Soil Carbon and Nutrient Changes Under Soil Erosion and GIS-Based Simulation

Zhu Yuanda[1],*Cai Qiangguo*[1] and *Zhang Guangyuan*[2]

[1]Institute of Geographical Sciences and Natural Resources Research, CAS; Beijing, 100101, PRC
E-mail**:** zhuyd@igsnrr.ac.cn
[2]The key Lab of Soil Resources and Environment of Agricultural Ministry in Subtropic, Huazhong
Agricultural University, Wuhan, 430070, PRC.

Abstract: After models of soil carbon and nutrient change, and soil erosion have been constructed, soil carbon and nutrient changes under soil erosion in each land unit of Wangjiaqiao watershed have been simulated and forecasted, which are based on IDRISIW GIS. The results of simulation showed that different element of soil nutrient (C, N, P, K) has different soil acceptable erosive modulus in different land use types, which means that one kind of soil element will decrease when soil acceptable erosive modulus is higher than the limited value.

Keywords: soil erosion, soil carbon, soil nutrient, change, simulation

Since 1980's, much attention was paid by soil scientists to that soil erosion affects soil productivity in the world, most of which was focused on expansion of soil erosion and its influence on soil resources reproduction. The process of erosion affecting productivity is a very slow one and is not easy to be examined (Li，1986). The research of it is almost suspended for difficulties of its check-up. Soil nutrient loss is a main approach by which soil erosion affects productivity. At present, most researches were calculating the gross of nutrient loss from surface runoff, underground runoff or sediments, which cannot clearly illuminate the process and exact degree of that erosion affects productivity in each land unit in watershed and tortured the relationship between erosion and responding decline of productivity. Therefore, in order to prove mechanism of that erosion affects productivity，it is very important illustrating the process and exact degree of that erosion affects soil carbon and nutrient.

1   Introduction

Area of Wangjiaqiao watershed is 16.7km^2. It is a second sub-watershed of Yangtze watershed, which locates in subtropical climate zone (Figure 1), and has alkalescency purple soil. The average air temperature of this region is 18.0℃. The rainfalls of the watershed are centralized between May and September, accounting for 67.16% of annual rainfall. In 1996, detailed investigations included soil, land use and erosion have been performed. All maps have been drawn and digitalized to build watershed spatial database. In the same time, soil of the whole watershed has been sampled to perform physical and chemical analysis. The results of analysis composed the watershed attribute database.

2   Analysis and methods

2.1   Analysis of simulating process

This study is to simulate spatial and time changing process of soil carbon, nutrient in watershed scale by taking account of soil erosion changed with space and time, differences of cycling and balance of soil carbon and nutrient between different types of land use, different influences of erosion on soil carbon and nutrient cycling.
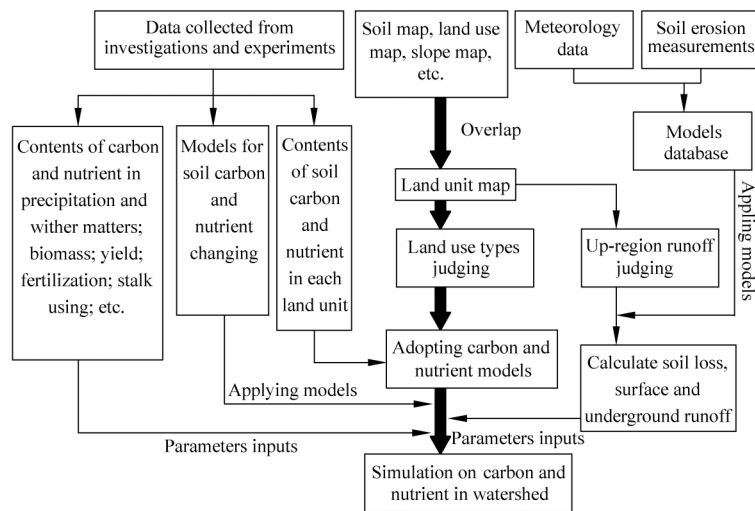
Fig. 1 Flow chart of simulation

2.2 Soil nutrient changing model

In terms of pools, soil nutrient are in status of dynamic changing. Regarding content of soil nutrient at one time point as Y_0, content at the point after a time interval of i as Y_i, and content change during the time interval as ΔY, we can get an equation as follow:

$$Y_i=Y_0+\Delta Y \tag{1}$$

According to Nutrient Runoff Model built by Gorham in 1979 (Marrs, 1993), the equation was transferring,

$$\text{Storage=Inputs–Outputs} \tag{2}$$
$$\text{Inputs}=J+F+G+W+N+H \tag{3}$$
$$\text{Outputs}=S+E+R+D+L+O \tag{4}$$

In above equations, J-precipitation, F-dry fallout, G-absorbed gases, W-mineral rock weathering, N-animal importation, H-nutrient added directly as fertilizer, S-outflow in runoffs, E-gaseous emissions, R- particulates released into the air, D-particulates released into runoffs，L-nutrient exported by animal，O-off-take in crop.

Then we can get the equation:

$$Y_i=Y_0+（J+F+G+W+N+H）-（S+E+R+D+L+O） \tag{5}$$

Taking account into availability of all parameters in the equations, we have dropped off some of them in this research, such as F, G, E, R and L, and choose soil erosion as a main factor of soil carbon and nutrient change especially to research impact of soil erosion on them. The model is simplified as follow:

$$Y_i=Y_0+（J+N+G+H+W）-（S+D+O+E） \tag{6}$$

Values of parameters concerned are showed in Table 1, which are cited from results of previous studies, investigation data and results of other related researcher. Concentrations of nutrient in surface runoff, underground runoff and sediments are key point for evaluating soil nutrient changes from erosion, which are showed in Table 2. Concentrations of nutrient in surface runoff and underground runoff are cited from previous results, which are carried out by this research group. Concentrations of nutrient in sediments are multiplying products of Nutrient Enrichment Ratio (NER) of sediment and initial concentrations of topsoil. That soil erosion affects soil carbon and nutrient mainly embodies by NER of sediment and runoff. Actually, NER varies with spatial and time change, which is proved by many experiments. Much more researches are needed to find the general law of the variation. After all of

parameters have been inputted, we could get soil nutrient changing models for different land use types.

2.3 Soil carbon changing model

Soil carbon was modeling solely because its cycling and balancing processes are very different with those of nutrient, which are affected by returned organic matters from crops, decomposing ratio of fresh organic matters, etc. Owing to without corresponding experimental confirmations, we use methods provided by D.S. Liu to simulate soil carbon dynamically (H.Y. Zhuang, 2000).

$$OM_t = X_0 e^{-kt} + \sum_{i=1}^{t} X_t e^{-k(t-i)} \tag{7}$$

$$X_t = \frac{R_t U}{W} \tag{8}$$

Where, t, - time (years), OM_t,- concentration of soil organic matters after t years, X_0, - initial concentration of soil organic matters, k,- mineralizing ratio of soil organic, been taken as 0.045 in forest and grass land, and as 0.06 in garden and tillage land (H.Y. Zhuang, 2000), X_t, -organic matter engendered from returned fresh organic matter, R_t, - quantity of returned fresh organic matter, U , - decomposing ratio, been taken as 0.25 (H.Y. Zhuang, 2000), W, - mass of soil concerned (t), been taken as 2.1×10^5 in the study.

2.4 Soil erosion models for each precipitation and each land unit

With regressing statistic analysis methods, we can get basic erosion model whose independent variable are quantity of precipitation, maximum intensity of one precipitation in 30 minutes and gradient of slope and length of slope, which are come from data of natural erosion observations and measurements that were performed by local Soil and Water Conservation Station between 1989 to 1996.

$$M = 0.000398 P^{0.7524} (I_{30})^{1.2281} S^{1.152} L^{0.791} \tag{9}$$
$$(n=38，\quad R^2 =0.8560^{**})$$
$$Q = 0.00147 P^{1.323} (I_{30})^{0.4730} S^{0.654} L^{0.473} \tag{10}$$
$$(n=38，\quad R^2 =0.8956^{**})$$

Where: M, - soil erosion modulus in one precipitation (t/km^2), Q,- deepness of surface runoff in one precipitation (mm/km^2), P, - quantity of precipitation (mm), I_{30}, - Maximum intensity of one precipitation in 30 minutes (mm), S, - gradient of slope (°), L, - length of slope (m). All units are same in paragraphs followed.

Equations 9 and 10 are designed to calculate soil erosion modulus and deepness of surface runoff in one precipitation in runoff plots without vegetation cover. In watershed soil erosion calculation, the equations should be modified by factors of land cover and management.

2.5 GIS-based simulation on process and effect of soil erosion affecting carbon and nutrient

The process means that soil erosion affects carbon and nutrient is a dynamic changing process with spatial and time changes. Spatial differences are embodying in that soil carbon and nutrient changes with different erosive condition, including gradient, length and parts of slope and other factors in different spatial scopes. Time differences are embodying in soil carbon and nutrient changes with erosion, cover, and precipitation and other factors in different time scales.

After calculating soil carbon, nitrogen, phosphorus and potassium changes under precipitation conditions of 1993 in each land unit of the watershed, we discovered that there are 44.14%, 55.8%, 39.2% and 75.7% of the total area of watershed in which contents of soil carbon, nitrogen, phosphorus and potassium decreased respectively, and the range of changes of carbon, nitrogen, phosphorus and potassium are –0.175—0.136, –0.021—0.019, –0.006—0.011 and –0.20—0.19 respectively. The changing area, and range of soil phosphorus are smallest among these changes.
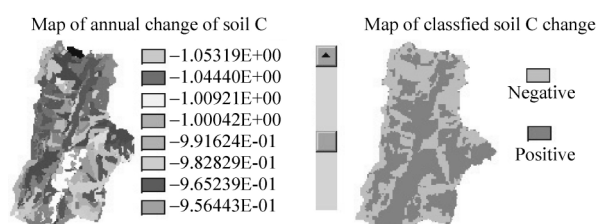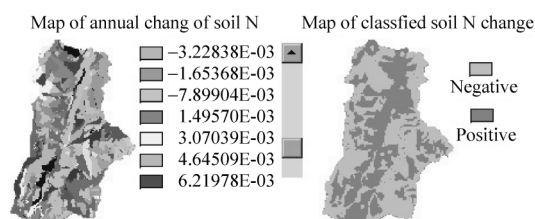
Map of annual change of soil C   Map of classfied soil C change

□ −1.05319E+00
■ −1.04440E+00
□ −1.00921E+00
■ −1.00042E+00
■ −9.91624E−01
■ −9.82829E−01
■ −9.65239E−01
□ −9.56443E−01

□ Negative

■ Positive

Fig. 2   Annual soil carbon change map

Map of annual chang of soil N   Map of classfied soil N change

□ −3.22838E−03
■ −1.65368E−03
■ −7.89904E−03
■ 1.49570E−03
□ 3.07039E−03
■ 4.64509E−03
■ 6.21978E−03

□ Negative

■ Positive

Fig. 3   Annual soil nitrogen change map

Map of annual change of soil P   Map of classfied soil P changem

■ −5.42652E−04
■ −3.98526E−04
■ −2.54399E−04
■ −1.10273E−04
□ −3.38533E−04
■ −1.77980E−04
■ −3.22106E−04
■ −4.66232E−04

□ Negative

■ Positive
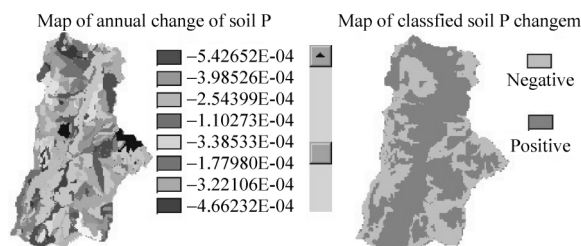
Fig. 4   Annual soil phosphorus change map

Map of annual chang of soil K   Map of clasfied soil K change

□ −3.89708E−01
■ −3.87058E−01
□ −3.84407E−01
■ −3.81757E−01
■ −3.79106E−01
■ −3.76456E−01
■ −3.73805E−01

□ Negative
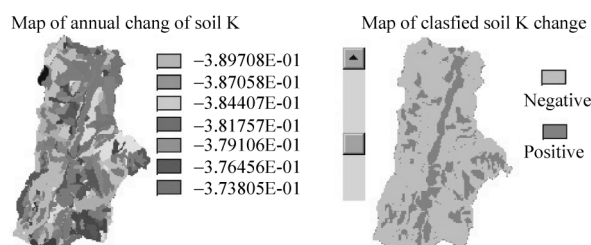
■ Positive

Fig. 5   Annual soil potassium change map

Table 1   **Ten years changes of soil carbon and nutrient in different land use types (g/kg)**

Items	C change	N change	P change	K change
Slope land	−1.252	−0.064	0.038	−1.83
Terraces	−0.477	0.088	0.052	−0.96
Slope garden	−0.136	0.012	0.033	−0.61
Terrace garden	0.113	0.166	0.051	−0.32
Forest land	0.135	0.124	0.010	0.36
Sparse-tree land	0.064	0.071	−0.006	−0.28
Grassland	0.059	−0.034	−0.024	−0.87
Watershed	−0.201	0.058	0.011	−0.50

Supposing that cultivating and managing condition of watershed do not change, and according to erosive status of each year and annual changes of soil carbon and nutrient, we got ten- year-change of soil carbon and nutrient of each land unit in watershed, which was showed in Figure 5. Results of forecasting indicated that under the cultivating and managing condition at present, content of soil carbon and potassium will decrease in ten years while nitrogen and phosphorus would increase in the period. As to different land use types, there have highest decrease of soil carbon, nitrogen and potassium in tillage slope land, which is related to that it has highest soil erosion modulus.

Table 2 Lowest soil erosion modulus that may make carbon and nutrient decreased (t/km^2)

Items	Carbon	Nitrogen	Phosphorus	Potassium
Tillage land	2,000—2,500	2,000—2,500	5,000—6,000	—
Garden land	2,500—3,000	3,000—3,500	6,000—7,000	—
Forest land	1,000—1,500	1,000—1,500	2,000—2,500	500—1,000
Grass land	2,000—2,500	1,000—1,500	2,000—2,500	—

The results of simulation showed that different element of soil nutrient (C, N, P, K) has different soil acceptable erosive modulus in different land use types, which means that one kind of soil element will decrease when soil acceptable erosive modulus is higher than the limited value. In terms of total watershed, there have many differences between changes of soil carbon and nutrient in different land use types, for example, carbon and nutrient of tillage slope land and grassland are decreased commonly in forecast while those are increased commonly in forest land. We also discovered that soil acceptable erosive modulus for carbon, nitrogen, phosphorus and potassium are different in same or different land use types. In the same time, changes of soil carbon and nutrient are also different in same land use types, for example, soil carbon and nutrient would decrease in land units that have high soil erosion modulus while increase in those have low soil erosion modulus. Furthermore, soil acceptable erosive modulus that may make carbon and nutrient decreased are not fixed, the same erosion modulus may have different consequences in different land unit, which relate to other factors except for erosion. Results of changes of soil carbon and nutrient calculating in single land unit showed that nitrogen is most sensitive to erosion while phosphorus is most inertial in all four substances.

3 Discussions

Through serried sampling, physical analysis and chemical analysis, we studied approaches and behaviors by which soil erosion affects soil carbon and nutrient changing and general laws of spatial distribution of soil carbon and nutrient in micro-topography scales under influence of soil erosion. Based on GIS, we have built soil carbon and nutrient changing models and erosion models, simulated the spatial and time process of erosion affecting soil carbon and nutrient changes, and forecasted annual and long term changes of soil carbon and nutrient under erosion.

The main purpose of this study is to find a method to illustrate process of changing in lager spatial scales by integrating single-aim research results come from smaller spatial scales, which is expected to modify the deficiency of soil erosion and nutrient balance research in practice guiding. Though we have done our best to rationalize all parameters and make results most precise, the study still has many deficiencies and shortages, because it involved many research fields, had many changing factors and dealt with many complex processes of changing.

Acknowledgements

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