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Organic carbon stock in topsoil of Jiangsu Province, China, and the recent trend of carbon sequestration

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Abstract: Data collection of soil organic carbon(SOC) of 154 soil series of Jiangsu, China from the second provincial soil survey and of recent changes in SOC from a number of field pilot experiments across the province were collected. Statistical analysis of SOC contents and soil properties related to organic carbon storage were performed. The provincial total topsoil SOC stock was estimated to be 0.1 Pg with an extended pool of 0.4 Pg taking soil depth of 1 m, being relatively small compared to its total land area of 101700 km^2. One quarter of this topsoil stock was found in the soils of the Taihu Lake region that occupied 1/6 of the provincial arable area. Paddy soils accounted for over 50% of this stock in terms of SOC distribution among the soil types in the province. Experimental data from experimental farms widely distributed in the province showed that SOC storage increased consistently over the last 20 years despite a previously reported decreasing tendency during the period between 1950—1970. The evidence indicated that agricultural management practices such as irrigation, straw return and rotation of upland crops with rice or wheat crops contributed significantly to the increase in SOC storage. The annual carbon sequestration rate in the soils was in the range of 0.3—3.5 tC/(hm^2 · a), depending on cropping systems and other agricultural practices. Thus, the agricultural production in the province, despite the high input, could serve as one of the practical methods to mitigate the increasing air CO_2.

Keywords: soil organic carbon; soil carbon stock; agricultural practice; carbon sequestration; paddy soil; China

Introduction

Since recently, increasing attention has been given to soil organic carbon(SOC) pool and its dynamics under land use changes concerned with terrestrial ecosystem carbon sink and the uprising atmospheric carbon dioxide (Scholes, 1999). Lal(Lal, 1999) estimated that the global SOC stock was about 1500 Pg. According to our recent study, the topsoil SOC pool of China soils amounts to 37.8 Pg, among which the cultivated soils occupied only 5.0 Pg and a significant part of 2.03 Pg of topsoil C stock has been lost due to cultivation (Song, 2004). Based on a carbon biogeochemistry model, Li(Li, 2000) has recently argued that SOC in China soils was in decline. Studies on soil carbon sequestration in forest soils (Huntinton, 1995), grassland soils(Davidson, 1995), and wetland or agricultural soils(Zdruli, 1995; Wood, 1992), as well as the soils under natural conditions (Schlesinger, 1990), have been documented worldwide. However, there is little data available on carbon sequestration in soils under intensified agriculture like in China. The purpose of this paper is to estimate regional SOC stock according to soil survey data and monitoring results on different scales, the recent trend of SOC sequestration in the soils and eventually to evaluate the effect of the present agricultural management practices on carbon sequestration in order to discuss the agriculture's role in mitigating the terrestrial carbon sink saturation.

1 Data collecting and estimation methodology

1.1 Provincial soil data

Jiangsu Province is located in eastern costal region of China occupying a total land of about 100 thousands square kilometers(Fig.1). The soil data of Soil Series of Jiangsu (Jiangsu Bureau of Soil Survey, 1995), which was a collection of soil data from the second provincial soil survey conducted in 1979—1982 and included soil data of the whole 154 series of the province, were used for statistical estimation of the total topsoil SOC stock.

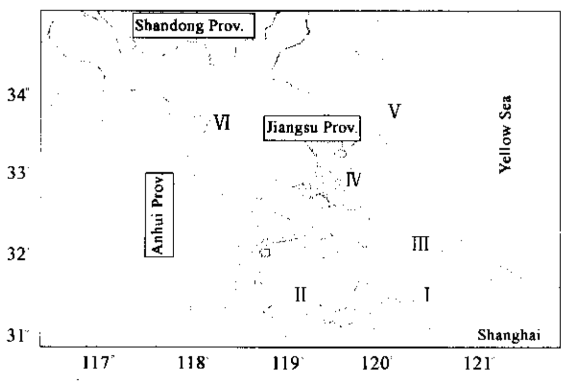

Fig.1 Map of Jiangsu Province, China

1.2 Field data from pilot agricultural experiments

In the 1970s, a number of field experimental farms were established across the province. The soil samples were collected in different years and the SOC contents were

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determined by wet digestion procedure (Soil Science Society of China, 2000).

1.3 Soil organic carbon stock estimation

The mean SOC content for individual soil series was obtained from a report "Soil Series of Jiangsu", which contained statistical data of depth, bulk density and SOC content of individual horizons. The value of the total SOC pool in the Jiangsu Province was calculated from the SOC contents of the soil series multiplied by their respective areas according to the following equation:

$$SOC(tC) = \sum_{i=1}^{n} S_i \times \sum_{j=1}^{n} SOC_j \times \gamma_j \times H_j \times 10^{-1}.$$

Where SOC_j, γ_j and H_j represent the mean SOC content (g/kg), and volume weight (g/cm^3), surface layer depth (m) of a soil horizon j, and S_i means the area number (hm^2) of soil series i, respectively. For topsoil carbon stock calculation, $j = 1$. Finally a relative distribution of this SOC stock was given in terms of soil groups according to the new Chinese Soil Taxonomy (Gong, 1999) and soil geographical distribution as well.

2 Results

2.1 Total topsoil SOC pool and the role of paddy soils

2.1.1 Total provincial SOC stock

The statistical analysis of the soil data from the second provincial survey allowed frequency distribution analysis of the contents of SOC both in terms of soil series and soil area, and of soil bulk density among the soil series (Fig.2 and Fig. 3). The total area of soils under cultivation in the province was 6022000 hm^2. The statistical mean SOC content of the soil series turned to be 16.46 g/kg, with the area-weighted mean content of SOC being 15.39 g/kg. The total topsoil SOC stock turned to be 0.1 Pg either by summing of the individual series or by the mean SOC content, bulk density and horizon depth multiplying the soil area. With the statistical data of depth, bulk density and SOC data, the total SOC stock considering depth of 1 m was estimated as 0.44 Pg (Table 1).

Table 1 The statistical data on topsoil SOC content (g/kg) and stock (Tg) of Jiangsu soil series (g/kg)

Soils	Area, 10^6 hm^2	Mean depth, cm	Mean bulk density, g/cm^3	SOC content			Mean storage, t/hm^2 *	Carbon stock (1)**	Carbon stock (2)**	Carbon stock in 1 m***
				Mean of observations	Median of observations	Weighted mean				
All soils	6.03	15.15 ± 3.02	1.30 ± 0.09	9.57	8.53	8.93	18.85	99.8	113	439.0
Paddy	2.15	13.85 ± 2.17	1.27 ± 0.07	13.11	12.65	12.47	23.06	46.7	49.6	205.4
Natural and un-irrigated soil	3.85	15.99 ± 3.21	1.33 ± 0.09	7.96	6.26	9.79	16.93	53.1	65.2	223.6

Notes: * Calculated with the mean SOC content; ** (1) calculated with the individual observations of soil series; (2) calculated with the statistical mean storage; *** estimation was made of the statistical data of depth distribution of SOC contents, bulk densities and thickness of the underlying horizons until 1 m deep

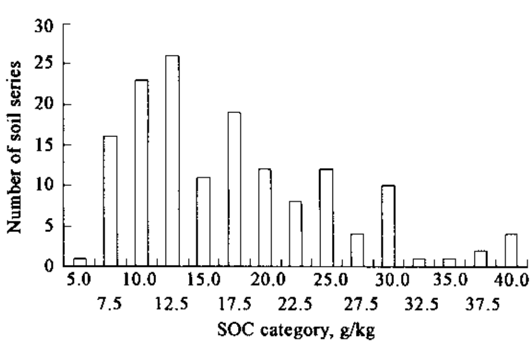

Fig. 2 Frequency distribution of SOC content in terms of observations of the soil series of Jiangsu Province

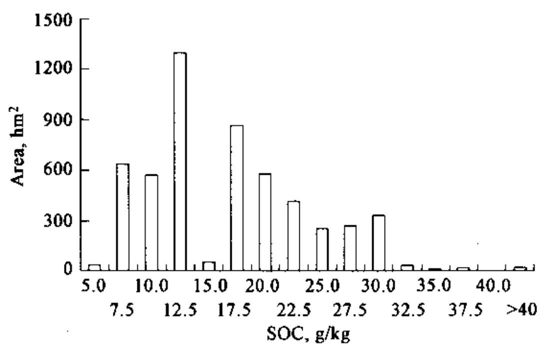

Fig.3 Frequency distribution of SOC content in terms of area of the soil series of Jiangsu Province

2.1.2 SOC stock distribution in major soil groups and in geographical regions

The distribution of calculated SOC pool among the soil groups is given in Table 2. Paddy soils (Hydroagric Anthrosols) had been considered as a unique dominated suborder of Anthrosols of the Chinese Soil Taxonomy, and interestingly consisted of one third of the provincial soil area. They had the highest mean SOC content and carried 55% of the total stock with its one third of the occupied area. Among the other soil groups important in SOC storage were the Mollic Cambisols (18.3% of the total stock) and Hapstagnic Gleysols (marsh soils, 8.2% of the total stock) due to either higher SOC content or relatively larger area (Jiangsu Bureau of Soil Survey, 1995). The Gelysols was the only one soil group that kept C storage as high as 106 tC/hm^2 despite a very low percentage of the soil area (ca. 1%). The above-mentioned three major soil groups stored over 80% of the total C stock while they occupied 60% of the total soil area, they should be given primary importance in pursuing soil C management strategy. Particularly, land use of paddy in the province had a key role in SOC storage and great potential of C sequestration. Therefore, paddy soils can be potentially important for carbon sequestration in terrestrial ecosystems in areas with intensive human-disturbed agricultural systems.

Table 2 Distribution of total SOC stock in major soil group classified with Chinese soil taxonomic classification (data source: Jiangsu Bureau of Soil Survey, 1995)

Soil group	Area, 10^4 hm^2	SOC, g/kg	C stock, Tg	C storage, tC/hm^2	Soil area, %	C stock, %
Altudic Ferralisols	1.98	9.11	0.36	17.9	0.33	0.37
Arpudic Luvisols	36.36	10.81	2.94	8.1	6.04	3.04
Hapudic Luvisols	16.09	4.66	1.48	9.2	2.67	1.52
Hapustic Luvisols	10.27	6.22	1.26	12.2	1.71	1.30
Cabudic Cambisols	2.89	17.05	0.97	33.6	0.48	1.00
Udiorthic Entisols	5.61	11.09	1.24	22.0	0.93	1.27
Pupudic Cambisols	0.93	6.50	0.11	11.5	0.15	0.11
Cabudic Verisols	24.58	8.11	3.93	16.0	4.08	4.05
Motudic Cambisols	133.27	6.76	17.74	13.3	22.13	18.29
Aquhydroagric Anthrosols	221.69	12.18	53.13	24.0	36.81	54.79
Aquorthic Halosols	40.92	7.27	5.86	14.3	6.80	6.05
Hapstagnic Gleysols	7.48	31.79	7.96	106.4	1.24	8.21
Total/mean	502.07	9.97	96.97	19.3	83.37	100.00

The geographical distribution of the estimated SOC stock is shown in Table 3. Meaningfully, the C stock in different regions was shown in close correlation with their paddy occupation percentage. The Taihu Lake region, where the paddy management could be traced back to 5000 yr B.P. (Xiong, 1980) and irrigated paddy soils under high-input agriculture presently dominated (over 90%), conserved 44% of the total pool compared to its area percentage of 17% for its considerably higher SOC storage in topsoil (25 t C/hm^2) than in the other regions.

Table 3 Geographical distribution of topsoil SOC storage of the Jiangsu Province

Regionalization	Soil area, 10^4 hm^2	Mean SOC, g/kg	Paddy occupation, % *	C stock, Tg	C storage, tC/hm^2	Soil area, %	C stock, %
Taihu Lake plain	99.65	14.04	97.0	25.21	25.3	16.55	25.7
Inland lowlands	67.64	11.72	68.4	12.49	18.5	11.23	12.7
Nanzhen hills	69.89	10.09	51.7	11.11	15.9	11.61	11.3
Yangtze valley plain	69.60	8.47	10.0	9.29	13.3	11.56	9.46
Coastal saltic lands	86.11	7.31	24.8	12.40	14.4	14.3	12.6
Central west uplands	209.3	6.73	0.90	27.74	13.3	34.76	28.2
Total/mean	602.2	9.17	42.1	98.24	16.33	100.1	100.0

Note: * The percentage of paddy in the total area of the region

2.2 Recent trend of SOC sequestration

2.2.1 Evidence from provincial soil fertility monitoring sites

Since the early 1980s, the soil organic carbon storage has been stabilized or increased as the agriculture developed with the introduction of high technology and soil conservation practices. Soil cropping systems shifted largely from triple rice-rice-wheat to double cropping system of rice and wheat or rice and rape seed. Consequently, increases of SOC contents were extensively observed during the last decade in most of the soil monitoring sites located in various regions of the province (Fig.4). Numerous data from field pilot experiments all over the province provided evidence for the existence of this trend although the increase in SOC content was less remarkable in some regions where the soils were initially rich in SOC. In 1997, the provincial mean of SOC content was shown as 11.13 g/kg. Taking the mean value of 8.93 g/kg in Table 1 as background, a mean increasing rate of SOC of Jiangsu soils since the second provincial soil survey in 1982 could be estimated to be 2.2 g/(kg·a) (Wang, 1999c), and the resulted total soil carbon sequestration to be 26 Tg for the province.

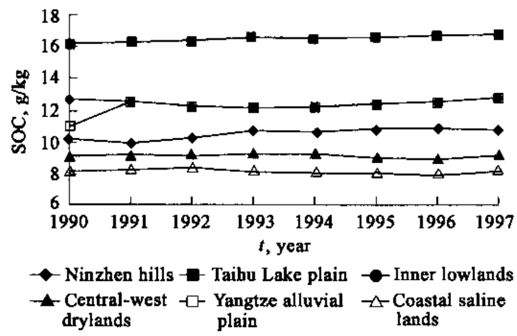

Fig.4 Change of SOC contents in different farmlands in the Jiangsu Province during 1990—1997

2.2.2 Evidence from county level soil reconnaissance data

SOC data of SOC contents of the samples collected in Donghai County by soil reconnaissance conducted in different periods exhibited a strong increasing trend of SOC of the soils, which were previously low in SOC (Table 4; Fig.5). Agricultural development in this county was most implemented during 1970's to 1990's with soil resilience of the low fertility upland soils. The calculated C sequestration rate ranged from 0.20 $tC/(hm^2 \cdot a)$ to 1.0 $tC/(hm^2 \cdot a)$. While in Yixing City near the Taihu Lake, remarkable enhancement of SOC storage had been detected in a number of soil monitoring sites for different soil series (Table 5). In

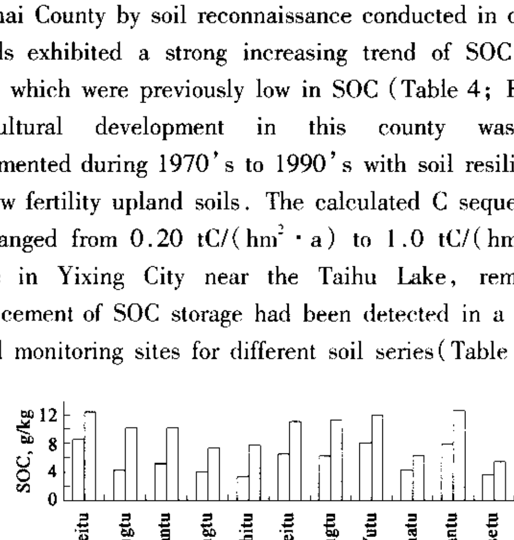

Fig.5 Change of mean SOC contents of the major soil series in Donghai County in west-central drylands, northern Jiangsu during 1981—1996
Bank: 1991; Shaded: 1996

this county, paddy soils dominated the soil resources, and economic development and high yielding rice production had a long history. The C sequestration rates were in range of 0.3 tC/(hm^2 · a)—0.4 tC/(hm^2 · a). An exception of SOC decline was observed in a low-lying paddy soil Hubaitu derived from paleo-lacustrine deposits. Nevertheless, this soil had a minor role in the city's agricultural production due to the smaller area.

Table 4 Mean SOC contents of major soil series of Donghai County, Jiangsu collected and determined in different periods and the C sequestration intensity

Soil series		Huheitu	Baijiangtu	Bantu	Baojiangtu	Shushitu	Gangheitu	Huangtu	Yutu	Huangshatu	Nianyantu	Zisetu
Soil area, hm^2		42127.3	24035.8	20890.1	11228.1	12499.3	9875.4	7774.2	2777.0	3035.1	2917.3	2003.8
Bulk density, g/cm^3		1.29	1.39	1.47	1.48	1.43	1.37	1.36	1.29	1.43	1.29	1.32
A horizon depth, cm		16.3	17.8	17.4	16.9	18.1	18.7	18.1	21	17	14.6	11.7
SOC content, g/kg	1981	8.58	4.23	5.22	4.12	3.42	6.61	6.38	8.18	4.41	8.06	3.71
	1986	9.87	6.15	5.97	5.45	4.99	8.98	8.35	9.94	5.32	9.73	4.41
	1991	11.31	9.16	9.16	6.84	7.13	10.09	10.27	11.08	5.63	11.37	4.87
	1996	12.47	10.21	10.21	7.42	7.83	11.19	11.37	12.12	6.38	12.76	5.57
Mean SOC increased, g/kg		3.89	5.97	4.99	3.31	4.41	4.58	4.99	3.94	1.97	4.70	1.86
Mean sequestr. rate, g/(m^2·a)		54.48	98.55	85.06	55.13	76.07	78.26	81.86	71.23	31.96	58.99	19.11
Total C sequestration, Tg		0.344	0.355	0.267	0.093	0.143	0.116	0.095	0.030	0.015	0.026	0.006

Table 5 Change of SOC during 1983—1996 of the major paddy soils in Yixing County, Jiangsu Province

Soil family (Observation sites)	Area, hm^2	% of total paddy	Bulk density, (g/cm^3)	A horizon depth, cm	SOC content, g/kg		Sequestr. Rate, tC/(hm^2·a)	Total sequestrated, Tg
					1982	1996		
Wunitu (16)	4194.7	5.65	1.32 ± 0.17	12.1 ± 1.9	12.12 ± 1.32	15.79 ± 4.65	0.39	0.025
Huangnitu (24)	33986.7	45.78	1.28 ± 0.13	12.6 ± 2.1	11.08 ± 1.68	14.82 ± 3.01	0.40	0.205
Baitu (12)	25754.5	34.69	1.29 ± 0.11	13.8 ± 2.1	9.55 ± 1.14	11.81 ± 2.46	0.27	0.104
Hubaitu (6)	2754.0	3.71	1.11 ± 0.16	15.0 ± 1.4	12.68 ± 0.85	9.89 ± 1.59	− 0.31	− 0.013

2.2.3 Evidence by yearly dynamics of SOC at farm level

We had collected soil samples and determined SOC from different treatment plots in an experiment farm in different year intervals. This farm was set up to monitor the soil dynamics of paddy soil under different fertilizer application in the Taihu Lake region. The yearly variation of SOC in these plots demonstrated a gradual increasing tendency of SOC content in all the treatment plots including a plot without any fertilization. The annual C sequestration was thus calculated to be 0.3 tC/(hm^2·a)—0.4 tC/(hm^2·a), being greater with the increasing input of organic amendments as manure or straw return. Thus, despite the high output of rice yield averaged 9 t/hm^2 or rape-seed 3 t/hm^2 and high chemical N fertilization at 750 kg/hm^2 per year. However, the increasing SOC tendency was valid under all the treatments in the paddy soil, which might be an evidence that China's paddy soils were gaining carbon at a relatively high rate, thus contributing to a great deal of air CO_2 sequestration.

3 Discussion

3.1 Level of Jiangsu SOC stock

Several authors reported China SOC stock in range of 50—185 Pg (Pan, 2003; Fang, 1996; Wang, 1999b; 2000). We recently reported an estimation of topsoil SOC stock of China's agricultural soils being 5.1 Pg with a mean SOC storage 35.1 tC/hm^2 (Song, 2004). While the topsoil of paddy soils of China carried a SOC stock amounting to 1.3 Pg with a mean SOC storage being 44.0 tC/hm^2 (Pan, 2002). The mean topsoil SOC storage given by the data mentioned above was in level of 18.8 tC/hm^2 for all Jiangsu soils and 23.1 tC/hm^2 for its paddy soils. Therefore, the Jiangsu soils had a relatively lower degree of SOC accumulation than the bulk China soils except for the paddy soils in the Taihu Lake plain. According to a report by Arrouays and Balesdent (Arrouays, 2002), France soils occupied approximately 3 Pg of SOC pool taking into account of 30 cm thickness of topsoil. However, the topsoil SOC storage ranged from 32 tC/hm^2 in vineyard and orchard soils, < 45 tC/hm^2 in other croplands, to 70—90 tC/hm^2 in grasslands and natural wetlands. Comparatively, the Jiangsu soils were prominently in much lower level of SOC accumulation and, thus, could have a big potential for sequestrating C by well-designed C management strategies.

3.2 Role of agricultural management practices in SOC sequestration

3.2.1 Irrigation development

The apparent C sequestration trend since the time of 1980's could be referred to several factors. Firstly, development of irrigation systems in agricultural soils made a significant contribution to SOC accumulation in soil. The area of irrigated farmlands had been growing fast following the development of modern agriculture in the province since 1950's. The total area of irrigated farmland increased from

934700 hm^2 in 1949 to 2669700 hm^2 in 1998. Data shown in Table 1 allowed an estimation of SOC sequestration due to irrigation development of 13.2 Tg C since 1950's, giving an approximation of annual carbon sequestration rate at 0.2 tC/($hm^2 \cdot a$). This was in agreement with the results by Zdruli *et al.* (Zdruli, 1995) who reported a significant C sequestration in Albanian agricultural soils after irrigation had practiced. Since the late 1980's, irrigation projects had been conducted mainly in the northwestern Jiangsu, where upland soils low in SOC were extensive and accumulation of SOC due to irrigation development had been detected significantly (Table 6). Thus, irrigation development in Jiangsu had not only advantages in keeping up crop production but also benefiting C sequestration for mitigating the uprising air CO_2.

Table 6 Comparison of SOC contents between of un-irrigated soils and irrigated soils in Central West Jiangsu region (data source: Soils of Jiangsu, 1995)

County	Un-irrigated soils		Soils irrigated for over 10 years	
	Number of observations	SOC content, g/kg	Number of observations	SOC content, g/kg
Siyang	16	8.53 ± 2.07	23	10.41 ± 2.01
Xuyi	17	9.93 ± 2.38	17	11.82 ± 2.25
Shuyang	18	12.25 ± 1.56	15	12.49 ± 1.23

3.2.2 Regional soil resilience by agricultural development projects

Since 1988, the regional agricultural development projects had been subsidized both by the state and provincial governments. These projects involved deep plowing, better cropping systems, and soil conservation tillage. As a result, the SOC content of the reclaimed low-yielding soils has been increased. Some examples of enhanced SOC accumulation obtained by this strategy are given in Table 7. As the soils under project implement were previously poor in soil quality with usually very low SOC content, the resulted carbon sequestration could be as high as 2.0—3.5 tC/($hm^2 \cdot a$), which was much higher than those reported for natural forest soils and wet land soils(Huntington, 1995; Zdruli, 1995). As the total soil area under such regional agricultural projects covered 1212×10^3 hm^2, an estimation of SOC sequestration could be amount to 23.6 Tg being similar to the total SOC pool lost between the 1950s and 1970s in the province. Since the regional agricultural development projects were conducted all over the country, the resultant SOC sequestration could be expected to make a significant contribution to the terrestrial carbon storage in China.

Table 7 Change of SOC (g/kg) in pilot experiment fields under the regional agricultural development projects

Location and Soil	Region located	Area, 10^3 hm^2	Implement period	Observed rise in SOC
Baitu, Jurong County(Ferralisols)	Nin-zhen hills	8.0	1993—1996	3.6
Changqing, Rugao City(Entisols)	Yangtze riversides	14	1992—1996	3.2
Wangji, Shuining County(Saltisols)	Central west drylands	7.0	1989—1991	1.3
Shihu, Donghai County(Alfisols)	Central wet drylands	8.0	1989—1991	1.7

3.2.3 Return of crop residue

Since the 1980s, return of straw as a soil conservation practice has been widely utilized in the farmlands, partly owing to the alternative of natural gas for household combustion in countryside. More than 1 million hectares of farmlands in the province received straw return at an annual rate of 8—10 t/hm^2. As observed in a number of experiment farms, the mean conversion coefficient of straw carbon to SOC ranged from 0.3 to 0.6 in a wide range of soil conditions. Under an input rate of 225 kgDW/hm^2, rice straw return gave a SOC rise of 0.3 g/(kg·a) in a silty bleached Hydragric Anthrosol(Tang, 1999) and 0.5 g/(kg·a) in a clayey Alfisol (Wang, 1999a). An increase of SOC as high as 0.4—1.0 g/(kg·a) was observed in the fields in central-west dry lands with the original SOC varying in range of 4—12 g/kg(Zhang, 1999). As a result, soil carbon sequestration rate as high as 1 tC/($hm^2 \cdot a$)—3 tC/($hm^2 \cdot a$) was realized, which was even much higher than the sequestration rate in the forest soils in temperate zones with constant inputs of organic matter (Huntington, 1995). An average of increased SOC stock of 1.5 Tg in Jiangsu soils by straw return could be expected.

3.2.4 Shifting cropping system

The agriculture in the Jiangsu Province is considered as intensive agriculture with double cropping in the last decade. There used to be double or triple grain crops before the 1980s. Since the 1990s, multiple cropping systems had been extended for balancing the benefits of both economy and ecology. Rotation of cereals and vegetables, and grain crops and legume crops has been widely adopted. An increase in SOC by 0.7 g/kg was observed through the conversion of wheat-rice rotation to corn-rice rotation for 10 years in the central Jiangsu Plain. Cotton inter-planted with vegetables for 4 years led to an increase of SOC in 1.2 g/kg in the eastern Jiangsu cotton production area. Another pilot experiment conducted in middle Yangtze valley in a sandy Entisols low in SOC indicated an increase of SOC by 1.73 g/kg in a 4-year rotation of rice-legume-corn-vegetables-wheat, compared to a rice-wheat rotation system. The calculated soil carbon sequestration rate achieved by these agronomic measures ranged from 0.3 tC/($hm^2 \cdot a$) to 14 tC/($hm^2 \cdot a$). Field experiments showed that return of corn straw with rotation of rice-wheat-corn enhanced SOC accumulation in clayey paddy soils by 0.2 g/(kg·a)(Zhang, 1999a). Fig.6 demonstrated an increasing trend of topsoil SOC after shifting to rotation of double cropping of rice and wheat in a paddy soil in Yixing City. Consequently, these agronomic measures enhanced soil function for buffering C emission by newly incorporated SOC in the soils while raising the economical benefits.

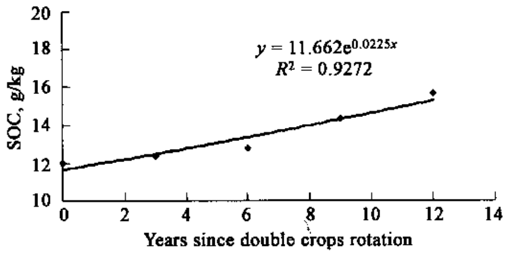

Fig.6 Change of topsoil SOC content after shifted from triple rice-rice-wheat to double croppingsystem of rice and wheat in a clayey paddy soil in Yixing County, Jiangsu, China (The observation began in 1983)

3.2.5 Change of fertilizer application scheme

Well-managed fertilizer application had been one of the foci of Jiangsu modern agricultural technology development (Wang, 1999a; 1999b; 1999c). The extension of combined fertilization with inorganic and organic fertilizers along with computer-aided fertilization has been conducted in the province since the 1990s. Technologies for reducing chemical fertilizer application but increasing application of organic manure or pig slurry are being under extension all over the province. According to our field observations, pig manure at rate over 15 t/hm^2 might generally increase SOC accumulation in paddy soil. Data in Fig. 7 showed also the results of different fertilizer application schemes on the SOC dynamics in a paddy soil with high fertility. The soil was a typical well-drained soil producing an annual rice yield of 9 t/hm^2. During the 15 years of experiment, the SOC increased by 2.5—3.8 g/kg. Compared to other treatments, chemical fertilization with manure(annual fertilization per hm^2: 427.5 kgN, 45 kgP_2O and 54 kgK_2O, and 17 t of fresh pig manure) resulted in a higher SOC accumulation by 0.03 tC/(hm^2 · a). However, lack of data on organic carbon of farmlands treated with different fertilization practices make it difficult to have a appropriate evaluation of this factor on SOC sequestration.

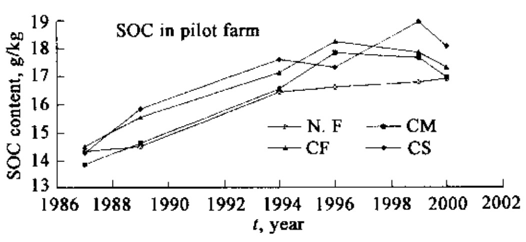

Fig.7 Yearly change of SOC content in a well-drained paddy soil under different fertilizer application schemes
NF: no fertilizer; CF: chemical fertilizer only; F-CF: formulated fertilizers; CS: chemical fertilizer plus straw return; CM: chemical fertilizer plus manure

4 Conclusions

The total topsoil organic carbon stock of the Jiangsu Province, China amounted to 0.11 Pg. The mean topsoil carbon storage was at level of 20 tC/hm^2. Among it, the irrigated paddy soils possessed 0.08 Pg with a mean C storage of 23 tC/hm^2. Nearly one half the total provincial C stock was found in the Taihu Lake plain region, where paddy soils are dominant.

Higher C sequestration were quite common in Jiangsu soils since 1980's at rates varying from 0.1 tC/(hm^2 · a) to 3—4 tC/(hm^2 · a). Agricultural management practices such as irrigation and regional agricultural development projects made significant contribution to the increased regional SOC storage, although Jiangsu soils were generally in low degree of SOC accumulation.

Among the soil orders, larger SOC pool was found in the paddy soils as a major anthropogenic soil (Hyagric Anthrosols). The soil carbon content in this soil order was considerably higher than in other soils, and further higher C sequestration rates could be reached by agricultural practices. Thus, paddy land use can play an important role in SOC storage and C sequestration.

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References:

Arrouays D, Balesdent J, 2002. Increasing carbon stocks in French agricultural soils. Scientific Assessment Unit for Expertise[ED]. INRA. http://www.inra.fr/actualites/ rapport-carbone.html.

Davidson E A, Nepstad D C, Klink C *et al*., 1995. Pasture soils as carbon sinks [J]. Nature, 376: 472—473.

Fang J, Liu G, Xu S, 1996. Carbon cycling of terrestrial ecosystem of China and the global implication[M]. In: Concentration and emission monitoring of GHGs and the involved processes(Wang, G., Wen, Y. ed.). Beijing: China Environmental Science Press. 129—139.

Gong Z, 1999. Chinese soil taxonomic classification[M]. Beijing: Science Press.

Huntington T, 1995. Carbon sequestration in an aggrading forest ecosystem in the Southern USA[J]. Soil Science Society of America Journal, 59: 1459—1467.

Jiangsu Bureau of Soil Survey, Jiangsu Provincial Agricultural Extension Service, 1995. Soils of Jiangsu[M]. Beijing: China Agriculture Press.

Lal R, 1999. World soils and greenhouse effect[J]. IGBP Newsletter, 37: 4—5.

Li C, 2000. Loss of soil carbon threatens Chinese agriculture: A comparison on agro-ecosystem carbon pool in China and the U.S[J]. Quaternary Sciences, 20: 349—356.

Pan G, Li L, Zhang X *et al*., 2003. On the stock and sequestration of SOC of China soils[J]. Advances in Earth Sciences, 18(4): 609—618.

Pan G, Li L, Wu L *et al*., 2003. Storage and sequestration potential of topsoil organic carbon in China paddy soils[J]. Global Change Biology, 10: 79—92.

Schelesinger W H, 1990. Evidence from chronosequence studies for a low carbon-storage potential of soil[J]. Nature, 348: 232—234.

Scholes B, 1999. Will the terrestrial carbon sink saturate soon? [J]. IGBP Newsletter, 37: 2—3.

Soil Science Society of China, 2000. Handbook of soil and agro-chemistry analysis [M]. Beijing: China Agricultural Press.

Song G, Pan G, Li L *et al*., 2004. Topsoil organic carbon stock of China soils and the cultivation-induced change[J]. Biogeochemistry(in press).

State Bureau of Soil Survey, 1998. Soils of China[M]. Beijing: China Agriculture Press. 851—865.

Sun X B, Song Y, Feng T, 1999. Soil fertility of farmlands of Donghai County, Jiangsu, China and the soil management approaches[M]. In: Soil science and technology in Jiangsu facing the 21st Century (Soil Science Society of Jiangsu ed.). Nanjing: Hohai University Press. 89—92.

Tang S, Ren L, Zhang L, 1999. Straw return and N fertilization in bleached soils in the Taihu Lake region[M]. In: Soil science and technology in Jiangsu facing the 21st Century(Soil Science Society of Jiangsu ed.). Nanjing: Hohai University Press. 47—51.

Wang B, Xu J, Zhong H *et al.*, 1999a. Balance of soil organic matter in upland soils in Nin-Zhen hills[M]. In: Soil science and technology in Jiangsu facing the 21st Century (Soil Science Society of Jiangsu ed.). Nanjing: Hohai University Press. 26—29.

Wang S, Zhou C, 1999b. Estimation of terrestrial soil organic carbon pool of China[J]. China Geographical Science, 18: 349—355.

Wang S, Zhou C, Li K, 2000. Soil organic carbon pool of China and the geographical distribution[J]. Geographica Sinica, 55: 533—544.

Wang X, Liu L, 1999c. Trend of soil fertility of farmlands in Jiangsu, China [M]. In: Soil science and technology in Jiangsu facing the 21st Century(Soil Science Society of Jiangsu ed.). Nanjing: Hohai University Press. 1—4.

Wood C W, Edwards J H, 1992. Agro-ecosystem management effects on soil carbon and nitrogen[J]. Agricultural Ecosystem and Environment, 39: 123—138.

Xiong Y, Xu Q, Lu Y, 1980. Paddy soils in the Taihu Lake region, China[M]. Shanghai: Shanghai Science and Technology Press.

Zdruli P, Eswaran H, Kimble J, 1995. Organic carbon content and rates of sequestration in soils of Albania[J]. Soil Science Society of America Journal, 59: 1684—1687.

Zhang B, Zhang Y, Wang L, 1999. Effect of land-use changes on soil fertility [M]. In: Soil science and technology in Jiangsu facing the 21st Century(Soil Science Society of Jiangsu ed.). Nanjing: Hohai University Press. 71—75.

Zhang J, 1999. Issues of straw return and the technical needs[M]. In: Soil science and technology in Jiangsu facing the 21st Century(Soil Science Society of Jiangsu ed.). Nanjing: Hohai University Press. 85—88.

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Storage and sequestration of organic carbon in major paddy soils of China: Mechanism, stability and the impact on global change

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China paddy soils occupy a land area of about 3×10^7 hm^2 and produce 44% of total cereals of the state with a land portion of 25%. Management of paddy soils can be traced back to 7000 years B. P. and have led to a particular soil type of anthropogenic wetland soils with enhanced C storage in comparison with the upland counterpart croplands. However, data from field observations and local soil expeditions have evidenced that the soil organic carbon (SOC) has generally increased in paddy soils since the late 1980's in China. Thus, this project is to demonstrate the rate or degree to which the C storage is increased in different paddy soils, to understand how this enhanced C storage is induced by interactions of mineral, chemical and microbial functions of soil, and to look into the stability of this increased C pool in paddy soils under different agricultural management measures and under environmental stress or global change scenarios. The overall effect of C sequestration for air CO_2 will be analysed by means of modeling of field monitoring data plus GIS information system procedures. The mechanism for enhanced C sequestration will be examined through a holistic study of mineral and chemical association, turnover of SOC and its structural characterization, and enzyme activities in a micro-scale of soil particle size fractions. The role of soil microbial activity on SOC turnover in these fractions will be specially emphasized in terms of both structural diversity and functional diversity.

Finally, a basic estimation of total C storage in paddy soils of China in a GIS format will be available and a potential evolution of this C storage under ongoing environmental stresses will be presented. The final result will also include a detailed understanding of enhanced C sequestration by paddy soils and the influencing factors, which are supposed to differ from upland cropland soils and other natural soils.