}1\begin{cases}
\dfrac{dW}{dt} = \dfrac{dW_G}{dt} + \dfrac{dW_S}{dt}, \\
\dfrac{dW_G}{dt} = R\dfrac{W_G W_S}{W_S + bW_G}, \\
W_S = S_N, \\
S_N = 0, \quad W = W_0, \quad W_G = W_{G0}, \quad t = 0
\end{cases}
$$

$$
1\text{—}2\begin{cases}
\dfrac{dR_W}{dt} = \dfrac{dW}{dt} - \dfrac{dP_W}{dt} = \dfrac{f}{1+f}\left(\dfrac{dW_G}{dt} + \dfrac{dW_S}{dt} - R_W\dfrac{d((1+f)/f)}{dt}\right), \\
Z_r = \dfrac{a_r Z_{\max}}{1 + b_r e^{-c_r t/t_m}}, \quad t \leqslant t_{\max} \\
L(z,t) = \begin{cases}
\begin{cases} f_R R_W \alpha_1 e^{-\beta(z/50)^2}, & z \leqslant Z_r, \quad t \leqslant t_{\max} \\ 0, & z > Z_r, \quad t \leqslant t_{\max} \end{cases} \\
\begin{cases} f_R R_W \alpha_1 e^{-\beta(z/50)^2}\left(1 - a_r\left(\dfrac{t - t_{\max}}{t_m - t_{\max}}\right)^2\right), & z \leqslant Z_{\max}, t > t_{\max} \\ 0, & z > Z_{\max}, \quad t > t_{\max} \end{cases}
\end{cases} \\
R_W = 0, \ L(z,t) = L_0(z), \quad t = 0, \quad z \geqslant 0 \\
L_N = \int L(z,t)dz, \ l_{Nt} = L_N/S, \quad t \geqslant 0, \quad z \geqslant 0 \\
l(z,t) = L(z,t)/(S\cdot\Delta z), \quad t \geqslant 0, \quad z \geqslant 0
\end{cases}
$$

$$
2\text{—}1\begin{cases}
S_W = \dfrac{4\pi D(\theta)}{\gamma + \ln\dfrac{R_\theta^2}{4D(\theta)\Delta t}}(\theta(t) - \theta(t-1))\cdot l(z,t), \\
E_t = 0.95\int 10\cdot S_W dz, \\
\theta = \theta_0(z), \quad t = 0, \quad z \geqslant 0 \\
Q = S_W/l, \quad t \geqslant 0, \quad z \geqslant 0
\end{cases}
$$

$$
2\text{—}2\begin{cases}
S_C = 2\pi r_c \alpha C_a l(z,t), \\
\alpha = \dfrac{F_{\max}}{K_m + C_a} = \dfrac{1}{2\pi r_c}\cdot\dfrac{I_{\max}}{K_m + C_{1a}}, \\
S_N = \iint S_C dz dt, \\
C_a = \dfrac{(2\pi r_c D_{sh}(\theta) + Q_c(R_c - r_c))C_2(z)}{2\pi r_c\left(D_{sh}(\theta) + r_c\cdot\alpha\cdot\ln\dfrac{R_c}{r_c}\right)} \\
S_C = 0, \quad t = 0, \quad z \geqslant 0 \\
S_N = 0, \quad t = 0,
\end{cases}
$$

$$3\text{—}1\begin{cases}\dfrac{\partial\theta}{\partial t}=\dfrac{\partial}{\partial z}\left(D(\theta)\dfrac{\partial\theta}{\partial z}\right)-\dfrac{\partial K(\theta)}{\partial z}-S_W,\\ D(\theta)\dfrac{\partial\theta}{\partial z}-K(\theta)=E-p(t) \quad z=0,\ t\geqslant 0,\\ E=f(E_0,\theta(z_1)) \quad z=0,\ t\geqslant 0,\\ D(\theta)\dfrac{\partial\theta}{\partial z}-K(\theta)=0 \quad z=z_D,\ t\geqslant 0,\\ \theta=\theta_0(z) \quad z\geqslant 0,\ t=0,\\ S_W=0 \quad z\geqslant 0,\ t=0\end{cases}$$

$$3\text{—}2\begin{cases}\theta\dfrac{\partial C_1}{\partial t}+\rho\dfrac{\partial S_1}{\partial t}=\dfrac{\partial}{\partial z}\left(D_{sh}(u,\theta)\dfrac{\partial C_1}{\partial z}\right)-q\dfrac{\partial C_1}{\partial z}-k_2(\theta C_1+\rho S_1)+k_1\theta C_N\dfrac{18}{14},\\ \dfrac{\partial S_1}{\partial C_1}=\dfrac{b}{\sqrt{C_1}}(S_{1m}-S_1),\\ S_1=0 \quad C_1=0,\\ C_1=C_1^0(z) \quad t=0 \quad z\geqslant 0,\\ -D_{sh}(u,\theta)\dfrac{\partial C_1}{\partial z}+qC_1=0 \quad z=0,\ z=z_D \quad t>0\end{cases}$$

$$3\text{—}3\begin{cases}\theta\dfrac{\partial C_2}{\partial t}=\dfrac{\partial}{\partial z}\left(D_{sh}(u,\theta)\dfrac{\partial C_2}{\partial z}\right)-q\dfrac{\partial C_2}{\partial z}+k_2(\theta C_1+\rho S_1)\dfrac{62}{18}-k_3\theta C_2,\\ -D_{sh}(u,\theta)\dfrac{\partial C_2}{\partial z}+qC_2=p(t)\cdot C_{2R}(t) \quad z=0 \quad t\geqslant 0,\\ C_2=C_2^0(z) \quad t=0 \quad z\geqslant 0,\\ -D_{sh}(u,\theta)\dfrac{\partial C_2}{\partial z}+qC_2=0 \quad z=z_D \quad t>0\end{cases}$$

Where: W is the dry weight of crop, g/cm^2; S_N is total uptake of nitrogen, g/cm^2; Zr is the depth of roots when time is t, cm; $L(z,t)$ is the roots' length in the unit of $10\times10\times15$ cm^3 when time is t and where depth is z, m; R_W is the dry weight of roots, g/cm^2; θ, θ_c, is represent the water content in soil and in crop, cm^3/cm^3; E_t is transpiration from crop, mm; E is evaporation from soil surface, mm; E_0 is evaporation from water surface, mm; S_W is present uptake of water; S_C is the uptake of nitrogen; $K(\theta)$ is vertical unsaturated conductivity, cm/d; $D(\theta)$ is the unsaturated diffusion coefficient, cm^2/d; $D_{sh}(u,\theta)$ is the coefficient of dispersion, cm^2/d; k_1 is mineralization rate constant, 1/d; k_2 is nitrification rate, 1/d; k_3 is denitrification rate, 1/d; C_1, C_2, C_N is represent concentration of NH_4^+, NO_3^-, organic nitrogen in soil, mg/L; R, b, α,β,γ, a_γ, R_θ, R_c is constant; r_c is the average radius of roots, cm.

4 Modeling analysis of water and nitrogen movement and uptaking in soil-crop system and model calibration——case study of simulation experiment Group B in the greenhouse

4.1 Parameters for the united model

All parameters selected in the computation were obtained through observing data from experiment Group D, E, F and part of Group C. Hydraulic and chemical dynamic parameters were determined through simulation by means of observing data of experiment Group B during period of sprouting before $t = 20$ days. All parameters adopted in the modeling study are listed in Table 1. All parameters selected for crop growth model and root distribution model in different growth phase were obtained through observing data of experiment Group C in order to coincide with greenhouse condition.

Table 1 Parameters for the united model

Parameter name	Symbol	Formula	Unit	Data origin
Vertical unsaturated conductivity	$K(\theta)$	$K(\theta) = 20.5478\theta^{3.998}$	cm/d	Group E
Unsaturated diffusion coefficient	$D(\theta)$	$D(\theta) = 308.683e^{0.551618\theta}$	cm^2/d	Group E
Dispersion coefficient	$D_{sh}(u,\theta)$	$D_{sh}(u,\theta) = 4.0219\theta^{0.2411} + 0.322u$	cm^2/d	Group E
Mineralization rate constant	k_1	$k_1 = 0.0014286$	1/d	Group C
Nitrification rate constant	k_2	$k_2 = 0.30054$	1/d	Group C
Denitrification rate constant	k_3	$k_3 = 0.052382$	1/d	Group C
Equilibrium sorption coefficient	S_1	$S_1 = 713.995(1 - e^{-2\times 0.29514\sqrt{c_1}})$	mg/kg	Group C
Evaporation from soil surface	E	$E = 2.5E_0\left[\frac{\theta - \theta_{min}}{\theta_{max} - \theta_{min}}\right]^2$	mm	Group F
Rooting depth	Z_r	$Z_r = \frac{1.4924z_{max}}{1 + 14.7237e^{-4.235t/t_m}}$	cm	Group C
Time span for growth	t_m	$t_m = 83$	d	Group B
Maximum rooting depth	Z_{max}	$Z_{max} = 80$	cm	Group B
Root distribution formula	L/L_N	$L/L_N = \alpha \exp[(-\beta(Z/50)^2]$		Group C

Air dynamic condition and solar radiation were not considered in modeling study. Instead, only synthesized factor, water surface evaporation, was used. The predecessor of modeling prediction is that daily water surface evaporation must be known in order to regulate solar radiation and air dynamic condition. Parameters for crop were all obtained under greenhouse condition through spring melting treatment rather than under winter condition, for example, time span for each growth phase, total growth period and growth rate pattern differ obviously from those in field experiment; the homogeneity of soil is consistent with its sorting degree; moreover, the bottom of experiment column is impermeable and it differs from field condition. Thus when doing modeling study for field condition correspondingly adjustment should be made in order to let the model work correctly.

4.2 Numerical modeling and analysis with the united model

4.2.1 Simulation and analysis of winter wheat growth

Crop growth during March 29—June 20 was simulated by using crop growth model and analysis was made that variation in different time and dynamic progress of crop dry weight (W), upper part weight of crop above the ground (P_W), crop structure dry weight (W_G), base dry weight (W_S) and crop growth factors. The dynamic progress of W, P_W and W_S is shown in Fig. 1. As shown in Fig. 1, crop dry weight increases slowly in early phase and with the increase of base density and affection of crop inheritage, the accumulation of crop dry weight goes up dramatically and it keeps going steadily. The accumulation of crop dry weight and the increase of crop dry weight in each growth phase are shown in Table 2. Daily growth rate of crop in mature phase is three times of that in sprouting phase. Under given environmental condition (include solar radiation, photosynthesis, *etc*.), accumulated nitrogen plays a significant role in crop growth and even more significantly in mature phase, indicating nitrogen requirement, assimilation and movement to winter wheat seeds.

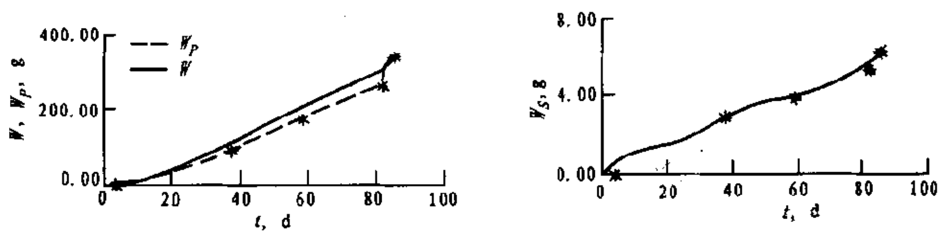

Fig. 1 Crop dry weight, upper part weight of crop above the ground, dynamic process of nitrogen accumulation (quantity in total in $30 \times 80\text{cm}^2 \times 95\text{cm}$)--- calculated number; * measured number

Table 2 Statistics of crop growth power in each growth phase (quantity in total in $30 \times 80\text{cm}^2 \times 95\text{cm}$), in 1994

Crop period	Tillering stage	Jointing stage	Booting stage	Heading stage	Flowering stage	Filling stage	Mature stage
Date, month/day	4/19	4/30	5/9	5/14	5/22	6/2	6/20
Time, d	21	32	41	46	54	65	83
Weight of crop, g	47.8	91.9	132.7	155.7	193.5	235.7	347.2
Weight growth during each period, g	47.8	44.0	40.9	22.9	37.8	42.2	111.6
Days of each period, d	21	11	9	5	8	11	18
Rate of crop growth, g/d	2.28	4.01	4.54	4.59	4.72	3.84	6.20

4.2.2 Simulation analysis of water and nitrogen uptaking pattern by roots in different growth phase of winter wheat

The performance and quantity variation of water and nitrogen uptaking by roots are different in different crop growth phases. From modeling study, the major factors affecting water uptaking by roots include water content in soil and evaporation intensity in environment apart from crop inherited characteristics. As shown in Fig. 2, water content in soil increases corresponding to each watering and there exists a sudden change to evaporation intensity as a result. From the dynamic curve of water uptaking intensity, the influence of watering is obvious at the surface layer and it is negligible at deeper layer. Influenced by water uptaking activities, the performance of nitrogen uptaking by roots is similar. The dynamic process of water and nitrogen uptaking by roots in different layers is shown in Fig. 3. At surface layer, watering effect is great, resulting in higher

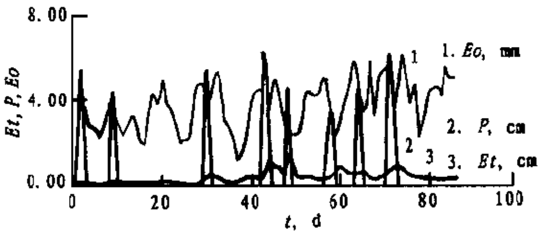

Fig. 2 Water uptaking by roots, water surface evaporation, watering dynamic curve (quantity in total in 30 × 80 cm^2 × 95cm column) in 1994

water uptaking intensity, and it affects nitrogen uptaking comparatively significant. While at deeper layer, this effect disappears and the performance is represented by inherited characteristics in each growth phase. As shown in the profile, it is obvious that water and nitrogen uptaking intensity in the surface layer is higher than that in deeper layer and the deeper the roots, the lower the intensity. Water and nitrogen uptaking intensity and quantity are different in different growth phases. Water uptaking, total nitrogen and daily nitrogen uptaking by roots are listed in Table 3, showing that nitrogen uptaking and water uptaking by roots increase evidently with the growth of winter wheat, but water uptaking intensity decreases in the final phase due to the death of roots. Therefore, dynamic curve of water uptaking intensity and nitrogen uptaking intensity take the shape of S. From filling stage to mature, nitrogen uptaking intensity increases because of the increase of nitrogen demand.

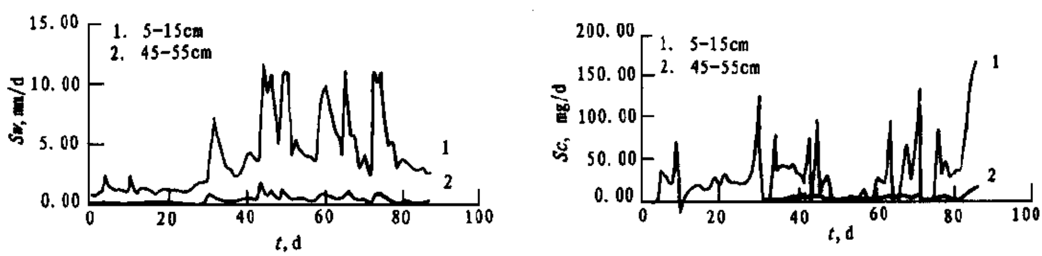

Fig. 3 Dynamics of nitrogen uptaking intensity, water uptaking quantity by roots in different layers uptaking by roots
S_c: nitrogen uptaking intensity; S_w: water uptaking quantity (for calculated number)

Table 3 Statistics for water and nitrogen uptaking by roots (quantity in total in 30 × 80cm^2 × 95cm column) in 1994

Period	Tillering stage	Jointing stage	Booting stage	Heading stage	Flowering stage	Filling stage	Mature stage
1	21	32	41	46	54	65	83
2	21	11	9	5	8	11	18
3	2.73	5.87	8.84	13.49	18.63	26.54	35.23
4	1.98	2.71	3.62	4.11	4.34	4.83	7.09
5	2.73	3.13	2.97	4.65	5.14	7.81	8.70
6	1.98	0.73	0.91	0.49	0.23	0.49	2.26
7	0.130	0.285	0.330	0.930	0.642	0.710	0.483
8	0.094	0.067	0.101	0.098	0.029	0.045	0.126

Note: 1: time, d; 2: time span, d; 3: water quantity uptaking by root in total, cm; 4: total accumulated nitrogen uptaking by roots, g; 5: water quantity uptaking during each growing period, cm; 6: nitrogen uptaking during each growing period, g; 7: water uptaking per day, cm/d; 8: nitrogen uptaking per day, g/d

4.2.3 Simulation analysis of water and nitrogen movement, transform and uptaking in soils

The movement of water and nitrogen is very complicated since it is affected by water, nitrogen uptaking by roots and chemi-dynamic transform of nitrogen compound, water evaporation and trans-evaporation, hydrodynamic dispersion and so on. Besides, considering unsaturated condition, it is even more difficult to describe water and nitrogen movement. In this integrated model, iteration method was used to calculate: crop growth; root distribution; water and nitrogen uptaking by roots; water and nitrogen movement, transform and uptaking; crop growth comprehensively and obtain a series of solutions. Restricted by the above factors, water and nitrogen content in soil allocated and reallocated and thus forms different water and nitrogen content distribution in sectional profile and dynamic process. Fig. 4 shows water and nitrogen content in the profile. Affected by watering, water content in surface layer increases and this facilitates nitrogen diffusion upward, thus nitrogen content in surface layer increases consistently. On the other hand, the increases of water content speeds up water uptaking by roots. But the increase of nitrogen uptaking is less than that of water uptaking due to the influence of crop genes, and the accumulation of nitrogen in surface layer of root carried by water facilitate the increase of nitrogen content in surface layer. From the analysis of nitrogen distribution in the sectional profile, a distinct high NO_3^- content zone exist in depth of 40—50 cm, and it keeps steadily high concentration from the beginning of the experiment to the end. This coincides with observing data from the experiment. And the reason might be that since small watering intensity, water and nitrogen moves for only shoot distance, nitrogen begin to transport upward due to evaporation and trans-evaporation, because at a certain depth, it is beyond influence of watering. In other viewpoint, at depth of 40—50 cm where roots are well developed and water uptaking by roots is comparatively big, this facilitate water movement toward this zone accompanied with nitrogen transport, but root fissures for water uptaking are fine according to the root distribution characteristic. Though water uptaking is intense, nitrogen uptaking is not in the same intensity for the seepage potential to pass through root surface is higher than that to pass through main roots, subroots and as a result, nitrogen required by crop is uptaken from main roots and subroots. Certainly the nitrogen demand of crop is affected by crop hereditary characteristic, and this results in that nitrogen accumulated in soil where roots are well developed (40—50 cm), forming high content nitrogen zone. Still this might result from the integrated influence of the above two reasons.

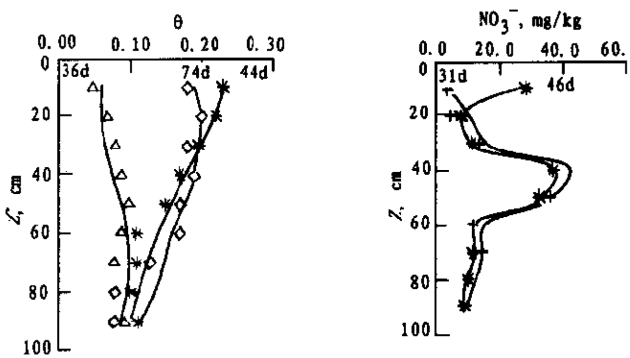

Fig.4 water content in soil, NO_3^- concentration in profile
— calculated; ◇ △ + * measured

4.3 Comparison of measured data from experiment to calculate data and verification of model predictability

Based on experiment Group B, analog computation of crop growth, water and nitrogen movement was made, thus observing data of experiment Group B was chosen to compare with calculated data. Fig. 1 shows the dried weight of upper part of crop above the ground and the comparison of calculated nitrogen content and measured nitrogen content during the dynamic process of nitrogen content of crop; Fig. 4 shows water content in soil, comparison of measured and calculated nitrogen concentration in sectional profile. Fig. 5 shows comparison of calculated and observed unit root length at different time in sectional profile. From above figures, the observed data coincide with calculated data quite well, possessing strong ability of modeling reclamation.

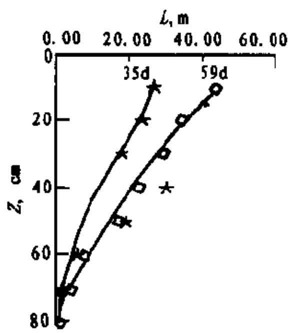

Fig. 5 Comparison of calculated and observed unit root length at different time in sectional profile (in 10×10×15cm^3) — calculated, ◇ ★ observed

It is described in this model that: the dynamic process of water, NO_3^-, NH_4^+ movement, uptaking and transformation in sectional profile in the system of crop growth; water uptaking and nitrogen uptaking by roots; soil under simulating experiment condition. And it is taken into account that the mineralization of organic nitrogen, sorption and desorption of ion, nitrification of NH_4^+ and denitrification of NO_3^-, assimilation of nitrogen compound base for crop growth, transform of dried substance of texture and dried substance of base and root growth and death, crop trans-evaporation and water uptaking by root, nitrogen demand for crop hereditary cause and so on. Therefore it is much similar to real condition and environment of winter wheat growth. The structure and calibration of the model are determined by analysis and comparison of experimenting condition. From the coincidence of comparison, it can be seen that the accuracy of the model developed under the same condition is assured. If this model is spread to the simulation in the field, the model structures corresponding to the condition in the field must be developed, and initial, boundary conditions as well as various parameters must be given. If the parameters given are appropriate and initial, boundary conditions are reasonable, then the model is available. Hence this model has a certain practical value. As to the concrete process, especially crop growth model, it needs further improvement. It is a new approach that is the coupling of crop growth and water and nitrogen movement in soil, and it would be an effective researching method if further research is done.

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(Received for review March 11, 1997. Accepted May 29, 1997)