Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 21 (2011) 212 – 220

Procedia Engineering

www.elsevier.com/locate/procedia

2011 International Conference on Green Buildings and Sustainable Cities

Modeling soil nitrogen mineralization dynamically based on GIS

Liu Kejing[a*]

[a]Hohai University, No.1 Xikang Rd, Nanjing, 210098, China

Abstract

Industrialization of human society and the expanding human space inspired the nitrogen cycling, that have caused environment problems. Nitrogen fertilizer application generates the most activity nitrogen. The nitrogen mineralization have been researched in the soil dynamic model in Yizheng county, then the simulation models have been realized it in the program of Grid block of ArcGIS Workstation. That layout the grids images of soil organic nitrogen containments and the grids images of other organic nitrogen containments in the special times, then though analysis the results in time got a probable future spatial nitrogen containments varieties in the whole area.

Selection and/or peer-review under responsibility of APAAS

Keywords: nitrogen ferilizer; organic nitrogen; dynamic model; GIS

1. Introduction

Soil is a huge source of carbon, for there is about 1.5 $\times 10^5$ kg carbon exists as soil organic carbon, which double as the carbon exist in the atmosphere. Even a tiny change of the soil carbon pool would drive substantial changes in atmospheric concentrations of carbon dioxide (CO_2) concentration [1,2] and result in a long-term impact of climate, this is one of the important factors of global warming. On the other hand, the nitrogen cycle accompany with the carbon cycle is an important factor which influencing on the environment change. The nitrogen circulation is accelerated by the industrialization and the expanding living space of human society, result in a lot of activity nitrogen which has cause serious environmental problems.

A century ago, the main source of active nitrogen is nitrogen fixation by plant. However, the ratio of

* Corresponding author.
E-mail addresses: x13a13@yahoo.com.cn

active nitrogen which product by anthropogenic activity is increasing along with the increased population, the acceleration of urbanization, the raising energy consumption, the agriculture development and the increased chemical fertilizer. The largest source of active nitrogen which product by anthropogenic activity is the nitrogenous fertilizer [3], which is the most common use of chemical fertilizer. There is about 100 Tg active nitrogen released from the nitrogenous fertilizer every year from 2000. The excessed active nitrogen not only brought a damage to the atmospheric environment, but activity nitrogen would also into the water. The nitrate of the nitrogenous fertilizer and excreta of domestic animal would into the streams, rivers, lakes and groundwater. The active nitrogen could be accumulated in soil as in water and in air. The quantity of nitrogen which could be absorbed by plants is limited, when the soil cannot take any more nitrogen, it is called “saturation”. In the saturated soil, the excessive nitrogen outflows, and the loss of nitrogen as well as other nutrients, eventually cause soil acidification. The loss of nitrogen also take material like magnesium and calcium into the water, there is about 30%~50% fertilizer in the soil get into the groundwater[4], cause the pollution of underground water, and eventual form a unbalance system [1]. Rodhe (1990) suggested that the increasing temperature effect caused by 1 mol N_2O is 150~200 times as the effect caused by 1 mol CO_2. N_2O has a long residence period in the atmosphere (about 150 years), and also participated in the photolysis reaction in the atmosphere, then destruct the ozonosphere [5,6]. The average utilization rate of the fertilizer in China is lower 10% than developed countries. The utilization rate of nitrogenous fertilizer is about 30%~35% in China, while is about 50% in developed countries. The low utilization rate of fertilizer not only lead to higher cost of production, but also the direct cause of environmental pollution such as eutrophication. The pollution from fertilization cause the burden about 1/3 ~ 1/2 of the eutrophication of Taihu lake and DianChi lake[7].

We developed a soil dynamic model in Yizheng of Jiangsu province based on the program of Grid block of ArcGIS Workstation to simulate the nitrogen mineralization, and estimate the variation of annual nitrogen mineralization and total number of nitrogen in lower layer in this region, then we estimated and analyzed the balance situation of nitrogen based on the model results.

2. Data

2.1. Region introduction

Yizheng located in the subtropical monsoon zone, it is a town-level city in Midwestern of Jiangsu province, near north shore of Yangtze River. Yizheng is one of the important national grain base and one of the 26 agriculture counties in Jiangsu province. Its area is about 903 km^2, with 11 countries and 7 large farms in it. The elevation of northwest of Yizheng is higher than southeast. The south of the region is an alluvial plain, with sufficient water and fertile soil, quite appropriate to fish-farming, planting grain and vegetables. The central and north is rolling country, with well ecological environment, quite appropriate to forest planting, animal agriculture and so on. The summer crops are mainly wheat, green manure and rape, while the fall crops is mainly rice, accounting for 90% of the total land areas. The drought crops are cotton, soybean, sweat potato, peanut, corn, and kinds of beans.

2.2. Data preparation

The used data of this study including the Yizheng maps of ArcGIS Shapefile format: every villages and towns border of Yizheng map, the land-use map (divided into 11 type), the map of soil type; the soil sample data in regular station in 2000 (there are 192 sample points, the largest distance between samples is 42 km, while the test is to quantify multiple elements, organic matter, and the Ph value of soil), the monthly average temperature and precipitation data, the utilization statistics of organic fertilizers in 2003, the monthly average soil temperature and soil humidity from surface to the following 20 cm layer, data of pore water, the population of Yizheng and the livestock statistical data. All vector data were converted into raster data. The statistical data also converted from table to rasters. In our study all map grid scale is 30m×30m.

3. The Soil Dynamic Modeling

The basic principles of soil dynamics model is that the soil organic nitrogen mineralization quantity is in proportion to the mineralization time. Since Jenny developed it in 1938, Russel made some research based on this model, Standford (1972) proposed the theory of nitrogen mineralization power, he improved Jenny's model and proposed the First-order reaction model, it has the form as:

$$\frac{dN}{dt} = -k_1 \cdot N \tag{1}$$

Where dN/dt is the mineralization rate, k_1 is the First-order relative mineralization rate constant.

Based on it, some classic models were developed, including the Nitrogen mineralization thermodynamic model of Sygihara and Konno (1981), the ANIMO model (Berghuijs-van Dijke et al. 1986), the Nitrogen cycle model (Bhat et al. 1986), the SOILN of Swedish University of Sciences. With GIS technology developing, many models have been developed into utility system to guide agricultural and to adapt different climate conditions [8]. In this study, we use the NLEAP model (Shaffer et al., 1991), which has been validated on a very wide range and approved to useful under various natural conditions[9,10]. Based on this model, the dynamic simulation is performed under the Grid block of ArcGIS workstation to simulate Yizheng's situations dynamically.

The soil nutrient mineralization model

This is a dynamic process, the NLEAP Mineralization of soil physical organization model is a dual pools model, and it divide soil component into two types: the components decompose quickly and the components decompose slowly. Mineralization of these two components is given as follows:

$$NOMR = k_{omr} \times SOM \times TFAC \times WFAC \times ITIME \times 0.58/10 \tag{2}$$

where *NOMR* is the mineralization of ammonium (kg/ha/t) in each time step, k_{omr} is the first-order reaction rate parameters,varies for available components or slow effect components, *SOM* is the composition of the soil (k/ha), *ITIME* is the recorded time step (days), *TFAC* is the temperature effect function, *WFAC* is the moderate effect function. According to the grid scale of the area, our unit of the *SOM*, *NOMR* is kg/900m^2.

Based on the division of the soil component, we calculate the different components of the first order reaction rate parameters with the function determined by mineralization rate of temperature proposed by Nordmeyer in 1985.

$$\begin{cases} k_{r,omr} = 40 \times 10^{9} \cdot e^{\left(-\frac{8400}{T+273}\right)} \\ k_{e,omr} = 5.6 \times 10^{12} \cdot e^{\left(-\frac{9800}{T+273}\right)} \end{cases} \tag{3}$$

where k_{romr} is the first order mineralization rate parameters of the components decomposed slowly, k_{eomr} is the first order mineralization rate parameters of the components decomposed quickly, T is the soil temperature (℃);

The quantity of organics left to the next time step at each time step is as follows:

$$SOM_{i+1} = SOM_i - NOMR_i \tag{4}$$

the organic carbon content is

$$TC_{i+1} = SOM_{i+1} \times 0.58 \tag{5}$$

the total soil nitrogen content is

$$TN_{i+1} = TN_i - NOMR_i \tag{6}$$

where *TN* is the total nitrogen content (kg/900m^2),and *TN* at the initial time is the measured values.

The C/N ratio of soil organic in each time step is

$$CN_{i+1} = TC_{i+1} / TN_{i+1} \tag{7}$$

The mineralization of crop residues and other exogenous tissue materials

According to the local agricultural data, we divide the external source of organic material into five types: Straw, wheat straw, pig manure, cow dung manure and human manure. Yizheng is a rice-wheat cropping rotation area and rice transplanting usually comes around June 21 each year, and be harvest around October 20. Wheat sowing usually happens in late October and harvest in early June. In this region, cover infields with wheat straw and rice straw is the main form of local straw [11, 12]. In the model, this rotation method is simply abstracted as for in a growing area, the four months from June 21 to October 20 in each year is the rice period, and in this period wheat straw, pig manure, cow dung manure and human manure play as exogenous material; the eight months from October 20 to June 21 of the next year is the wheat period, and in this period straw, pig manure, cow dung manure and human manure play as exogenous material. For the average annual total production is derived from these five organic materials, the rice period is one third of a year, we consider the quantity of the manures is one third of annual total quantity. Similarly, the quantity of the manures in wheat period is two thirds of the annual total quantity. Based on this model assumption, the mineralization of the external organic matter source can be divided into two processes, mineralization process in rice period and wheat period respectively. These two processes constitute a cycle of one year, both processes are described by the following model:

$$CRES = fr \times RES \tag{8}$$

where *RES* is the quantity of dry residue (kg/900m^2), *fr* is the proportion of carbon in residues, *CRES* is the carbon content in residues(kg/900m^2).

$$CRESR = k_{resr} \times RADJST \times CRES \times TFAC \times WFAC \times ITIME \tag{9}$$

where *CRESR* is organic carbon which has produced metabolic changes in each time step (kg/900m^2/t), k_{resr} is the first reaction rate parameters, *RADJST* is the speed regulation factor determined by the current soil C: N ratio;

When C: N=25, the factor *RADJST* is 1.0; when C: N=9, it is 2.6; when C: N=100, it is 0.29; when C: N=40, it is 0.57. The *RADJST* is obtained by linear interpolation when C: N ratio between these values.

The tensile equation used is

$$\begin{cases} RADJST = 0.76 - 0.005 \times CN \text{L} \ (40 < CN < 100) \\ RADJST = 1.725 - 0.029 \times CN \text{L} \ (25 < CN < 40) \\ RADJST = 3.5 - 0.1 \times CN \text{L} \ (9 < CN < 25) \end{cases} \tag{10}$$

where CN is the C: N ratio in the current residues.

Residual carbon content which each time step residues to the next step declines as

$$CRES = CRES - CRESR \quad (CRESR \leq CRES) \tag{11}$$

according to the formulas from (2) to (4), each lattice of the residual nitrogen mineralization can be given by

$$NRESR = CRESR \times (1/CN - 0.0333) \ (NRESR \leqslant NAF + NIT1,\ NRESR < 0) \tag{12}$$

where $NRESR$ is the lattice residual nitrogen mineralization in each time step (kg/900m^2/t); NAF is the ammonia nitrogen within 30cm of topsoil to the ground; $NIT1$ is the nitrate within 30cm of topsoil to the ground.

Arter each time step, the nitrogen content in the decomposed residues is:

$$NRES = NRES - NRESR \quad (\text{NRESR} \leqslant \text{NRES}) \tag{13}$$

The C: N ratio left to the next time step is:

$$CN = CRES / NRES \tag{14}$$

From (1) to (6), all formulas are based on the hypothesis of carbon contents in the crop residues. When C: N=30, the lattice mineralization is 0, when the microbial C: N=6.0, the relevant first reaction velocity parameters, i.e. k_{resr}、k_{manr}、k_{other} increases.

Based on the set of equations, we can derive the quantity of mineralization of nitrogen and residual nitrogen content for each time step.

We take the formula (1) and (3) into (2), then get

$$CRESR_{i+1} = k_{resr} \times RADJST \times (CRES_i - CRESR_i) \times TFAC \times WFAC \times ITIME \tag{15}$$

where i is the code of present step.

Then taking formula (8) into (4) and get

$$NRESR_{i+1} = k_{resr} \times RADJST \times (CRES_i - CRESR_i) \times TFAC \times WFAC \times ITIME \times (1/CN_{i+1} - 0.0333) \tag{16}$$

By taking the formula (6) and (8) into (4), we can get the residual nitrogen for each step

$$NRES_{i+1} = NRES_i - k_{resr} \times RADJST \times (CRES_{i-1} - CRESR_{i-1}) \times TFAC \times WFAC \times ITIME \times (NRES_i / CRES_i - 0.0333) \tag{17}$$

The *TFAC* can be obtained by Arrhenius equation, and WFAC according to a set of statistical calculation formulas.

4. Results and Analyze

It can be seen from Fig 1-4 that nitrogen mineralization has similar spatial distribution with the soil organic matter and total soil nitrogen. It can be seen from the legends of the above four figures, the mineralization order in a year is summer, autumn, spring, winter, with the largest quantity in summer while the smallest in winter, and the changes in steepness is quite evident. The main reason is that mineralization rate is the variable of soil temperature and moisture and the mineralization is most active in summer for that the soil temperature and moisture is higher. Compare the computed results with the original grid values it is found that the amount of grids with identical value increased from 94 to 291, it indicating a greater differentiation in soil nitrogen content after a year of post-mineralization. This is reflected in the plaques increases, the color contrast increases between the southwest and the light regions, but decreases with that between the south-east, the overall contrast across the region increases.

The Fig 5-7 show that the exogenous organic nitrogen and soil organic nitrogen in rice period have the same analogous mineralization pattern that is with a faster mineralization rate and with the decreasing mineralization rate after entering autumn. The exogenous organic matter mineralization of the wheat period reflects the change pattern from winter to summer, so the mineralization rate increase gradually.

Different from the soil organic matter spatial distribution, exogenous organic matter (with the unit volume of kg/900m^2) is highest in southwest of Yizheng and the corresponding county are Qingshan, Maji, Zhenzhou, etc, with the highest use of fertilizer per unit, the soil texture of which are rice soil, yellow brown soil. The overall content of exogenous organic matter was decreasing along the southwest to northeast. The exogenous organic matter is addition to soil organic matter, the exogenous organic matter without mineralization in a period will be deeper into the soil and become soil organic matter. Although the southwestern region has the highest quantity of organic fertilizer per unit area, it is not the highest area of total nitrogen content and soil organic matter for the arable land area is very scattered and the cultivable area is relatively small, while, this area is the second only to the southeast in the content of soil organic matter and total nitrogen and the differences are narrowing. It can be concluded that from the simulation results that, If the region continues to maintain its high fertilization, it is very likely to catch up with the the high soil organic matter and total nitrogen contents of southeast.

Fig 8 and Fig 9 were overlaying by the maps of contents of soil and exogenous organic nitrogen. In comparison, the annual mineralized quantities of soil and exogenous organic nitrogen in the Southwest is lower than that in the Southeast. As the result, Fig 9 presents nitrogen accumulation in the Southwest. Furthermore, there is a great differentiation in the distribution of area total nitrogen. There are 335 grids with identical values in the property table of Fig 8, while 768 grids with identical values in that of Fig 9. It is represented as patches increase in Fig 9. The effect combined with other soil processes changing the physicochemical property of soil, and finally causes the district difference of soil property.

It can be seen in Fig 8 that the southeastern part of Yizheng has a highest distribution of soil matter, the corresponding counties are Xinji, Piaoji, Xincheng.etc, which have a distribution of relative concentration of farmland, the soil are paddy soil with fertility retention of heavy soil in the highest organic matter content areas in general, which is a kind of artificial soil with its source characteristics changed after long –term cultivation and accumulated a large amount of organic matter. Coupled with the topography of Yizheng area down from the northwest to the southeast, and south of the Yangtze River are alluvial plain, so the soil organic matters composition with heavy quality are tend to accumulate in the plains. Thus the areas have a high content of organic matter. For nitrogen mainly presenting in organic matter, soil nitrogen also with higher content in the southeast as showed in Fig 9.

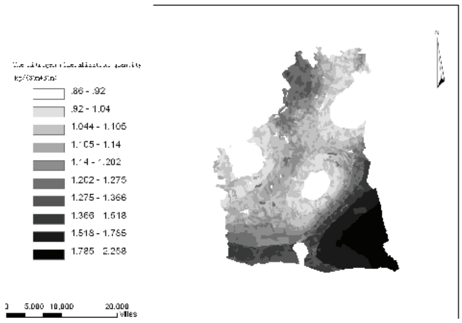

Fig. 1. The mineralization quantity of soil organic Nitrogen of March

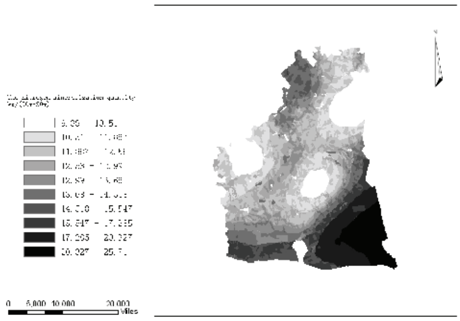

Fig. 2. The mineralization quantity of soil organic Nitrogen of June

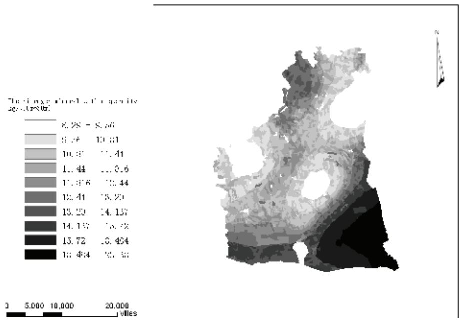

Fig. 3. The mineralization quantity of soil organic Nitrogen of September

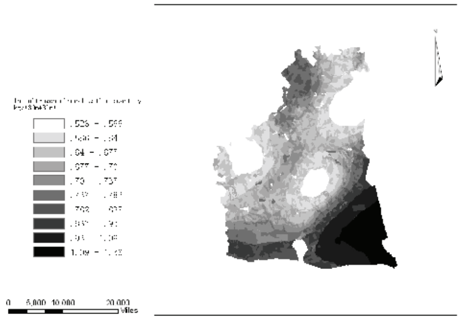

Fig. 4. The mineralization quantity of soil organic Nitrogen of December

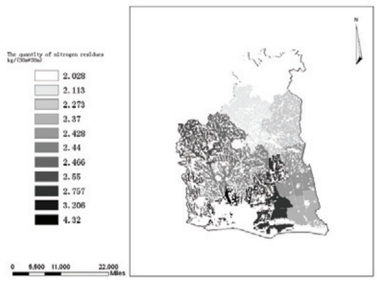

Fig.5. The exogenous organic nitrogen residues of rice period in 7.22

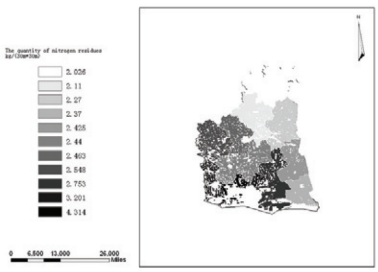

Fig.6. The exogenous organic nitrogen residues of rice period in 9.20

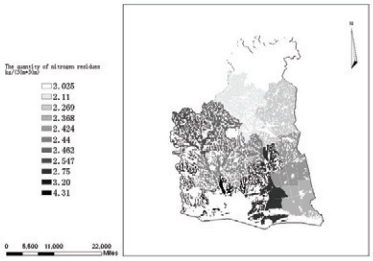

Fig.7. The exogenous organic nitrogen residues of rice period in 10.20

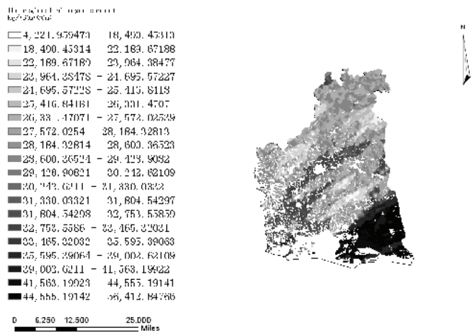

Fig.8.The total annual regional Nitrogen content

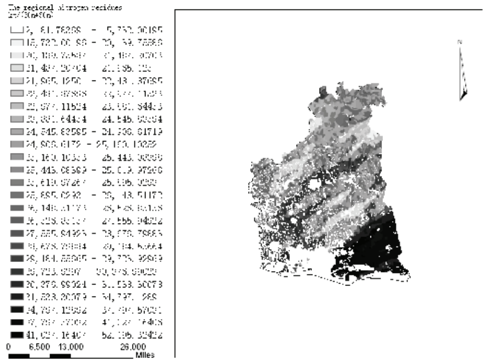

Fig.9.The total Nitrogen residuals after one year

Acknowledgements

Thank Professor Shen Runping of Nanjing University of Information Science and Technology (NUIST) for data available and helpful agriculture knowledge.

References

[1] Fields S. Nitrogen cycle out of control-a global problem. *Environmental Health Perspectives, Chinese Edition* 2004;**112**:a556-a563.

[2] Shen Y, Huang Y, Zong LG, Zhang W, Xu M, Liu LW. Simulation and Prediction of Soil Organic Carbon Dynamics in Jiangsu Province Based on Model and GIS Techniques. *Scientia Agricultura Sinica* 2003; **36**:1312-1317. (in Chinese).

[3] Howarth RW, Boyer EW, Pabich WJ, Galloway IN. Nitrogen Use in the United States from 1961-2000 and Potential Future Trends. *Ambio* 2002; **31**: 88-96.

[4] Bi JW, Zhang JB, Chen XM, Zhu AN, Feng J. Simulation of soil water leaching and nitrate-N loss with leachate in the field using HYDRUS-1D model. *Rural Eco-environment* 2004; **20**: 28-32 (in Chinese).

[5] Xu WB. Extrapolation of N_2O flux measurement at regional and global scales. *Chinese J. Soil Science* 2000; **31**: 91-95 (in Chinese).

[6] Liu XR, Dong YS, Qi YC. Research Progresses in Nitrous Oxide Emission from Soil. *Progress In Geography* 2005; **24**: 50-55 (in Chinese).

[7]Meng WG. Precision Agriculture and its technology. *Jiangsu Agricultural Mechanization* 2005; **6**:32-33 (in Chinese)

[8] Mu XM, Fan XL. A review on ecological models of soil N mineralization. *Chinese J. Applied Ecology* 1992; **10**:114-118 (in Chinese).

[9] Stoichev D, Kercheva M, Stoicheva D. *Use of NLEAP model for estimation of nitrates fate in Leached Chernozem*. Montpellier, France : Proc. Congres Mondial de Sci. du sol, 16; 1998.

[10] Fort Collins.. NLEAP Publications. *Soil Plant Nutrient Research*, Colorado State University, Department of Soil & Crop Sciences; 2002.

[11] Liu JH, Wang XD. Cultivation technology of a high-grade wheat cultivar-Yangmai No. 10. *China Seed Industry* 2001; (in Chinese).

[12] Li Bin, He G, Li C, Zhou DC. Biscuit wheat variety - Building No. 1 wheat. *Bulletin of Agricultural Science and Technology* 2003; **12**: 37(in Chinese).