Changes of soil organic carbon in different agro-ecological zones in China over 20 years

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Abstract
Soil organic carbon (SOC) is important to the cycling of carbon in ecosystems which is related to greenhouse gas emissions and global warming. The changes of SOC caused by different management practices over 20 years were investigated in three different agro-ecological zones: (1) the North China Plain where soils were derived from an alluvial flood plain in warm and sub-humid conditions, (2) the Loess Plateau developed from aeolian deposits in warm and sub-arid climate, and (3) the Northeastern China Plain representing cool and sub-humid climate and soils developed from loess-like materials. A total of 130 soil profile (0 to 1.5 m) and 1184 plough layer samples were collected twice at the same location, one was in the early 1980s and the other was in 2000. The results showed that the SOC increased by 1.83 and 0.97 kg C/m^2 in the North China Plain and the Loess Plateau over 20 years, respectively; whereas it decreased by 2.33 kg C/m^2 in the Northeast China at the same period. High fertilizer input (300 to 350 kg N/ha and 100 to 120 kg P_2O_5/ha) and high cropping index have produced more crop residues, thus resulting in a net gain of SOC in the North China Plain and the Loess Plateau. The very low SOC content (2 to 5 g/kg) of the benchmark soils in the 1980s was possibly another reason for SOC increase in these two regions. Low fertilizer input (80 to 250 kg N/ha and 80 to 250 kg P_2O_5/ha) and low cropping index, and high SOC content (20 to 50 g/kg) of the bench mark soils may be responsible for the apparent decrease of SOC in the Northeastern China.

Key Words
Agro-ecological zone, farmland, soil organic carbon, total carbon storage.

Introduction
Soils may act as a sink or a source of atmospheric CO_2 depending upon carbon additions via primary and secondary production (including excretions) and carbon losses via erosion, leaching and decomposition of soil organic matter. Agricultural soil plays a key role as the C sink. Recently, many researches estimated the agricultural soil carbon stock on different scales, for instance, the global scale (Post *et al.* 1982; Eswaran *et al.* 1993; Kirschbaum *et al.* 2000), the national scale (Paul *et al.* 1995; Tatyana *et al.* 1998; Lars *et al.* 2003), and the regional scale (Susan *et al.* 1998). The change of soil carbon stock and the physical and humans driving factors, such as soil characteristics, altitude, tillage management, crop system, etc, are research hotspots (Alessandra *et al.* 2002; Follett, 2001; Lal, 2004).With economic development in China where arable land is only 0.1ha per capita, the pattern and intensity of land uses have been changed, but the changes of soil carbon content in the last 20 years have been rarely reported. Almost all documented papers dealt with soil carbon content data collected in the early 1980s. Therefore, the aims of this study are: (i) to estimate the changes of soil organic carbon in different agro-ecological regions in China over 20 years; and (ii) to determine the impacts of soil managements on the SOC stock in China.

Materials and methods
Site descriptions
Three different agro-ecological zones, the North China Plain, the Loess Plateau and the Northeastern China Plain were selected for this study. The two Ustepts soils (Haplustepts), located in Daxing county (N39º26′-39°51′, E116º13′-116°43′) of southern Beijing and Quzhou County (N36º35′-36º58', E114º50′-115º13′), Hebei Province were selected in the temperate sub-humid region in North China Plain. Both locations had a similar annual precipitation (556 to 569 mm), but Quzhou was characterized with slightly higher annual temperature (13.1ºC) and ≥10ºC heat degree day (DD = 4472ºC) than Daxing (11.5ºC and DD = 4161ºC) and a longer frost free days (201 vs. 190 days, Table 1). Soils at both locations were developed from alluvial deposits. Crops have been cultivated over thousands of years. In warm and semi-arid region of the Loess Plateau two loess soils were selected in Youyu county (N39º41′-40°18′, E112º6′-112°38′) in northern Shanxi province and Lishi county (N37º20′-37°44′, E110º56′-111°36′) in central Shanxi province. The topography is upland and mesa covered with deep loess. Both locations had a similar annual temperature (8.6 to 8.7°C),

Table 1. Relationships between SOC and depth in soil profile.

Sample site	Number of samples	Regression equation[a]	R^2	Average SOC content g/kg
North China Plain				
Quzhou2000	31	Y=-1.6566Ln(x)+10.069	0.5861	4.096
Quzhou 1980	45	Y=-1.0266Ln(x)+7.0454	0.5126	3.344
Daxing2000	6	Y=-2.5915Ln(x)+14.187	0.6221	4.844
Daxing1981	4	Y=-1.1494Ln(x)+6.8765	0.5453	2.733
Loess Plateau				
Lishi2000	3	Y=-1.8156Ln(x)+10.937	0.548	4.391
Lishi1980	3	Y=-1.1903Ln(x)+6.2089	0.6184	1.918
Youyu2001	8	Y=-1.5568Ln(x)+10.438	0.7169	4.825
Youyu 1981	8	Y=-0.9525Ln(x)+6.5943	0.502	3.160
Northeastern China				
Gongzhuling2000	6	$Y=13.033e^{-0.0138x}$	0.5728	7.068
Gongzhuling1980	6	$Y=13.129e^{-0.0088x}$	0.5547	8.731
Hailun2000	5	$Y=30.72e^{-0.0155x}$	0.8582	15.613
Hailun 1980	5	$Y=33.935e^{-0.0138x}$	0.8599	18.404

while Lishi had higher precipitation (550 mm), greater ≥10ºC heat degree day (DD = 3000 to 3500ºC), and a longer frost free period (100 to 150 days) than Youyu (442.8 mm and DD = 2300 to 2500ºC). The two Udolls soil locations selected from the cold humid region in Northeastern China were Beian (N47º53′-48º33′, E126º16′-127º53′) in northern Heilongjiang and Hailun (N46º58′-47º52′, E126º14′-127º45′) in central Heilongjiang Province. The average annual temperature was much lower in Beian (0.2ºC) and Hailun (1.5ºC) than Usteps and loess soils. The DD was 1710 to 2300 and frost free day was 105 to 121 days. The annual precipitation was in the range of 553 to 570 mm. The precipitation was mainly concentrated in summer. The Udolls has been cropped for about one hundred years.

Data acquisition

Background soil samples at all six locations were collected from 1980 to 1982, and comparable samples were taken in 2000. A total of 126 soil profiles and 1184 plough layers (0 to 20 cm) were sampled (Table 2). The SOC content was determined using a Verio EL III element analyzer (Elementar, Hanau, Germany) for the Udolls soil samples and rapid dichromate oxidation techniques as described by Tiessen and Moir (1993) for samples of the Ustept soil and loess soil. The relationship between these two SOC measurements was investigated.

Table 2. The change of the density and the storage of agri-soil organic carbon (0-20cm) in the research area in recent 20 years.

agro-ecological regions	Sample site	Sample No.	C g/Kg	SOC density kgC/m2	SOC stock kgC	Change scope %
North China Plain	Quzhou2000	79	11.93	3.08	2.05×109	40.33
	Quzhou 1980	79	8.50	2.20	1.46×109	
	Daxing2000	297	12.41	3.16	3.37×109	28.72
	Daxing1981	208	9.64	2.45	2.62×109	
Loess Plateau	Lishi2000	70	5.55	1.40	1.84×109	47.12
	Lishi1980	58	3.77	0.95	1.25×109	
	Youyu2001	70	6.87	1.72	3.66×109	63.54
	Youyu 1981	70	4.20	1.05	2.24×109	
Northeastern China	Gongzhuling2000	70	12.37	2.63	12.25×109	-6.72
	Gongzhuling 1980	51	13.26	2.82	13.13×109	
	Hailun2000	76	28.21	5.84	32.56×109	-10.81
	Hailun 1980	56	31.62	6.55	36.46×109	

The change of SOC density and storage (1 m) in the North China Plain, the Loess Plateau and the Northeastern China Climatic conditions and soil pedongenic processes were similar in each agro-ecological zone, thus, soil properties in the whole region are considered relatively homogeneous within the same dominant soil type.

Calculations and statistics

The SOC density is defined as the amount of soil organic carbon in one cubic meter (in kg m^{-3}), and is calculated by multiplying SOC content with soil bulk density (BD). The total SOC stock (kg C) for each agro-ecological regions was estimated by multiplying the SOC density and the total arable land at a given depth in an eco-zone. Thus, SOC density and stock can be obtained as:

$$SOC_{density} = C \times BD \times d \times (1-\delta)/100 \quad (1)$$

where C is SOC average content (g/kg), BD is the bulk density of soil <2mm fraction (g cm^{-3}) at a given depth, d is soil profile depth (cm), δ is the gravel (>2mm) content.

$$SOC_{stock} = S \times d \times SOC_{density} \quad (2)$$

Where S is total area interested and d is soil depth (m).

The calculated model of SOC density and SOC storage in sample site

Taking soil SOC data (1999) at Quzhou as an example, a strong logarithm relationship between SOC and soil profile depth was obtained after performing regression analyses.

$$Y=-1.6566Ln(d) + 10.069 \quad (3)$$

$R^2 = 0.5861$, sample number n = 31

where Y is SOC content (unit), and d is soil profile depth (cm).

Through the definition of SOC density, soil profile depth is 100 cm. According to integral median theorem (Newton-Leibniz formula),

$$\int_0^{100} (-1.6566\text{Ln}(x) + 10.069)dx = \int_0^{100} Cdx \quad (4)$$

C is the SOC content;

From equation 4, the estimated SOC content was is 4.096g/kg in 1m soil profile, on the average.Similarly, the estimations of SOC content and total stock estimation could be applied to other regions.

The parameters of BD and δ varied slightly with soil profile, however, they were assumed as a constant in a given region, because the targeted region had a similar soil management practice, soils were derived from the same deposits, and more than 2 mm gravels were rarely found in research regions. Based on above assumptions, the BD averaged 1.36 g/cm^3 at Quzhou. The SOC density was 5.29 kg/m^3 when δ value was 0.5% and the SOC storage was approximately 3.51×109 kg in 2000 in Quzhou.

Results and discussion

The SOC storage change in the North China Plain

With adoption of the household responsibility system and land tenure in the early 1980s, more fertilizers were used (300 to 350 kg/ha for N and 100 to 120 kg/ha for P_2O_5) to produce crop yields 3 to 8 times (3500 to 4500 kg/ha for wheat, 5000-6500 kg/ha for corn) higher than pre-1980. The cropping system changed to two crops per year. With high inorganic fertilizer input, the amount of crop residue (straw and roots) produced has increased considerably, thus resulting in the increase of SOC in North China plain. This was well paid off from declining use of organic fertilizer (livestock manure or municipal sewage). Increases in SOC after adopting the land reform policy were also reported in other regions of Northern China since both aboveground biomass and root residues increased with fertilizer use. In addition, with the improvement in living standards farmers have not taken crop residue as the fuel for heating and cooking. Thus, a greater proportion of crop residue is retained on agricultural land. This also contributed to the increase of SOC in Ustepts soils. Apart from crop residues (shoot and roots) left over on the field after harvest, C and N compounds are also released by plant roots into the soil during the growing season, and undergo several transformation processes. This improves soil structure and contributes to increases in SOC content.

The SOC storage change in the Loess Plateau

The low input was reflected by low SOC content, especially in the early 1980s. Cultivation worsened soil erosion, thus resulting in a negative soil cycle: mature-erosion-mature, this low input cycle did not obtain high and stable yields. As SOC content had reached to the lowest level, any increasing inputs management would improve SOC content. With the comprehensive treatment and development of watershed, the improvement of field ecological environment, the control of the erosion to some extent, the farmers' labor zest brought by the household responsibility system and land tenure, all these can explain the inputs continually increasing. The field investigations in Lishi location gain the crop yield (500-550 kg/ha for soybean, 1300-1450 kg/ha for millet, 4500 kg/ha for corn) and fertilizer input (80-250 kg/ha for N and 80-250 kg/ha for P_2O_5). There are different fertilizer inputs for different crop. The corn yield is higher relative to higher fertilizer inputs. Soybean is the opposite.

The SOC storage change in the Northeastern China Plain

The initial SOC in the Northeastern China Plain was from 2 to 8 times of that in the North China Plain in the early 1980s. Crop production in this region relied largely on the soil's natural fertility rather than fertilizer input. Thus, high yields were achieved through depletion of soil fertility, leading to the decrease of SOC in the Northeastern China Plain. The combination of short cultivation history, lower fertilizer input and lower crop residues were attributed to the rate of SOC decomposition exceeding that of SOC formation. Thus, SOC has decreased and will probably continue to decrease under current practices. The SOC decrease in the Northeastern China Plain will lead to erodibility to be increased, causing more offsite transport of soil particles and associated nutrients to surface water. This further illustrates the need to increase crop residue input for sustainable agriculture production.

Table 3. The change of the density and the storage of agri-soil organic carbon in North China Plain, Loess plateau and northeast of China in recent 20a.

agro-ecological regions	depth cm	SOC density kg C m^{-3}	SOC storage kg C	Change of SOC storage kg C	Change scope %
North China Plain	100(1980-82)	3.90	9.56×10^{10}	4.48×10^{10}	46.92
	100(2000)	5.73	14.04×10^{10}		
	20(1980-82)	9.07	5.71×10^{10}	1.94×10^{10}	
	20(2000)	12.17	7.64×10^{10}		
Loess Plateau	100(1980-82)	3.19	4.88×10^{10}	3.99×10^{10}	81.82
	100(2000)	5.80	8.87×10^{10}		
	20(1980-82)	22.44	2.30×10^{10}	-0.69×10^{10}	
	20(2000)	20.29	3.59×10^{10}		
Northeastern China	100(1980-82)	14.18	32.61×10^{10}	-5.36×10^{10}	-16.43
	100(2000)	11.85	27.26×10^{10}		
	20(1980s)	3.98	7.18×10^{10}	1.29×10^{10}	
	20(2000)	6.21	6.49×10^{10}		

Conclusion

Soil organic carbon loses by conversion of natural vegetation to cultivated use. For example, the low fertilizer input in northeastern China makes low crop yields, which results in depletion of soil organic carbon. As a result, the net balance between built-up and mineralization of SOC the rate of soil organic carbon inputs and rate of mineralization is negative. Soil organic carbon storage will be increasing through more fertilizer input. This was demonstrated by the case study in the North China Plain and the Loess Plateau in recent 20 years. Since agricultural soils play dual roles, sink and source for CO_2 in the atmosphere, it is an effective way to use soil as an important means of sequestrating global warming gas CO_2. For the large population pressure, it is unfeasible to adopt fallow mode. The food security of the 1.3 billion people is the most important thing for the development of national economy. It is realism that farmland per capita is limited in China, and the best way increased inputs will result in more outputs. The above study indicates that increasing the agricultural inputs not only meets food demand but also promotes SOC content, which will make some contribution to the sequestration of global warming gas CO_2.

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