Agricultural Sciences in China
2005, 4(1): 101-105
http://www.ChinaAgriSci.com

Studies on the Situation of Soil Organic Carbon Storage in Croplands in Northeast of China

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Abstract

This paper aims to estimate the soil organic carbon (SOC) storage in North east of China, identify its balance situation and changing trends under current cropping systems, and finally put forward some strategies to keep the SOC in balance. A biogeochemical model (DNDC) for agro-ecosystem was employed to predict SOC dynamics in agricultural ecosystems at regional scale. Data on climate, soil properties, cropping systems, acreage, and management practices at county scale were collected from various sources and integrated into a GIS database to support the model runs at the regional scale. The model predicted results revealed that (1) Total SOC storage in agricultural lands in Heilongjiang, Jilin and Liaoning provinces in Northeast of China is about 1 243.48 × 10^6 t (0-30cm soil layer), respectively occupying 58.4, 25.5 and 16.1%; (2) Under the current cultivation systems, SOC is in a negative balance with carbon losing at a high rate of 31.22 × 10^6 t a^{-1} (respectively 59.3, 25.9 and 14.8% in Heilongjiang, Jilin and Liaoning provinces) and 2.05 t ha^{-1} a^{-1}, the situation is more serious in Heilongjiang and Jilin provinces; and (3) Protective cultivations, such as manuring, returning more residue of crop to the field, adopting no-till, are very useful for the accumulation of SOC in these regions.

Key words: Northeast of China, Soil, Soil organic carbon, Simulation model

INTRODUCTION

The three provinces in Northeast of China, Heilongjiang, Jilin and Liaoning, are the important agricultural production bases in China, they cover 115 × 10^4 ha land areas, around 1/10 of total national land, more than 200 counties, and 1 523 × 10^4 ha of crop land. With a dry-cold winter, 80-180 d frost-free period from north to south, only single crop can be harvested annually in most areas. However,the output of grain per capita is the highest in China, with 810 kg grain per agricultural capita on the average, and the corn and bean production account for 47.4% and 42.8% of the national totals, respectively. Located in one of the three world-famous black earth belts, the soil is rich and fertile, only in Heilongjiang Province , 67.6% of the total areas of cropland is covered by black earth, chernozem and meadow soil . Since large areas of black earth were brought under cultivation, the soil organic matter content decreased annually due to the unreasonable field management, low manuring , less crop residue returned to the field and soil erosion. As a result, the organic matter content in black earth and chernozem decreased from the original 6-8% to the current 1-3%, the soil depth of humus dropped from 60-70 cm to 20 cm[1]. Currently, the layer of black earth in hill cropland annually decreases by 0.1-0.5cm. If things continue this way, black soil in the reclaimed land will disappear in 40-100 years[2], the Northeast of China will be changed from a granary to the desolate and infertile land, which will bring an immeasurable loss to the wet land,

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biodiversity and global eco-environment.

Taking the three provinces of Northeast of China as example, this paper aims to estimate the soil organic carbon (SOC) storage in cropland in these regions by employing a biogeochemical model (DNDC) for agro-ecosystem, to identify its changing trends under current cropping systems, and finally to put forward some strategies to keep the SOC in balance so that provide scientific foundations for sustainable development of agriculture in Northeast of China.

MATERIALS AND METHODS

To estimate the SOC storage in cropland in Northeast of China, DNDC model was employed. Firstly, the model was tested by local experimental data; Secondly, the GIS database for supporting the regional modeling was built according to the local agricultural cultivation systems; Finally, the regional modeling was run and the modeling results analyzed.

DNDC model

The DNDC (DeNitrification & DeComposition) model, developed in the University of New Hampshire since 1992, is a process-orientated simulation tool of soil carbon and nitrogen based on biogeochemistry cycles , it is one of the most succesful biogeochemical models in the world[3-11]. The model contains six interacting sub-models which describe the generation, decomposition and transformation of organic matter, and output the dynamics of components of SOC and fluxes of greenhouse gases. Sub-models are: (1) Soil climate and the thermal-hydraulic sub-models use soil physical properties, air temperature, and precipitation data to calculate soil temperature and moisture profiles and soil water fluxes through time. The results of the calculation are fed to the other sub-models. (2) Nitrification sub-model and (3) Denitrification sub-model calculate hourly denitrification rates and N_2O, NO, NH_3 and N_2 production during periods when the soil has water filled pore space greater than 40%. (4) Decomposition sub-model simulates decomposition of each SOC pool, i.e., it calculates daily decomposition, nitrification, ammonia volatilization processes, and C_2O production (soil microbial respiration). (5) Plant growth sub-model calculates daily root respiration, N uptake by plants, and plant growth. (6) Fermentation sub-model calculates daily methane (CH_4) production.

Input data for the model include data of daily weather (temperature and precipitation), soil properties (bulk density, texture, initial SOC content, and pH), landuse (crop types, cropping rotation), and practices (tillage, fertilization, irrigation, ratio of crop residue return to the field and weeding). For the site mode running, the data need to be input according to the cropping rotation, the model can run year by year if input several years' data. For the regional mode running, all the above data for site mode need to be integrated into a GIS dataset (one county is a data record). The DNDC model is a process-orientated simulation model that can completely describe soil carbon and nitrogen circulation which is suitable to the agro-ecosystem in both the site mode and regional mode.

At present, the DNDC model has been conducted in practice by scientists in many countries, for example, the model is applied to simulate the carbon circulation in paddy field in Italy and Germany, in wheat field in Canada, and it has been used to simulate the dynamics of soil organic matter in experimental field for 100 years in Rothamsted Experimental Station in England. In the international conference on global change in Asia-Pacific areas in 2000, the DNDC model was recommended in the first place to extend in Asia-Pacific areas. DNDC model has merits in many aspects, such as powerful simulation function, easy obtainment of input data, and a friendly interface of software, etc. and being specialized for agro-ecosystem.

Establishment of datasets and identification of basic parameters

A major challenge in applying an ecosystem model at regional scale is assembling adequate data sets needed to initialize and run the model. Applying the DNDC model to estimate the SOC storage in arable land in Northeast of China requires spatial databases of soil properties, daily weather, cropping and other data of agricultural management practices. County-scale (totally 202 counties in Northeast of China) data sets were developed to present the status of agricultural production in 1998 with the aid of maps (county boundary map in 1990), agricultural census data, and ground investigations. The datasets consist several sub-datasets, (1) dataset of crop types, including physiological data of typical crops and cropping data of planting date, harvest date, maximum yield, etc.; (2) agricultural dataset, such as sowing acreages of all kinds of crops, nitrogen fertilizer, effective acreages of irrigation and cropland acreages, livestock and agricultural population at county level in 1998; (3) climate dataset, including daily weather data for 1998 (precipitation, maximum and minimum air temperature) which were acquired from 60 weather stations in Northeast of China, each county was assigned to the nearest weather station; (4) soil dataset, including soil physical properties of bulk density, clay content, initial SOC content and pH.

DNDC model was used to simulate SOC storage and its change for each crop/management scenario at county level (e.g. rice/crop rotation). Since the SOC storage is directly related to the soil organic matter content, we estimated the likely range of SOC storage and dSOC (value of SOC at the end of cropping season minus the previous value) for each crop by simulating one calendar year (1998) for each rotation in every county based on both the high and low soil organic matter content values. In this paper, the mean results (average of high and low estimates) were presented,county SOC and dSOC were calculated by multiplying the mean SOC and dSOC for each crop rotation scenario by the area of each crop rotation in each county, then the sum of these totals for all crop rotations in a county equals the county total. The regional total equals summation of all the county totals.

Some important assumptions under the model running for the baseline scenarios are given below: (1) because the nitrogen in different kinds of fertilizers exist and transform in various forms and have different properties in soil, so based on the total amount of fertilizer, it is necessary to distribute the nitrogen according to fertilizer types. The fertilizer mix assumption: 40% urea, 40% NH_4HCO_3, 20% $NH_4H_2PO_3$; (2) base case scenario assumption:15% of non-grain aboveground crop biomass returned to soil, which is set according to the investigations organized by the Ministry of Agriculture, China; (3) livestock and human populations were used to calculate manure additions to croplands. The baseline scenario assumptions: 20% of livestock and 10% of human manure added to soil. This assumption represents the average regional condition; and (4) tillage assumptions: twice tillage for each cropping season, 20 cm deep on the planting day, 10 cm deep one day after harvest.

RESULTS

Model test and sensitivity analysis

The DNDC model has been validated throughout the world by using long-term and short-term experimental data to test its behavior on the modeling of the carbon biogeochemical process in agricultural soils, involving some works conducted in China[4-6]. In this paper, DNDC model was verified further in the aspect of simulating SOC dynamics in order to meet the needs of simulating SOC balance

Two long-term experimental data about SOC dynamics were selected to test the model's behavior on the modeling of the carbon biogeochemical process in agricultural soils. Fig.1-a presents a comparison of measured and simulated results on the SOC dynamics in a

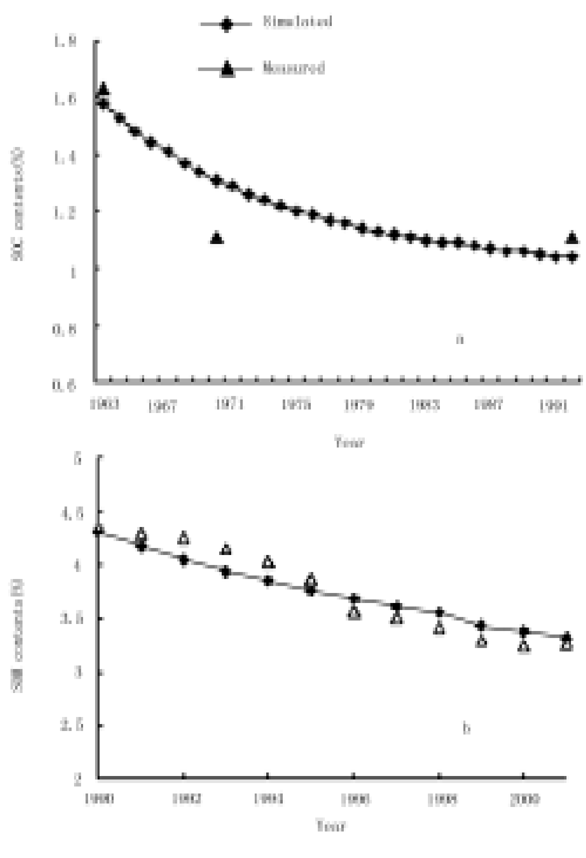

Fig. 1 The test of DNDC model for simulating SOC dynamics

long term of 30 years since reclamation in Zhonghehou experimental site in Wuchuan County in Inner Mongolia (data source: Academy of Agricultural Sciences in Inner Mongolia), and Fig.1-b shows a comparison of measured and simulated results on the SOC dynamics in a field of continuously planting corn for 12 years in Longjiang County in Heilongjiang Province. Above comparison results demonstrate that the model simulated results tally with the long term experimental data, and in the example of Longjiang County it has high correlation coefficient (r= 0.975), indicating that the DNDC model can simulate SOC dynamics in agricultural soil precisely and hence can be used to simulate the SOC balance in agricultural field at regional scale with the support of database.

The sensitivity studies were designed to illustrate the DNDC behavior in simulating soil carbon response to changing of climate, soils, and agricultural practices, the results are primarily based on scenarios designed to study the response of soil carbon in corn (maize) plots (in Longjiang County in Heilongjiang Province) to the changes in tillage, fertilization rates, manure amendment, and irrigation practices which are currently applied in the Northeast of China. The sensitivity of changes in SOC storage to varied climate/soil conditions was appraised under various cropping activity scenarios of (a) manure amendment, (b) increased fertilization, (c) conversion from conventional tillage to no-till, and (d) irrigation (Fig.2). Soil/climate condition was respectively soil texture (sand, sandy loam, loam, clay loam, clay), pH (4.5, 5.5, 6.5, 7.5, 8.5), initial SOC content (0.005, 0.01, 0.015, 0.025, 0.035 kg kg^{-1}), annually average temperature (0.5, 2.5, 4.5, 6.5, 8.5°C).

The largest gains in SOC resulted from manure amendment indicate that manure amendment is more effective on the accumulation of SOC than other practices such as increased fertilization of chemical, no-till, and irrigation in Northeast of China. The bars in the Fig.2 represent the difference in SOC storage between the standard conditions and the modified conditions.

Sensitivity analysis results showed that the initial SOC content induced increase in SOC is sensitive to variations in soil texture, pH, and temperature under the current cultivation and cropping practices. According to the results, estimates of SOC storage and its changes in Northeast of China by using DNDC model were conducted based on the scenarios of highest and lowest initial SOC content respectively, from which the changes and ranges of SOC storage were drawn, and the average value of SOC represents the current situation of SOC storage in Northeast of China.

Modeled results of SOC storage

According to the model simulation results, the SOC

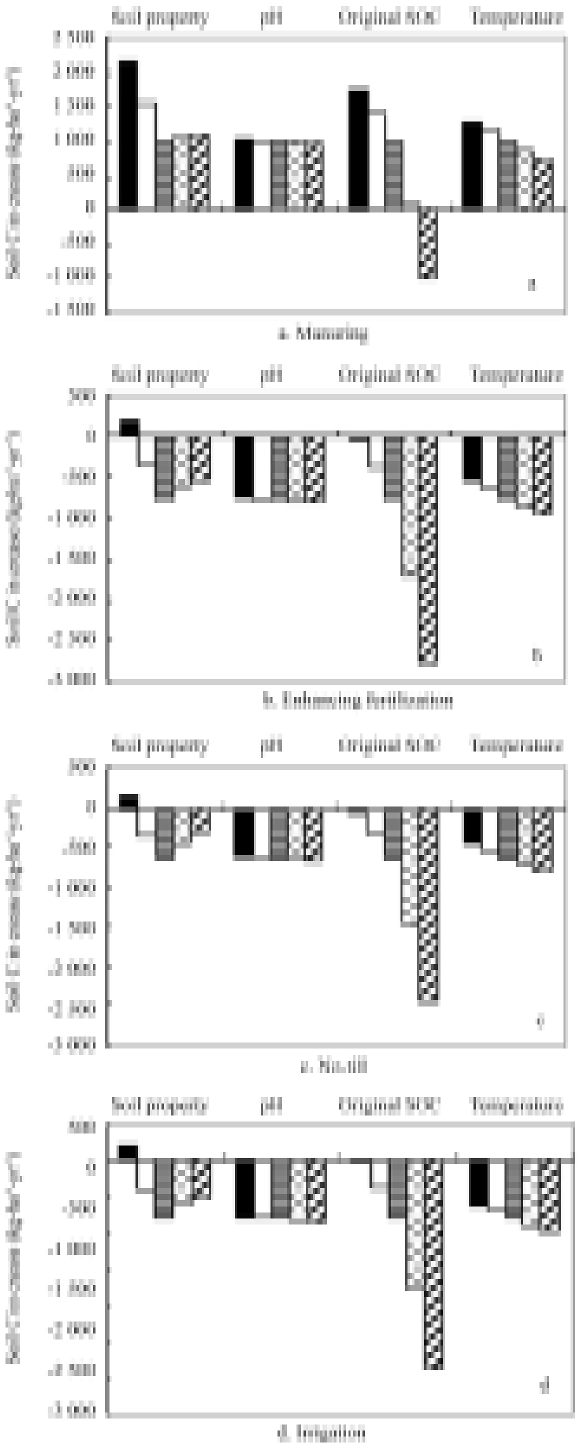

Fig. 2 The sensitivity analysis on simulating SOC balance for DNDC

storage in the total of 1 523´10[4] ha croplands in North-east of China is about 1 243.48 × 10^6 t, average 81.65 t per hectare cropland (Table). In Heilongjiang Province, due to the huge area of black earth, it reaches the maximal 725.271 ×10^6 t (Table), accounting for 58.4% of the total SOC storage in the province, while its arable land being only 50 % of the regional area. The average SOC storage is 95.9 t per hectare of cropland which is more than the average value of the three provinces. The SOC storage in Jilin and Liaoning provinces is respectively 317.562 ×10^6 t and 200.645 ×10^6 t, 25.5% and 16.1% of the three provinces total respectively.

The simulated values of SOC storage in some representative counties in the three provinces were listed in Table. In Heilongjiang Province, the largest SOC storage in cropland is in Hailun County at a value of 27 × 10^6 t, while the largest SOC storage per hectare of cropland is in Jixian County with 147 t ha^{-1}. In Jilin Province, the largest SOC storage in cropland is in Nongan County at a value of 22 × 10^6 t, while the largest SOC storage per hectare of cropland is in Zhenpen County at 122 t ha^{-1}. In Liaoning Province, the largest SOC storage per hectare of cropland is in Fengchen County at a rate of 110 t ha^{-1}.

Table The situations of estimated SOC (0-30cm) in North-east of China in 1998

Regions	Cropland areas (ha)	SOC storage (×10^6 t)	Annual change of SOC storage (×10^6 t yr^{-1})	Change rate of SOC storage (kg ha^{-1} yr^{-1})
Heilongjiang Province	7 562 733	725.271	-18.523	-2 449.25
Hulan County	151 909	15.274	-0.4938	-3 250.63
Duerbote County	91 682	11.239	-0.4138	-4 513.43
Gannan County	137 905	17.667	-0.5060	-3 669.15
Wuchang County	162 271	16.366	-0.4840	-2 982.66
Binxian County	141 872	14.297	-0.4297	-3 028.78
Nenjiang County	128 340	16.346	-0.5673	-4 420.28
Jixian County	118 951	17.595	-0.5636	-4 738.08
suihua County	173 487	17.547	-0.4558	-2 627.28
Beian County	92 030	11.707	-0.4091	-4 445.28
Bayan County	179 616	18.039	-0.6117	-3 405.59
Jilin Province	3 860 933	317.562	-8.0790	-2 092.49
Nongan County	290 998	22.317	-0.7733	-2 657.41
Fuyu County	225 336	17.392	-0.4911	-2 179.41
z henpen County	95 415	11.697	-0.4315	-4 522.34
Gongzhuling County	219 428	18.169	-0.5735	-2 613.61
Liaoning Province	3 805 340	200.645	-4.6200	-1 214.08
Zhuanghe County	124 646	11.201	-0.4357	-3 495.49
Haicheng County	99 657	9.012	-0.2989	-2 999.28
Linghai County	102 050	9.270	-0.4145	-4 061.73
Fengcheng County	65 256	7.200	-0.2943	-4 509.93
Total	15 229 006	1 243.480	-31.2200	-2 050.04

The values for each province are the totals of tha t of all counties.

The situation of net SOC balance

In view of SOC balance, the SOC in cropland in North-east of China is in a severely negative balance, SOC is losing at a rate of 31.22 × 10^6 t a^{-1}, and 2.05 t per hectare cropland (Fig.3). Arable soils release 44.49 × 10^6 t carbon as carbon dioxide (CO_2) into the atmosphere, while recoup only 9.948 × 10^6 t C from crop residue annually. SOC losing occurred most heavily in Heilongjiang Province, at a loss of 18.52 × 10^6 t in 1998,

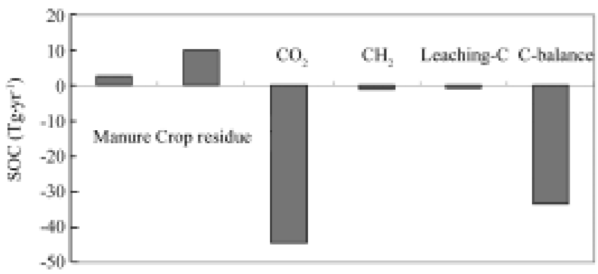

Fig. 3 The model estimated balance of SOC in croplands in North-east of China in 1998

which represented nearly 59.3% of the total loss of SOC in the three provinces, reaching 2.449 t per hectare cropland, and 4 t ha^{-1} in Nengjiang and Jixian counties. In Jilin and Liaoning provinces, they are 8. 079 × 10^6 t and 4.62 × 10^6 t, respectively 25.9 and 14. 8% of the total loss of SOC in the three provinces, and 2.092 and 1.214 t ha^{-1} for unit area in separate. The simulated results implied that SOC in cropland is in a heavy loss in Northeast of China,especially in

Heilongjiang and Jilin provinces, so it's urgent to launch strategies to protect the black earth.

Protection of SOC in cropland

The dynamic equilibrium of SOC in agro-ecosystem is a gradual process, SOC is easy to lose while relatively difficult to accumulate. It possibly takes 160 years or longer for the soils to approach a equilibrium, and SOC contents at equilibrium are independent of their initial SOC levels (1% or 5%) but depend on cropping practices (Fig.4).The model predicted results revealed that protective cultivations, such as manuring, returning more crop residue to the field, no-till, are very useful for the accumulation of SOC in this region. The continuous accumulation of SOC is the foundation of soil sustainable fertility, which in turn is of significance to the sustainable development of agriculture. In conclusion, effectively increasing SOC and protecting soil resources should be a long-term policy.

DISCUSSIONS AND CONCLUSIONS

In this experiment, a biogeochemical model (DNDC) for agro-ecosystem was employed to predict soil organic carbon dynamics in agricultural ecosystems at regional scale by integrating the data in 1998. The modeling results revealed that total soil organic carbon storage is about 1 243.48 × 10^6 t (0-30 cm soil layer) in agricultural lands in Heilongjiang, Jilin and Liaoning provinces in Northeast of China, occupying 58.4, 25.5 and 16.1%, respectively. Under the current cultivation system, SOC is at a negative balance with carbon losing at a high rate of 31.22 × 10^6 t a^{-1} (59.3, 25.9 and 14. 8% for Heilongjiang, Jilin and Liaoning provinces respectively) and 2.05 t ha^{-1} a^{-1} , the situation is serious especially in black earth-rich areas of Heilongjiang and Jilin provinces. In order to return the cropland SOC to balance, it is urgent to increase the rate of crop residue returned to the field, and apply protective cultivations, such as manure amendment, no-tillage, which are all very useful for accumulation of SOC in these areas.

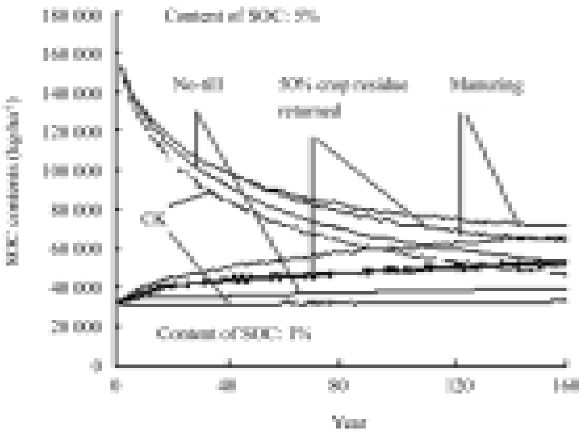

Fig.4 Model estimated the long-term effects on the SOC dynamics to various practices

Terrestrial soil is the largest carbon pool in the earth surface, with a carbon stock of 1 400-1 500 Pg (within 0-100cm soil layer), of them soil carbon in cropland is about 142 Pg[13]. Soil is the slowest turnover carbon pool in the terrestrial ecosystem, and carbon in soil usually exists in the form of organic carbon , the amount of SOC storage is one of the important indexes of soil fertility, since soil carbon is the core of the soil quality. Due to the huge stock of SOC, even a change within a narrow range will cause tremendous influence on global climate, just like the great changes in global climate caused by CO_2 tremendously emitted by human activities; it will also affect nutrients supply for terrestrial vegetations. So, whether to study the matter circulation in each earth biosphere for preserving eco-environments, or to protect soil resources for maintaining sustainable development of agriculture requires a thorough understanding on the carbon storage and fluxes between all kinds of carbon pools [14]. Currently, under the background of global climatic changes, the researches focusing on SOC storage, distribution, influence factors and ecological effects will be useful for scientifically utilizing and protecting limited soil resources, mitigating the emissions of greenhouse gases from soil, increasing the carbon stock in soil and improving the soil quality, it is also significant for ecological rehabilitation of the degenerated land and the environmental harness and protection.

The three provinces in Northeast of China are located in the range of middle and high latitudes in the Northern hemisphere, which is one of the most sensitive areas to global climatic changes and also one of world famous black earth belts. The characteristics of the biogeochemical circulation in these regions greatly affect the evolution of its terrestrial ecosystem, food security and the gross of the pools and sinks of greenhouse gases in China. So, the researches on the SOC storage and its change in cropland in this region will be of significance in theory and practice to correctly evaluate the soil fertility in cropland and its change trends, to control the organic matter distribution, identify the status of pools and sinks of carbon and carbon fixing potential, and further formulate rational countermeasures for the sustainable development of agriculture.

In China, the researches on the carbon storage were conducted before mostly by the way of soil carbon density times soil areas[15], or using statistic regression model on the relation between SOC storage and soil depth[16] based on the data from the second national soil survey. Because of an uneven three-dimensional structure, soil has complicated inlaid properties in space and also complicated interactions to climate, terrestrial vegetations and biomasses, so the density of soil carbon has extreme variability in space, plus that researchers utilize different sources of data and statistic sampling, the results thus have great differences. Especially due to shortage of data on soil carbon properties reported before domestically, the estimated results based on limited data lack definition. In resent years, the process models of soil carbon are adopted by more and more researchers in the research of SOC storage [11].

The DNDC model is a process-orientated simulation tool of soil carbon and nitrogen circulation based on biogeochemistry, which is suitable to the agro-ecosystem for both site mode and regional mode. The results derived from model simulation reflect the actual situation of SOC storage in cropland in Northeast of China, and some effective countermeasures for protecting SOC were pointed out, the estimated results and methodology are applicable. Only two long-term experimental data were selected to test the model in the paper, it's needed to enhance the test and validation for the model's simulation on carbon circulation in the future. An accurate estimate of SOC is directly related to the exact values of the data in the regional GIS datasets which are derived from statistic data, while it is noted that some data such as the data of cropland acreage are obviously underestimated in each of the Statistic Year Books, so the estimated result of SOC is possibly underestimated, though the datasets were the best which can be collected currently. The identification of a few important parameters, such as the rate of residue returned to the field and rate of manure, will also significantly affect the results. So more investigations will be required to identify the sensitive parameters,by this way it can gradually perfect the GIS datasets, and acquire more precise estimated results.

Acknowledgements

The study was supported by the National Key Technologies R&D Program of China During the 10th Five-Year Plan Period, P.R.China (2002BA516A08).

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(Edited by ZHAO Qi)