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Changes of Soil Carbon and Nitrogen Storages under Modern Industrialization in a Rural Landscape of North China Plain

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***Abstract* – Modern industrialization pushes agricultural modernization, which is changing nutrients biogeochemical cycles in soil as well as regional and global environmental changes. Taking a typical agricultural county of North China Plain as an example, the article, choosing initial stage (year 1983) , middle stage (year 1990) and modern stage (year 2004) of agricultural modernization across agricultural reform process, studied on soil pH, bulk, contents and storages of organic carbon and total nitrogen. During recent 20 years from traditional agriculture to modern in the region, soil pH decreased, bulk increased lightly, the contents of organic carbon and total nitrogen significantly increased by 70% and 133% respectively, and the storages of organic carbon and total nitrogen in whole county increased by 72% and 113% respectively, with rapider increase rates after 1990. Modern industrial technologies applied to agriculture, including large quantity of chemical fertilizers inputs, modern machine irrigation and agricultural mechanizations, were the main causes reduced these changes.**

Keywords – soil organic carbon; total nitrogen; biogeochemical cycle; industrialization; global change; North China Plain

I. INTRODUCTION

Under natural and anthropogenic disturbances, the biogeochemical changes and their environmental impacts of various life elements on earth are the key aspects of current researches on global climate changes [1-3]. In terrestrial ecosystems, soil is a great organic carbon pool. It has been estimated by various models to be about total 1288~1939 Pg organic carbon existing in the world's soils [4], and 500 Pg of those in the surface (0~20cm) soils, which was more than total organic carbon in terrestrial biomass. On the other hand, nitrogenous cycle in soil is closely related to environmental quality. Compared to those in natural soil, carbon and nitrogen pools in surface soil of arable land are much more active and change more greatly along with enhanced human activities. Especially in the recent century, to meet rapid grain needs with increasing population, modern industrialization of intensive farming, chemical fertilizers overusing and machine tilling to agriculture changed fertility and productivity of arable lands [5-6], and also biogeochemical cycles of carbon and nitrogen in agro-ecosystems, which led to more greenhouse gas emission s including CO_2、CH_4 and N_2O from rural ecosystems [7], and then affected global climate [8-11]. Moreover, in some agricultural region with high productivity, keeping increasing chemical nutrients input for more products harmed environment and human's health [12].

North China Plain has been an intensively agricultural populated, frequently ecology and environment changed largest rural region in China for hundreds of years. Since 1945, this rural region has gone through several massive reforms of production relationship [13]. Among those, the Household Responsibility System from the end of 1970s to the beginning of 1980s impacted most deeply to the rural region. Subsequently, the region stepped into initial stage (1980s), middle stage (1990s) and modern stages (since new century) of agricultural reform and development. During the stages, modern industrialization technologies were applied rapidly to agricultural produce, which raised agricultural productivity greatly and improved the agricultural modernizations. Carbon and nitrogen cycles in agro-ecosystems were greatly influenced by this process too [14]. Thus, the objective of this paper, choosing a typical agricultural landscape in North China Plain, is to assess the contents and storages changes of agricultural topsoil organic carbon (SOC) and total nitrogen (TN) under modern industrialization, as well as to lay the foundation for evaluating regional biogeochemical cycles and their environmental effects.

II. METHODS

A. Site Description

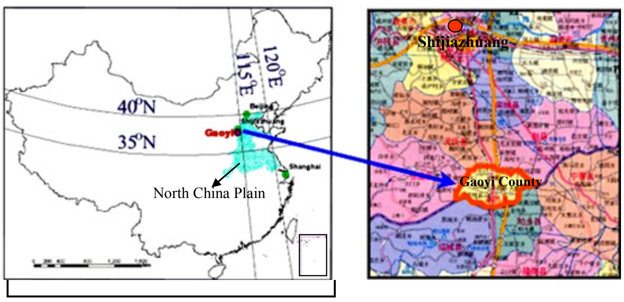

Figure 1. Gaoyi County location in China and North China Plain

Our typical research site, Gaoyi county in Hebei province, is located in the west edge of North China Plain (37°33′N~37°42′N, 114°26′E ~ 11443′E) and one part of piedmont plain（figure 1）with average yearly temperature of 12.6℃ and percipient of 513.1 mm. Total area of the whole county is only 222 km^2, of which alluvial-proluvial plain accounts for 99.5%, and cinnamon soil is main soil group [15]. In 2008, total population of the county was 175,645, 89% of which were agricultural population. Arable land area of 16,673 hm^2 accounts for 75% of total land area. In a word, Gaoyi is a typical small plain county mainly with agricultural industry.

B. Sampling, Measurements and Calculations

The soil composition in Gaoyi is simple and homogeneous with only two groups of cinnamon soil and flvuo-aquic soil, and 4 subgroups. Since limestone cinnamon soil and meadow cinnamon soil account for 19.9%% and 78.33% of the county area [15], soil samples were taken from this 2 subgroup soils related to 7 soil types (table 1). The data of initial stage were adapted from the Gaoyi soil database of the second national soil survey in 1983, that of middle stage from the data of 98 typical soil samples in 1990, and that of modern agricultural stage was obtained in 2004 by resampling 98 same soil places as those both in 1990 and 1983.

TABLE 1. MAIN SOIL TYPES IN GAOYI COUNTY [a)]

Soil Code	Soil type	Soil subgroup	Soil group	Area (hm^2)	Area percentage %	Number of samples
1	Sandyloam limestone cinnamon soil	limestone cinnamon	Cinnamon soil	140.28	0.67	2
2	Lightloam cinnamon soil	limestone cinnamon	cinnamon soil	3522.37	16.8	26
3	Thick-stone lightloam cinnamon soil	limestone cinnamon soil	cinnamon soil	67.84	0.32	1
8	Low-stone lightloam cinnamon soil	limestone cinnamon	cinnamon soil	54.74	0.26	2
10	Sandyloam meadow cinnamon soil	meadow cinnamon	cinnamon soil	184.76	0.88	1
12	Lightloam meadow cinnamon soil	meadow cinnamon	cinnamon soil	15226.9	72.54	58
15	Deep-clay lightloam meadow cinnamon soil	meadow cinnamon	cinnamon soil	923.81	4.39	8

[a)] Soil codes instead of soil type names will be used in the contents below

Soil sampling in 1990 and 2004 was based on the 1:50,000 digital soil map made in 1983 (a 2002 IKONOS image as reference). The locations of all field sampling places were recorded and imported to digital soil map (figure 2). To minimize temporal error, soil sampling times in three stages were consistent. Each soil sample was a mixed sample from 5 samples taken from 20m scope around the centre point, and another sample was taken from the center soil profile simultaneously using circular soil cutter to test soil bulk. After a standard pretreatment process at laboratory, pH, bulk, contents of organic carbon (potassium dichromate oxidation titration, Chinese GB 7857-1987) and total nitrogen (semimicro-Kjeldahl method, Chinese GB 7173-1987) [16] for each soil sample. Thereafter, based on measured soil bulks and contents and referenced calculations[17-18], soil organic carbon density (SOCD，kg/m^3), total nitrogen density（TND，kg/m^3）, organic carbon storage（SOCS，kg）, total nitrogen storage（TND，kg）and C/N ratio（%）of 0~20cm topsoils were calculated.

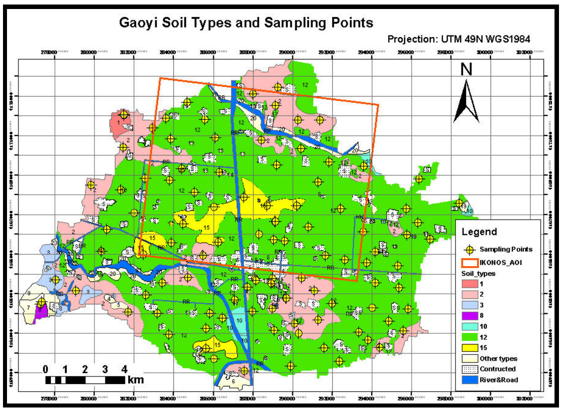

Figure 2. Distribution of soil points sampled in Gaoyi County

III. RESULTS AND DISCUSSIONS

A. Changes in Soil pH and Bulk

From reform initial stage to modern agriculture stage, average soil pH showed declining trend with decreases from 8.35 (1983) down to 8.25 (1990) and down to 8.15 (2004). This trend in sandyloam soils located on hillock and riverbank slopes was especially significant. One cause for these changes was that these soils were reclaimed with only short history and fostered by agricultural fertilizers, which also improved soil quality. At the same time, along with rapid agricultural modernization in recent 20 years, water demands in this region increased suddenly. Irrigations using traditional manually pumped wells were replaced by motor-pumped wells, which subsequently resulted in the rapid decline of groundwater levels. In 2004, average yearly groundwater level was down to -43.31m [19]. Decline of groundwater levels changed the salinization situation of some soils. As a result, average soil pH declined in this region.

Soil bulk lies on soil particulate alignment and soil voidage[20]. According to our data, the bulks of main soil types of type 12 and type 15 also showed ascendant trends since 1983, with increase rates of 13% and 9% in recent 20 years, respectively. Contrary to common rule that soil bulk usually increases along with increase of fertility because of more organic matter adding soil voidage, soil bulk change trends here implied that the wide development of mechanical farming in this region, especially after 1990s, pressed most of arable lands and made lower part voidage of topsoils declined. Another cause for the bulk changes was that large quantity of chemical fertilizers instead of traditional organic fertilizers used to farmlands resulted to topsoil hardening [21].

B. Changes in SOC and TN Contents

Contents of SOC and TN are impacted by comprehensive factors including natural factors such as soil types, moisture, temperature and anthropogenic factors such as fertilizing, farming and managing as well. As for long-term farming soil, anthropogenic factors play a key role on nutrient cycles [14]. In recent 20 years, the contents of SOC and TN for all soil types had increased steadily (table 2). From the initial stage to middle stage, average content of SOC increased by 40% from 6.13 g/kg up to 8.20 g/kg, and then from the middle stage to modern stage it reached to 10.46 g/kg, increased lowlier by 29%. The average SOC content increased by 70% in recent 20 years, to which was mainly contributed by the doubled SOC content growths of two main soil types, type 2 and type 15.

TABLE 2. SOIL C AND NITROGEN CONTENTS CHANGES OF ARABLE LANDS（0~20 cm)

Soil code	Year	SOC（g/kg)	Growth rate of SOC	TN（g/kg)	Growth rate of TN
1	1983	5.1	-	0.59	-
	1990	6.32	24%	0.7	19%
	2004	8.42	33%	1.57	124%
2	1983	6.86	-	0.77	-
	1990	7.76	13%	0.86	12%
	2004	10.64	37%	1.44	67%
3	1983	7.02	-	0.77	-
	1990	8.47	21%	0.95	23%
	2004	10.53	24%	1.62	71%
8	1983	4.37	-	0.51	-
	1990	11.19	156%	1.25	145%
	2004	12.17	9%	1.98	58%
10	1983	5.57	-	0.7	-
	1990	7.66	38%	0.85	21%
	2004	9.66	26%	1.62	91%
12	1983	6.76	-	0.74	-
	1990	7.7	14%	0.85	15%
	2004	10.67	39%	1.45	71%
15	1983	7.23	-	0.83	-
	1990	8.27	14%	0.99	19%
	2004	11.12	34%	1.75	77%

Similar to SOC changes, TN contents of the soils in this region rose sharply from 1983 to 2004. Average TN content changed from 0.7 g/kg in 1983 up to 1.63 g/kg in 2004, increasing greatly by 133%. It increased by 36% from the initial stage to middle stage, and much more rapidly by 80% from middle stage to modern stage. As another index of soil fertility, average soil C/N ratios of Gaoyi County were 8.7 in 1983 and 8.9 in 1990, respectively. Although SOC and TN contents rose simultaneously, these C/N ratios implied relatively stable. However, average C/N ratio declined suddenly to 6.4 in 200, which implied the nitrogen in the soils increased rather quickly. The phenomenon of the increases of SOC and TN contents and the decrease of C/N ratio indicated significant rising of soil fertility in this region. The main causes were both large amount of chemical fertilizers applied to agriculture since the beginning of 1980s and surge return of crop residue to farmlands [15, 19].

C. Changes in Storages of SOCS and TNS

Affected by the changes of soil bulks and nutrient contents, organic carbon densities (0~20cm topsoils) of all soil types had been ascending stably in recent 20 years (table 3). Similarly, total nitrogen densities showed increasing trend, in accord with general phenomenon that agricultural nitrogen amount is positively related to organic carbon [20]. From initial stage to modern stage, average SOCD and TND increased by 87% and 148%, respectively. The increase speed of TND was much higher than that of SOCD. But from initial stage to middle stage, increase range of average SOCD and TND, 38% and 35% respectively, were very close. However, from middle stage to modern stage, increase range of TND (83%) was much higher than that of SOCD（31%）, implying that soil nitrogen in this region accumulated very fast during the period. Taking account of soil types, SOCDs and TNDs of all sorts of light-loam soils were usually more than those of sandy-loam soils. This is due to special nature of the sandy-loam soil, i.e. loosen texture, fast organic matter decomposition, easily water and fertilizer leaching, all of which result in low fertility of sandy-loam soils.

TABLE 3. SOIL C AND NITROGEN SEQUESTRATION CHANGES OF ARABLE LANDS（0~20 cm)

Soil code	SOC density (kg/m^2)			TN density (kg/m^2)		
	1983	*1990*	*2004*	*1983*	*1990*	*2004*
1	1.54	1.85	2.39	0.18	0.21	0.45
2	1.96	2.15	2.85	0.22	0.24	0.39
3	1.71	2.30	3.15	0.19	0.26	0.49
8	1.17	2.87	2.98	0.14	0.32	0.48
10	1.38	2.10	2.9	0.17	0.23	0.49
12	1.65	2.00	2.94	0.18	0.22	0.40
15	1.76	2.11	2.96	0.20	0.25	0.47
Average	1.60	2.20	2.88	0.18	0.25	0.45

Total storage changes of SOC and TN infer basic situations of regional nutrient accumulation and soil fertility changes. From initial stage to middle stage and from middle stage to modern stage, total SOCS of the soils increased 1~2.45 times and 1.01~1.47 times, respectively (figure 3). Total SOCS of the whole county rose from 343Gg in 1983 to 410Gg in 1990 to 588Gg in 2004 (1Gg =10^6kg), 1.2 times and 1.4 times of the former stages. As a whole, SOCS increased by 72% with yearly increase rate of 3.14% in recent 20 years. These results indicated that the carbon fixation capability of the arable lands was enhanced rapidly in this region.

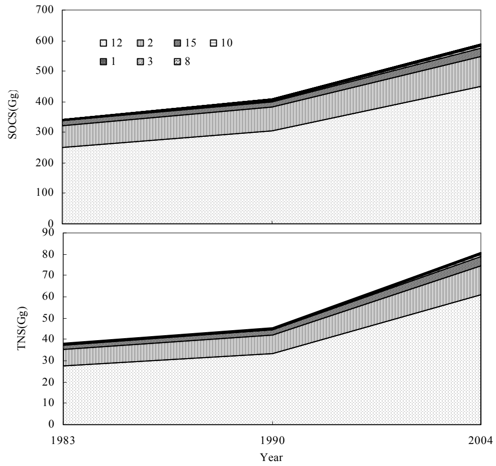

Figure 3. SOCS (upper) and TN (lower) sequestration changes of arable lands（0~20 cm)

D. Impacts of Modern Industrialization on Arable Soil Nutrients

According to analysis above, from the traditional agriculture of initial stage to modern agriculture after 2000, in this region soil pH decreased, bulk increased lightly, contents and storages of SOC and TN ascended greatly, and regional soil fertility enhanced. All of these changes were induced by many natural and anthropogenic forces. However, at decade-temporal scale, influenced degree and speed of human activity on agroecosystem nutrient cycle surpasses that of natural changes [7]. These human activities include population growth, land use changes, industrial technology application, farming, and management changes and so on [7, 23-25]. Especially in the densely-populated north china plain, rapid industrialization impacted these factors greatly, thereafter changed soil nature and nutrient cycles [26-27]. These influences were embodied mainly at two aspects below.

Firstly, wide applications of modern agricultural machines stimulated agricultural produce transformation from traditional agriculture to mechanize, automation and scale, so that impacted on land farming and management. In this region, these driving forces included the increasing numbers of harvest machine, farming machine and irrigation machine. Total power of agricultural machine and electricity consumption for agriculture can be two indexes reflecting the forces. Total power of agricultural machine ascended from 8.2×10^4 kw in 1983 up to 26.7×10^4 kw in 2000. At the same time, total electricity consumption for agriculture ascended from 1343 $\times10^4$kwh in 1983 up to 4307×10^4 kwh in 2000. Total power of agricultural machine and total electricity consumption for agriculture arrived to 3.3 and 3.2 times, respectively. Very rapid increases happened during 1990s. Currently, machine farming and irrigating have covered all arable lands in the county. Tractor deepened the plowing depth from traditional approximately 10cm to 15~20cm, benefiting crop root deep into soil. However, tractor and big harvest machine also pressed the lower part of topsoil to enhance the total bulk of whole profile. On the other hand, irrigation machine liberated agricultural produce from rainfall limit, and transformed most of dry lands into irrigated lands. Thus the effect showed land productivity increase and lower groundwater depth [28], as well as the pH decreases of some soils. Finally, modern disintegrators for crop residue cut crop stems into pieces and made large amount of crops residue leave in the farmlands directly, which afforded soil much more organic matter source and enhanced nutrient recycle rates [29] in this region. Our survey showed that crop residue return in this region carried out in 1983. Since that time, arable land area applied this measure increased 667hm^2 per year. Return measure for wide extent started since the beginning of 1990s, and in 1997 covered 77% of maize land area. Currently, 90% of total arable lands have implemented crop residue return measure.

Secondly, during the recent 20 years, increasing use of chemical fertilizers made by industry input nutrients into farmlands and soils, which enhanced land productivity rapidly, and simulated agricultural structure adjustment. Gaoyi County started chemical fertilizer application to farmlands since the end of 1960s. Since the end of 1970s, chemical fertilizer (especially chemical nitrogen) input increased very quickly and total amount reached to 16,860 tons in 1983, so that chemical fertilizers instead of organic fertilizers became the main nutrient sources for agricultural produce. Average amount of chemical fertilizer applied to arable lands was 1416kg/hm^2 in 1986, and then up to 1616kg/hm^2 in 2001 [15, 19]. At the same time, the outputs of grain, vegetables and byproducts in the county grew greatly along with input increase of chemical fertilizers with particularly rapid outputs increase since 1980s. However, due to agricultural adjustment, vegetable output of the region climbed up straightly since 1990s. In a word, increasing input of chemical fertilizers added more nitrogen to soil pool, but also afforded more matter basis for crop residue return and root remain to enhance carbon fixation capability of arable lands.

IV. Ⅳ. CONCLUSIONS

During the recent 20 years with transformation from traditional agriculture to modern agriculture in North China Plain, industrial technologies applications to agriculture, such as chemical fertilizer use, irrigation system improvement and agricultural mechanize, enhanced agricultural productivity and simulated carbon and nitrogen fixations in soils. The contents of SOC and TN in topsoil (0~20cm) increased by 70% and 133%, respectively. Total SOC storage and TN storage increased by 72% and 113%, respectively. These increasing trends showed particularly significant from 1990 to 2004. However, numerous accumulation and turnover of carbon and nitrogen in soils and agro-ecosystems also means more loss and potential risks on environment. For example, it was proved by many researches that overuse or misuse of chemical fertilizer would result in non-point pollutions in agricultural environment [27, 29], and in the emission increases of N_2O and NO from arable lands [31-33]. Thus, further researches on nutrient fluxes, fixations and releases from agricultural soil are necessary obviously.

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