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ORIGINAL ARTICLE

A study of soil organic carbon distribution and storage in the Northeast Plain of China

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Abstract Employing the Unit Soil Carbon Amount (USCA) approach, soil carbon storage was calculated across the Northeast Plain of China based on the Multi-purpose Regional Geochemical Survey conducted in 2004–2006 (MRGS). The results indicated that the soil organic carbon (SOC) storage in topsoil (0–0.2 m), subsoil (0–1 m) and deep soil (0–1.8 m) was 768.1 Mt, 2978.4 Mt and 3729.2 Mt with densities of 3327.8 t/km^2, 12,904.7 t/km^2 and 16,157.5 t/km^2, respectively. These values were consistent with national averages, whereas the soil carbon densities showed a clear increasing trend from the southern area of the Northeast Plain (Liaoning), to the middle (Jilin) and the northern Plain (Heilongjiang) — particularly in terms of topsoil carbon density, which increased from 2284.2, to 3436.7 and 3861.5 t/km^2, respectively. In comparison to carbon data obtained from the Second National Soil Survey in 1984–1986 (SNSS), the topsoil SOC storage values from the MRGS were found to have decreased by 320.59 Mt (29.4%), with an average annual decline of 16.0 Mt (1.73%) over the 20 years. In the southern, middle and northern areas of the plain, soil carbon densities decreased by 1060.6 t/km^2, 1646.4 t/km^2 and 1300.2 t/km^2, respectively, with an average value of 1389.0 t/km^2 for the whole plain. These findings

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indicate that the decrease in soil carbon density varied according to the different ecosystems and land-use types. Therefore, ratios of soil carbon density were calculated in order to study the carbon dynamic balance between ecosystems, and to further explore distribution characteristics, as well as the sequestration potential of SOC.

1. Introduction

The distribution of soil organic carbon (SOC) is of great significance when studying the global carbon cycle and the greenhouse effect (Lal, 1999, 2004; Pan et al., 2002). Some studies have shown that the pool amount of SOC in China accounts for 1/30 of the world's total SOC, with 12.6 Pg or 28.3% of the country's domestic storage found in the Northeast Plain of China (Pan et al., 2003). It was estimated that the average SOC density of the Northeast Plain was about 10.5 kg/m^2 (Li et al., 2001), with an annual change rate of −1.8% (Han et al., 2004), which was thought to be linked to land-use changes in the area (Wang et al., 2003; Liu and Zhang, 2009). For example, the SOC pool in the Sanjiang Plain of the Northeast Plain decreased by around 47% as a result of agricultural activities in this area (Zhang et al., 2003), while in the early stages of wetland reclamation, soil carbon density declined by 10 t/hm^2 every year, with an accumulated storage decline of approximately 25% (Liu and Zhang, 2005). In addition to the release of CO_2, water loss and soil erosion would have also contributed to the decline (Fang et al., 2003), accounting for up to 0.2376 Mt/a of the decrease observed in the Sanjiang Plain (Liu and Zhang, 2005). In light of the above findings, the development and status of SOC concentration in the Northeast Plain of China have become a cause for concern, and attracted significant attention in recent years.

The Multi-purpose Regional Geochemical Survey (MRGS) in 2004–2006 provided highly precise SOC data for the Northeast Plain, covering almost the whole Plain of around 230,000 km^2. The survey (The Specification of Multi-purpose Regional Geochemical Survey, 1:250,000, China Geological Survey) was conducted according to a dual-layer gridded sampling methodology, that allowed the authors to calculate the organic carbon content of both the topsoil (0–20 cm) and deep soil (150–180 cm) in the Plain (Xi et al., 2009). This paper focuses on the characteristics and trends in SOC concentration for the different regions, periods, ecosystems and land-use types found across the Northeast Plain.

2. Distribution of SOC across the Northeast Plain

As shown in Table 1, topsoil SOC storage (0–0.2 m) was 768.1 Mt with a density of 3327.8 t/km^2; subsoil SOC storage (0–1 m) was 2978.4 Mt with a density of 12,904.7 t/km^2, and deep soil SOC storage (0–1.8 m) was 3729.16 Mt with a density of 16,157.5 t/km^2. Compared to average national soil carbon densities (topsoil 3186 t/km^2, subsoil 11,646 t/km^2 and deep soil 15,339 t/km^2; Xi et al., 2010), the average densities in the Northeast Plain were at the national mean levels.

Soil carbon densities in the Northeast Plain also showed a clear increasing trend from the southern region of the Northeast Plain (Liaoning), to the middle (Jilin) and the northern Plain (Heilongjiang). For example, topsoil carbon density increased from 2284.2 to 3436.7 and 3861.5 t/km^2, respectively, whereas subsoil carbon density increased from 8318.3 to 13,853.7 and 14,708.6 t/km^2, and deep soil carbon density increased from 12,809.2 to 14,472.6 and 20,211.9 t/km^2, respectively.

2.1. SOC distribution in various ecosystems across the Northeast Plain

Tables 2, 3 and 4 present the distribution of SOC across the different ecosystems of the Northeast Plain. These tables show that the forest, marsh and wetland ecosystems usually have the highest soil carbon densities, but due to their small area, total carbon storage in these ecosystems is not dominant in the Plain. In contrast, lower SOC mainly occurs in farmland and grassland ecosystems, with topsoil carbon storage in these ecosystems accounting for 91.5% of the Liaoning provincial storage (Table 2), 67.3% of Jilin (Table 3) and 86.7% of Heilongjiang (Table 4). Despite their relatively lower soil carbon densities, the fact that farmland and grassland ecosystems usually cover a much wider area makes them the dominant source of SOC in the Plain. Soil carbon densities in urban ecosystems are more complex, with higher values observed in Liaoning and Jilin, than Heilongjiang.

Table 1 Soil carbon storage in the Northeast Plain (Yang et al., 2007; Bai et al., 2008; Cui et al., 2009).

Province	Survey area (km^2)	0–0.2 m (Topsoil)		0–1.0 m (Subsoil)		0–1.8 m (Deepsoil)	
		Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)
Liaoning	52,376	119.64	2284.2	435.68	8318.3	670.90	12,809.2
Jilin	95,488	328.17	3436.7	1322.86	13,853.7	1381.96	14,472.6
Heilongjiang	82,936	320.26	3861.5	1219.87	14,708.6	1676.30	20,211.9
Total	230,800	768.07	3327.8	2978.41	12,904.7	3729.16	16,157.5

Table 2 Soil carbon storage distribution among ecosystems in Liaoning Province (Yang et al., 2007; Bai et al., 2008; Cui et al., 2009).

Ecosystem	Survey area (km^2)	0−0.2 m (Topsoil)		0−1.0 m (Subsoil)		0−1.8 m (Deepsoil)	
		Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)
City	1232	5.18	4200.5	17.68	14,354.5	26.12	21,202.5
Wetland	1632	3.73	2286.6	15.94	9768.3	26.80	16,422.3
Farmland	48,936	109.44	2236.4	397.50	8122.9	611.12	12,488.2
River	576	1.29	2240.8	4.55	7892.9	6.85	11,898.5
Total	52,376	119.64	2284.2	435.68	8318.3	670.90	12,809.2

Table 3 Soil carbon storage distribution among ecosystems in Jilin Province (Yang et al., 2007; Bai et al., 2008; Cui et al., 2009).

Ecosystem	Survey area (km^2)	0−0.2 m (Topsoil)		0−1.0 m (Subsoil)		0−1.8 m (Deepsoil)	
		Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)
City	704	3.64	5177.0	14.20	20,176.8	15.12	21,479.9
Forest	14,196	84.21	5931.7	279.50	19,689.0	288.21	20,302.5
River	1368	4.55	3327.7	22.44	16,402.9	23.01	16,823.5
Farmland	50,464	171.57	3399.8	720.52	14,278.0	756.65	14,993.9
Lake	4448	14.70	3304.6	57.74	12,981.0	61.00	13,714.3
Grassland	24,308	49.50	2036.3	228.45	9398.0	237.96	9789.3
Total	95,488	328.17	3436.7	1322.86	13,853.7	1381.96	14,472.6

Table 4 Soil carbon storage distribution among ecosystems in Heilongjiang Province (Yang et al., 2007; Bai et al., 2008; Cui et al., 2009).

Ecosystem	Survey area (km^2)	0−0.2 m (Topsoil)		0−1.0 m (Subsoil)		0−1.8 m (Deepsoil)	
		Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)
Marsh	2376	21.18	8916.1	77.89	32,783.8	97.17	40,897.7
Forest	2872	15.31	5331.0	62.89	21,897.0	86.23	30,024.9
Farmland	58,648	227.25	3874.9	873.70	14,897.3	1211.73	20,661.0
City	1844	6.14	3331.3	23.51	12,750.9	32.58	17,665.5
Grassland	17,196	50.37	2929.1	181.88	10,576.9	248.59	14,456.3
Total	82,936	320.26	3861.5	1219.87	14,708.6	1676.30	20,211.9

Table 5 SACDR among ecosystems of the three provinces in the Northeast Plain.

Province	City	Wetland	Farmland	River	Lake	Forest	Grassland	Marsh
Liaoning	1.84	1.00	0.98	0.98				
Jilin	1.51		0.99	0.97	0.96	1.73	0.59	
Heilongjiang	0.86		1.00			1.38	0.76	2.31

Note: SACDR = ecosystem's topsoil average carbon density/provincial topsoil average carbon density.

In the natural environment, SOC tends to be distributed unevenly among different ecosystems. For example, wetland, lake, forest and swamp ecosystems usually have higher carbon densities and are more favorable to carbon enrichment than other ecosystems. The SOC circulation among these ecosystems results in a dynamic equilibrium, which allows a density ratio relationship to be quantitatively described. For example, the carbon density across various ecosystems is often quantified according to the soil average carbon density ratio (SACDR) (ecosystem's soil average carbon density/soil average carbon density). SACDRs of the three provinces in the Northeast Plain are listed in Table 5, showing that the SACDRs decrease significantly from north to south. In Heilongjiang Province the ratios easily help identify the natural characteristics of soil carbon densities in each ecosystem, whereas in Jilin Province they are less helpful, and in Liaoning Province, there is no obvious difference among the ecosystems, except for the urban system. If a SACDR of 1 is deemed to be the critical value between SOC affluence and depletion, then the forest and marsh ecosystems across the three provinces would be considered affluent, whereas the farmland, wetland and lake ecosystems

Table 6 SACDR among ecosystems in the Northeast Plain.

Province	City	Wetland	Farmland	River	Lake	Forest	Grassland	Marsh
Liaoning	1.26	0.69	0.67	0.67				
Jilin	1.56		1.02	1.00	0.99	1.78	0.61	
Heilongjiang	1.00		1.16			1.60	0.85	2.68

Note: SACDR = ecosystem average soil carbon density/topsoil average carbon density of the Northeast Plain (3328 t/km^2).

would be considered depleted and the grassland ecosystem would be considered significantly depleted.

Based on the soil average carbon densities in the Northeast Plain, Table 6 compares the SACDRs for the different ecosystems across the three provinces. The table indicates a general decline in SACDRs from north to south, with only the grassland ecosystem of Heilongjiang being below 1, whereas in Jilin both the lake and grassland ecosystems were below 1 with the exception for the urban system. All ecosystems in Liaoning were much lower than 1. In contrast to other ecosystems, the carbon densities in the urban system were found to increase from north to south (Tables 5 and 6). Therefore, it is necessary to conduct further research in order to explain this phenomenon (Ye and Li, 2009).

2.2. SOC distribution of land-use types in the Northeast Plain

The Northeast Plain consists mainly of agricultural lands, which account for 96.1% of the survey area, and whose SOC storage accounts for 93.9%. According to Tables 7−9, the soil carbon density of agricultural lands increases gradually from south to north, with topsoil carbon densities in the southern, middle and northern regions, respectively, of 2233.8 t/km^2 (Table 7), 3483.6 t/km^2 (Table 8) and 3702.7 t/km^2 (Table 9). Similar trends were observed for subsoil and deep soil, indicating that climate and farming patterns are likely to be significant factors affecting the SOC storage. In terms of the soil carbon densities for unused land, these are more closely related to factors like soil types. For example, the unused marshes in Heilongjiang had higher carbon densities than the unused sandy lands and saline in Jilin, whereas the unused lands in Jilin had higher carbon densities than the unused swamps in Liaoning.

A comparison of the soil carbon density between unused and agricultural lands in Heilongjiang revealed that the average carbon density in the unused land was 2.4, 2.3 and 3.0 times that of the agricultural lands, respectively, for topsoil (8916.1 t/km^2), subsoil (32,783.8 t/km^2) and deep soil (59,380.6 t/km^2). In Liaoning (Table 7), the difference between the soil carbon density for unused and agricultural lands was lower than 1.2 times, suggesting a smaller difference between their soil carbon densities than in Heilongjiang. Overall, this comparison reveals significant decline of SOC in agricultural lands.

3. SOC distribution across the Northeast Plain for different periods

SOC data from the MRGS and the Second National Soil Survey (SNSS) in 1984−1986, which differ by a time period of 20 years, were analyzed for three provinces in the Northeast Plain. SNSS data were obtained from the “Liaoning Soil” “Jilin Soil Species Record” and “Heilongjiang Soil” datasets, while the average soil organic content of the samples corresponding MRGS sampling network were retrieved from an SNSS soil organic content map. These values were then divided by a conversion coefficient of 1.724, in order to convert them into SOC content. Topsoil SOC characteristics and trends were analyzed based on the different ecosystems and land-use types, the findings of which are discussed in the following sections.

3.1. Topsoil SOC distribution in Liaoning Province in different periods

Tables 10 and 11 present the topsoil carbon density distribution of various ecosystems and land-use types from 1984 to 2004, respectively. Overall, these tables show a total reduction in topsoil SOC of 55.55 Mt and 31.7% reduction in carbon density for Liaoning Province during the 20 years. Table 10 also shows that the rate of decline in soil carbon density increases from river to farmland to wetland ecosystems; the only increase in carbon density was observed for the urban ecosystem. For land-use types (Table 11), the rate of decline increases from unused to agricultural to construction lands.

3.2. Topsoil SOC distribution in Jilin Province in different periods

Tables 12 and 13 indicate a total topsoil SOC reduction of 157.21 Mt and a 32.4% reduction in carbon density for Jilin Province from 1985 to 2005. These tables also show that the rate of decline in soil carbon density increases according to the following order: urban, forest, river, lake, farmland and grassland ecosystems (Table 12); and construction, agricultural and unused land-types (Table 13).

Table 7 Soil carbon storage of various land-use types in Liaoning Province.

Land-use type	Survey area (km^2)	0−0.2 m (Topsoil)		0−1.0 m (Subsoil)		0−1.8 m (Deepsoil)	
		Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)
Agricultural land	50,308	112.38	2233.8	409.77	8145.3	631.51	12,553.0
Construction land	1320	5.57	4216.8	19.15	14,508.2	28.42	21,529.5
Unused land	748	1.69	2262.8	6.75	9028.6	10.96	14,657.8
Total	52,376	119.64	2284.2	435.68	8318.3	670.90	12,809.2

Table 8 Soil carbon storage of various land-use types in Jilin Province.

Land-use type	Survey area (km^2)	0–0.2 m (Topsoil)		0–1.0 m (Subsoil)		0–1.8 m (Deepsoil)	
		Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)
Agricultural land	89,804	312.84	3483.6	1253.19	13,954.7	1309.39	14,580.5
Construction land	1524	6.66	4371.2	26.34	17,281.6	27.78	18,229.0
Unused land	4160	8.66	2082.3	43.33	10,416.7	44.79	10,767.2
Total	95,488	328.17	3436.7	1322.86	13,853.7	1381.96	14,472.6

Table 9 Soil carbon storage of various land-use types in Heilongjiang Province.

Land-use type	Survey area (km^2)	0–0.2 m (Topsoil)		0–1.0 m (Subsoil)		0–1.8 m (Deepsoil)	
		Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)
Agricultural land	78,716	291.47	3702.7	1118.47	14,208.9	1561.70	19,839.6
Construction land	1844	6.14	3331.3	23.51	12,750.9	52.43	28,433.8
Unused land	2376	21.18	8916.1	77.89	32,783.8	141.09	59,380.6
Total	82,936	318.79	3843.8	1219.87	14,708.6	1755.22	21,163.5

Table 10 Topsoil carbon storage among ecosystems in Liaoning Province in different periods (Jia, 1992).

Ecosystem	Survey area (km^2)	MRGS (2004)		SNSS (1984)		Density change rate (%)
		Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)	
River	576	1.29	2240.8	1.48	2578.1	−13.1
Farmland	48,936	109.44	2236.4	164.57	3363.0	−33.5
Wetland	1632	3.73	2286.6	5.92	3629.1	−37.0
City	1232	5.18	4200.5	3.21	2604.6	+61.3
Total	52,376	119.64	2284.2	175.19	3344.8	−31.7

Table 11 Topsoil carbon storage among land-use types in Liaoning Province in different periods (Jia, 1992).

Land-use type	Survey area (km^2)	MRGS (2004)		SNSS (1984)		Density change rate (%)
		Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)	
Agricultural land	50,308	112.38	2233.8	169.49	3369.1	−33.7
Construction land	1320	5.57	4216.8	3.75	2841.7	+48.4
Unused land	748	1.69	2262.8	1.95	2601.0	−13.0
Total	52,376	119.64	2284.2	175.19	3344.8	−31.7

Table 12 Topsoil carbon storage among ecosystems in Jilin Province in different periods (Jilin Soil and Fertilizer General Station, 1997).

Ecosystem	Survey area (km^2)	MRGS (2005)		SNSS (1985)		Density change rate (%)
		Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)	
City	704	3.64	5177.0	3.82	5424.5	−4.6
Forest	14,240	84.38	5925.5	91.35	6415.1	−7.6
River	10,564	39.52	3740.7	56.11	5311.6	−29.6
Lake	3356	11.50	3425.6	17.15	5108.8	−32.9
Farmland	42,040	139.17	3310.5	207.77	4942.1	−33.0
Grassland	24,584	49.96	2032.1	109.19	4441.3	−54.2
Total	95,488	328.17	3436.7	485.38	5083.1	−32.4

Table 13 Topsoil carbon storage among land-use types in Jilin Province in different periods (Jilin Soil and Fertilizer General Station, 1997).

Land-use type	Survey area (km^2)	MRGS (2005)		SNSS (1985)		Density change rate (%)
		Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)	
Agricultural land	89,804	312.84	3483.6	457.62	5095.8	−31.6
Construction land	1524	6.66	4371.2	8.21	5390.2	−18.9
Unused land	4160	8.66	2082.3	19.54	4698.2	−55.7
Total	95,488	328.17	3436.7	485.38	5083.1	−32.4

Table 14 Topsoil carbon storage among ecosystems in Heilongjiang Province in different periods (Land Administrative Bureau of Heilongjiang Province and Heilongjiang Soil Survey Office, 1992).

Ecosystem	Survey area (km^2)	MRGS (2006)		SNSS (1986)		Density change rate (%)
		Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)	
City	1844	6.14	3331.3	7.74	4195.0	−20.7
Forest	2872	15.31	5331.0	20.22	7042.0	−24.3
Farmland	58,648	227.25	3874.9	306.59	5227.6	−25.9
Grassland	17,196	50.37	2929.1	74.14	4311.4	−32.1
Marsh	2376	21.18	8916.1	19.40	8165.4	+9.2
Total	82,936	320.26	3861.5	428.09	5161.7	−25.2

Table 15 Topsoil carbon storage among land-use types in Heilongjiang province in different periods (Land Administrative Bureau of Heilongjiang Province Heilongjiang Soil Survey Office, 1992).

Land-use type	Survey area (km^2)	MRGS (2006)		SNSS (1986)		Density change rate (%)
		Storage (Mt)	Density (t/km^2)	Storage (Mt)	Density (t/km^2)	
Agricultural land	78,712	291.47	3702.9	400.95	5093.9	−27.3
Construction land	1848	6.14	3324.1	7.74	4185.9	−20.6
Unused land	2376	21.18	8916.1	19.40	8165.4	+9.2
Total	82,936	318.79	3843.8	428.09	5161.7	−25.5

Note: Because of small difference with the aggregated MRGS storage data between Tables 14 and 15, the statistical data in Table 15 subject to Table 14.

3.3. Topsoil SOC distribution in Heilongjiang Province in different periods

The total reduction in topsoil SOC for Heilongjiang Province from 1986 to 2006 (Tables 14 and 15) was 109.30 Mt, with a 25.2% decline in carbon density. Topsoil SOC densities for the various ecosystems (Table 14) decreased at various rates, with urban, forest, farmland, and grassland ecosystems each having a greater rate of decline than the previously listed system, only the marsh ecosystem experienced an increase in SOC density. For land-use types (Table 15), construction, agricultural and unused lands each had a greater rate of decline than the previously listed land-use type.

3.4. Topsoil SOC distribution features across the Northeast Plain in different periods

The MRGS and SNSS results for the Northeast Plain (Table 16) show that topsoil SOC storage experienced a reduction of 320.59 Mt over the 20-year period (annual reduction 16.03 Mt), with an average decrease of 1389.0 t/km^2, accounting for 29.4% of the original SOC (annual decline rate 1.73%). A detailed analysis of topsoil SOC storage in the Northeast Plain revealed that SOC storage decreased by 25.2% (1300.2 t/km^2) in the north (Heilongjiang), 32.4% (1646.4 t/km^2) in the middle (Jilin) and 31.7% (1060.6 t/km^2) in the south (Liaoning), at a rate of 1.44%, 1.94% and 1.89% per year, respectively. These findings indicate a higher rate of decrease but a smaller absolute decrease for the southern plain than the northern plain, whereas the middle plain demonstrated the greatest decline in terms of both annual change rate and absolute amount.

Table 17 shows the changes in topsoil SOC for the different ecosystems and land-use types in the Northeast Plain. Over the 20 years, the reduction in organic carbon storage in wetland and lake ecosystems was the most significant (54.6% or 5250.7 t/km^2) compared to grassland (45.5% or 2010.8 t/km^2), farmland (25.1% or 1079.8 t/km^2), and forest ecosystems (10.8% or 706.5 t/km^2). Only the urban ecosystem showed a slight increase of 1.4% in organic carbon storage. Table 18 shows that the most significant decrease occurred in agricultural lands, with a decrease in topsoil SOC storage of 30.3% and a decline in density of 1423.0 t/km^2. The unused lands had the second greatest decline, followed lastly by construction lands.

It must be stated that SNSS data have certain limitations because of different sampling densities and sampling approaches compared to the MRGS, and therefore, possible errors related to this limitation should be considered and assessed. As previously

Table 16 Topsoil SOC storage in the Northeast Plain in different periods.

Province	Survey area (km^2)	MRGS storage (Mt)	SNSS storage (Mt)	Change (Mt)	Change ratio (%)	Carbon density change (t/km^2)	Annual change (Mt)	Annual change rate (%)
Liaoning	52,376	119.64	175.19	−55.55	−31.7	−1060.6	−2.78	−1.89
Jilin	95,488	328.17	485.38	−157.21	−32.4	−1646.4	−7.86	−1.94
Heilongjiang	82,936	320.26	428.09	−107.83	−25.2	−1300.2	−5.39	−1.44
Total	230,800	768.07	1088.66	−320.59	−29.4	−1389.0	−16.03	−1.73

Table 17 Topsoil carbon storage among ecosystems in the Northeast Plain in different periods.

Ecosystem	Surveyarea (km^2)	MRGS storage (Mt)	SNSS (Mt)	Change amount (Mt)	Change rate (%)	Carbon density change (t/km^2)	Anual change (Mt)	Anual change rate (%)
Marsh and lake	10,400	45.46	100.07	−54.61	−54.6	−5250.7	−2.73	−3.87
Forest	17,068	99.52	111.58	−12.06	−10.8	−706.5	−0.60	−0.57
Farmland	158,048	508.26	678.93	−170.67	−25.1	−1079.8	−8.53	−1.44
City	3780	14.96	14.76	+0.20	+1.4	+52.7	+0.01	+0.07
Grassland	41,504	99.87	183.32	−83.45	−45.5	−2010.8	−4.17	−2.99
Total	230,800	768.07	1088.66	−320.59	−29.5	−1389.9	−16.03	−1.73

Table 18 Topsoil carbon storage among land-use types in the Northeast Plain in different periods.

Land-use type	Surveyarea (km^2)	MRGS storage (Mt)	SNSS (Mt)	Change amount (Mt)	Change rate (%)	Carbon density change (t/km^2)	Anual change (Mt)	Anual change rate (%)
Agricultural land	218,824	716.69	1028.06	−311.37	−30.3	−1423.0	−15.57	−1.79
Construction land	4692	18.37	19.70	−1.33	−6.8	−283.6	−0.07	−0.35
Unused land	7284	31.54	40.89	−9.35	−22.9	−1283.8	−0.47	−1.29
Total	230,800	766.60	1088.66	−322.06	−29.6	−1396.4	−16.10	−1.74

mentioned, some studies have concluded that water loss and soil erosion can cause reductions in SOC, as well as carbon enrichment, thus indicating that the contribution of farming soil emissions to greenhouse gas concentrations should not be underestimated (Fang et al., 2003; Liu and Zhang, 2005). The SOC loss in Heilongjiang province has been studied and attributed to warming and land-use change (Xia et al., 2010). This paper focuses on the trends in SOC concentration. However, further research is necessary in relation to the underlying causes of SOC decline, and it is of equal value to continue monitoring the amount and rate of change. This will not only help develop effective measures for dealing with this problem, by ensuring the transfer of carbon from sources to sinks, but also help the Northeast Plain maintain its status as a significant reservoir for organic carbon.

Ecosystem carbon density proportion (ECDP), which measures “ecosystem soil carbon density/sum of soil carbon densities in various ecosystems”, was utilized to demonstrate the distribution of carbon in different ecosystems in order to evaluate topsoil carbon storage potential, as well as the rates of development and change. Table 19 illustrates that over the 20 years the ECDPs for the Northern Plain differed according to the type of ecosystem, with the greatest EDCP observed for marsh ecosystems, followed by forest, farmland, grassland and urban ecosystems. In Jilin in 1985, the highest ECDP was observed in forest ecosystems, followed by urban, river, lake, farmland and grassland ecosystems. However, it is noteworthy that human-oriented urban ecosystems rose to second place and their ECDP value continued to increase throughout the 20 years, while the EDCP values for the grassland ecosystem declined significantly during the same period. Carbon density of Liaoning in 1984 was the greatest in wetland ecosystems, followed by farmland, urban and river ecosystems. By 2004, however, the ECDPs for the urban ecosystem ranked first, with EDCP values for wetland and farmland ecosystems declining significantly. On the whole, agricultural areas in the Northeast Plain were found to have the largest soil carbon storage, the fluctuations of which had a widespread and fundamental impact on the whole ecosystem. Therefore, improving the biological cycle of cultivated lands will serve to enhance the fixation and storage of soil carbon in the Northern Plain. In relation to the urban ecosystem, carbon density was found to increase from north to south, which corresponded to the increasing levels of urbanization in the northern regions and indicated that urbanization could serve as an indicative parameter for estimating soil carbon storage (Zhang and Zhou, 2006).

ECDPs may also differ according to different climates and geographical landscapes, and generally, the more diverse the ecosystems, the more favorable they are to maintaining the stability of SOC. However, a decline in SOC in one ecosystem may encourage a decline in other ecosystems, which is also an explanation for the declining differences in SACDRs as one moves from north to south across the Northeast Plain.

Table 19 Topsoil ECDPs in the Northeast Plain in different periods.

Ecosystem	Heilongjiang topsoil ECDP (%)		Jilin topsoil ECDP(%)		Liaoning topsoil ECDP(%)	
	MRGS	SNSS	MRGS	SNSS	MRGS	SNSS
Marsh	36.6	28.2				
Forest	21.9	24.3	25.1	20.3		
Farmland	15.9	18.1	14.0	15.6	20.4	27.6
City	13.7	14.5	21.9	17.1	38.3	21.4
Grassland	12.0	14.9	8.6	14.0		
River			15.8	16.8	20.4	21.2
Lake			14.5	16.1		
Wetland					20.9	29.8
Sum of soil carbon density of various ecosystems	24,382	28,941	23,611	31,643	10,964	12,175

Note: Topsoil ECDP = ecosystem's topsoil carbon density/sum of topsoil carbon density of ecosystems.

4. Conclusion

The Northeast Plain of China is an important agricultural and economical region for the country, whose SOC development and distribution is of great scientific value and practical significance. The changes in SOC in the Northeast Plain are also likely to reflect global change patterns, which will serve as important references for related global research. The "Climate Change Conference" held in Copenhagen in 2009, predicted that global climate change would increase in the coming years. As a large country, China should make efforts to reduce its emissions. This would require conducting carbon-related scientific research, which should be based on the study of organic carbon development and storage. Ideally, this would involve: setting up a theoretical and methodological system to investigate SOC distribution, migration and ecological effects; conducting research on soil carbon storage potential; establishing soil carbon monitoring networks; and conducting studies on soil geochemical carbon sequestration mechanisms and technologies. This will not only provide a theoretical and methodological basis for global change research, but also serve as an active response to the major scientific challenges and social problems facing the world today.

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