Carbon sequestration in paddy ecosystems in subtropical China

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Abstract
Carbon (C) sequestration in paddy soils was studied in 4 selected landscape units as representatives for the lowland (LL), low-hill (LH), high-hill (HH) and karst-mountain (KM) areas in subtropical China. The mean values for organic C content in paddy soils (0-20cm) in the landscape unit varied from 16.0 to 27.7 g /kg, which were remarkably larger than those for soils under arable cropping and orchard, and even under woodland except in the KM landscape unit. In the LH landscape unit, the mean organic C content in paddy soils increased by 1.67 times ($P<0.01$) in the period of 1979-2003. This increase was concordant with the prolonged increase (since 1950s) in rice productivity in the region. It is concluded that paddy ecosystems in subtropical China had the ability to sequester organic C in amounts larger than those in other ecosystems. As these landscape units represent the real situations for paddy ecosystems under farmers' practices for rice production, data from this study confirm that the trend of continuing organic C sequestration in paddy soils occurred in subtropical China.

Key Words
Carbon stock, paddy soil, landscape unit, subtropical China.

Introduction

Changes in soil organic C by agriculture affect terrestrial C stock, which is a twice as large as the atmospheric C stock and the associated global changes (IPCC 2007). Rice cultivation globally covers a total area of about 153 million ha (FAOSTAT database) and has been proposed to have a great potential in sequestrating atmospheric CO_2 (Lal 2004; IPCC 2007). This paper was armed to understand the C sequestration capability of paddy ecosystems in a landscape scale in subtropical China.

Materials and methodology

Four landscape units were selected as the representatives of the land types of lowland (LL; with an elevation of 35-45 m), low-hill (LH, 81-122 m), high-hill (HH; 202-395), and karst-mountain (KM; 202-450 m) areas, which cover the major region of subtropical China (Table 1). They contained multiple ecosystems with native woodlands and various cropping lands including paddy, arable and orchard fields under farmers' practices, providing real information for evaluating the impacts of agriculture on soil C stock at the landscape scale. Each of the landscape units selected covered an area of 5-8 km^2. For each landscape unit, samples of surface soil (0-20 cm) at 538-744 sites (about 3-4 /ha for farmlands and 1 /ha for woodland and orchards) were collected between July, 2003, and March, 2004. Each was taken as 6-10 soil cores (∅ 3.0 cm). In the same area where the LH landscape unit was selected, 347 and 115 additional samples were taken in 1979 and 1990, respectively.

Organic C content of the soils from the low hill and high hill landscape units was measured by the combustion method using an automated C/N analyzer (vario MAX, Elementar, Germany). Because soils from the LL and KM landscape units contained $CaCO_3$, which interferes with instrumental analysis, organic C was determined by the traditional wet digestion with potassium dichromate.

Results and Discussion

In the LL landscape unit, about 94% of paddy soils (0-20 cm) had the values of organic C content ranging from 20.1 to 35.0 g /kg, with a peak distribution (51%) occurring in the range of 25.1 to 30.0 g /kg (Figure 1a). However, the values for arable soils distributed mainly in a distinctly lower range, from 15.1 to 25.0 g C /kg.

In the LH landscape unit, the majority (84%) of paddy soils contained organic C ranging from 12.6 to 20.0 g /kg (Figure 1b). For arable and woodland soils, organic C content ranged mainly from 7.6 to 15.0 g /kg. The range for the majority of orchard soils was narrowed to 7.6 to 10.0 g C /kg.

Table 1. Mean and coefficient of variation of soil organic C content in selected landscape units

Landscape unit	Land use	Sample number	Organic C content		
			Mean (g /kg)^A	SD	C.V. (%)
Lowland (LL)	Paddy	545	27.7 a	4.1	14.7
	Arable	82	19.9 b	4.9	24.5
Low-hill (LH)	Paddy	253	16.0 a	2.7	16.6
	Arable	70	11.2 b	2.8	25.2
	Woodland	17	8.4 b	2.3	28.0
	Orchard	198	9.5 b	2.0	21.2
High-hill (HH)	Paddy	77	21.0 a	5.4	25.9
	Arable	336	17.8 ab	5.4	30.5
	Woodland	197	18.2 ab	4.9	26.8
	Orchard	97	13.6 b	3.3	24.4
Karst-mountainous (KM)	Paddy	339	22.9 b	7.2	31.5
	Arable	313	13.9 c	4.7	33.7
	Woodland	92	35.3 a	25.2	71.5

^{A}Letters indicate the significant difference for the mean between land uses ($p<0.05$)

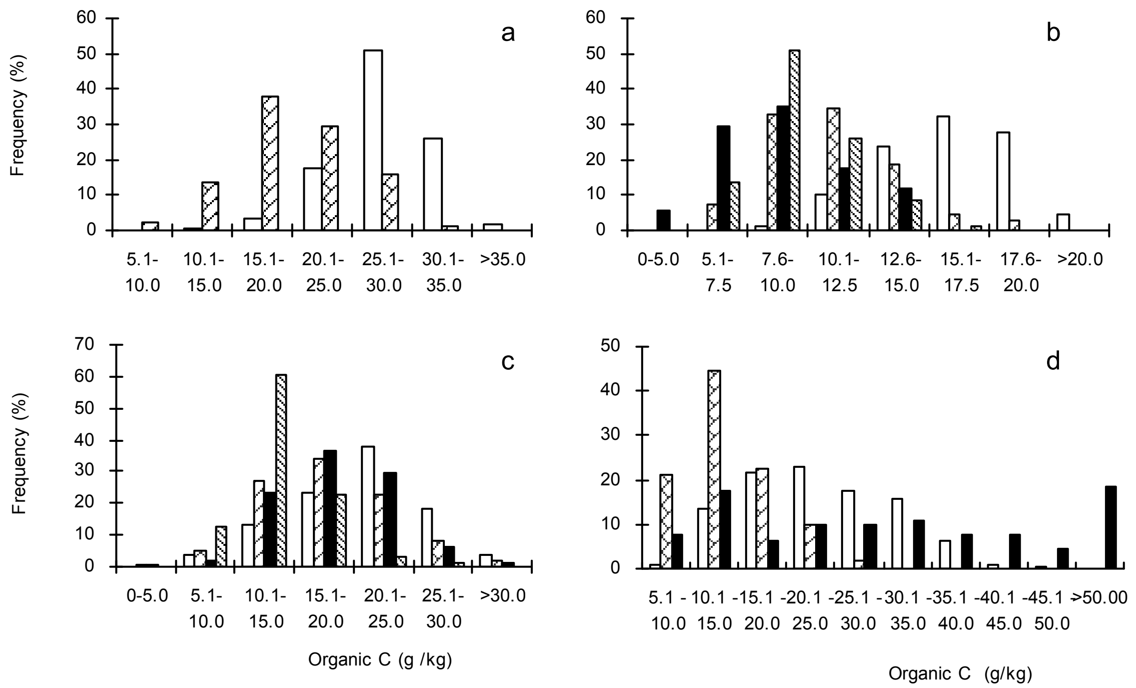

Figure 1. requency distribution of organic C content in soils in the lowland (a), low-hill (b), high-hill (c), and Karst-mountain (d) landscape units selected in subtropical China. Paddy soils (□), Arable soils (▨), Woodland soils (■), and Orchard soil (▧).

Although the majority (61%) of paddy soils contained organic C in the range of 15.1 to 25.1 g /kg in the HH landscape unit, the frequency distribution increased steadily from about 4% below 10 g C /kg to 38% within the range 20.1 to 25.0 g C /kg, then decreased (Figure 1c). The distribution of organic C content in arable and woodland soils was very similar, with 87% in the range of 10.1 to 25.0 g /kg. However, the majority of orchard soils contained organic C in a much narrower range, because 61% appeared between 10.1 and 15.0 g /kg.

In the KM landscape unit, the majority of paddy soils contained organic C in the range from 15.1 to 35.0 g /kg (Figure 1d). This range was much wider than that for the three landscape units described above. Organic C content for arable soils in this landscape unit was distributed mainly (88%) in the range of 5.1 to 20.0 g /kg, with a peak distribution (44%) appearing in the range of 10.1-15 g /kg. However, woodland soils showed a wider range of organic C values (from 5.1 to over 50.0 g /kg). For paddy and arable soils, the mean values for organic C content in the LL landscape unit were significantly larger than those in other three landscape units (LH, HH, and KM) (Table 1). However, the mean values for all of the 4 land-use types (paddy, arable, orchard, and woodland) in the LH landscape unit were significantly smaller than those in other three landscape units (LL, HH, and KM). For woodland soils, the mean values of organic C content differed significantly in the order of KM>HH>LH.

Our data also indicated that there were large differences in the distribution frequency of organic C content in paddy soils in the different landscape types, as 20.1-35.0 g /kg for LL, 12.6-20.0 g /kg for LH, 15.1-25.0 g /kg for HH, and 15.1-35.0 g C /kg for KM (Figure 1). Both of paddy soils and arable soils in the LL landscape unit had been converted from wetland ecosystems between 1950s and 1970s. Therefore, the differences between organic C contents in these two types of soils indicated a large loss of soil organic C under arable cultivation in the area (Table 1). Clearing native vegetation such as forest and grassland in order to create land for farming usually results in a loss of soil organic C (Jenkinson 1990). However, data obtained in the present study suggest that rice cultivation seems to be an exception. This is in agreement with previous studies with historical data in subtropical China (Li and Zhao 2001) and field trials (e.g. Pampolino *et al.* 2008) in India. For all of the four landscape units investigated, paddy soils showed significant higher organic C content, compared to those in soils under arable and orchard management, and also under woodlands, with the exception of woodland soils in the KM landscape unit.

In paddy soils sampled in 1979 from the low-hill area from where the LH landscape unit was selected, about 56% had organic C contents ranging from 7.6 to 12.5 g /kg. As organic C content increased, the distribution frequency of soils decreased sharply (Figure 2a). By 1990, organic C content of paddy soils in this landscape unit mainly distributed in the range of 10.1-17.5 g /kg), and then moved to a significantly higher range (15.0 and 17.5 g C /kg) by 2003. Therefore, the mean value of organic C content in these soils (16.0±2.7 g /kg) was 17% ($p<0.01$) larger than that (13.7± 3.0 g /kg) in 1990, or 60% larger than that (10.0 g /kg) in 1979, respectively. In the same landscape unit, the distribution frequency of organic C in arable soils sampled in 1990 and 2003 was very similar to that for soils sampled in 1979 in the low-hill area, with a peak distribution (about 40%) appearing the range of 7.6-10.0 g /kg (Figure 2b), and the mean of organic C in the arable soils crossing these three sapling times were comparable. These results provide clear evidence of a temporal increase in organic C content in paddy soils at the landscape scale, suggesting that the trend for organic C sequestration by paddy soils was a real one.

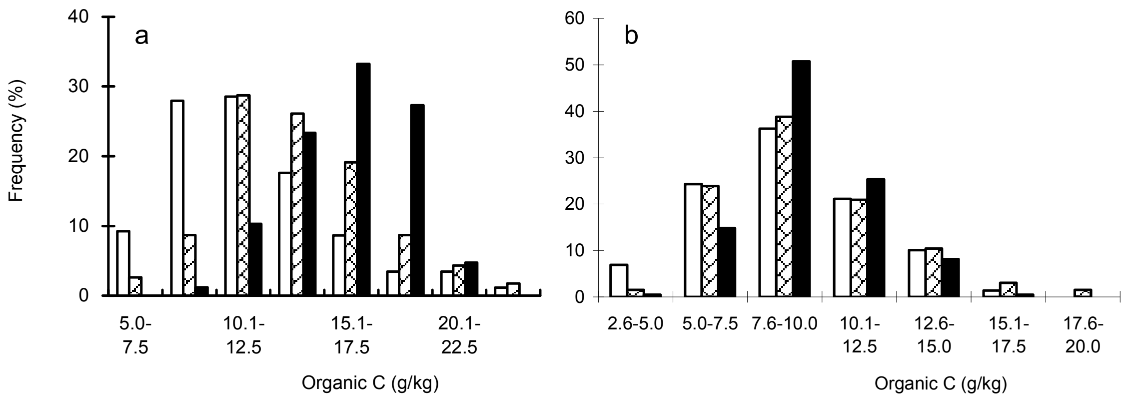

Figure 2. Temporal change (1979–2003) in the frequency distribution of organic C content in (a) paddy and (b) arable soils in the low-hill landscape unit (□1979 ▨1990 ■2003).

Organic inputs from ground cover vegetation or external manure sources are essential for maintaining the cycling and sequestration of organic C in soil. Based on data from China Agriculture Yearbook, the mean grain yield of rice (single crop) in subtropical China increased from about 2 t /ha in the 1950s to 3.5-4.0 t /ha in 1977. because double-rice systems have been widely introduced in this region, together with a continuous increase in the application of chemical fertilizers, the mean yield was increased further to about 11 t /ha by the mid-1990s and afterwards. Assuming that the primary productivity and the amount residue of rice was proportionally related to grain yield, the amount of C input as straw and root biomass to cultivated rice soils must have increased by approximately a similar extent between 1978 and 2003. It is logical to suggest that such a large increase in organic inputs can support prolonged C sequestration by paddy soils in subtropical China.

Conclusion

Investigations in the landscape units suggest that paddy ecosystems in subtropical China have the ability to sequester organic C in amounts that are larger than those in of other ecosystems. Because these landscape units represent the real situations for the paddy ecosystems under farmers' practices for rice production, the data obtained by in this study indicate a trend of continuing organic C sequestration in paddy soils in subtropical China.

Reference

IPCC (2007) 'Climatic Change 2007: The physical science basis-summary for policymakers'. www.ipcc.ch.

Jenkinson DS (1990) The turnover of organic carbon and nitrogen in the soil. *Philosophical Transactions of the Royal Society B* **329,** 361-368.

Lal R (2004) Offsetting China's CO_2 emissions by soil carbon sequestration. *Climatic Change* **65,** 263-275.

Li Z, Zhao QG (2001) Organic carbon content and distribution in soils under different land uses in tropical and subtropical China. *Plant and Soil* **231,** 175-185.

Pampolino MF, Laureles EV, Gines HC, Buresh RJ (2008) Soil carbon and nitrogen changes in long-term continuous lowland rice cropping. *Soil Science Society of America Journal* **72,** 798-807.