Development of bulk density, total C distribution and OC saturation during paddy soil evolution

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Abstract

Considerable amounts of organic matter (OM) are stabilized in paddy soils, and thus a large proportion of the terrestrial carbon is conserved in wetland rice soils. Nonetheless the mechanism for stabilization of total organic carbon (TOC) in paddy soils as driven by redox cycling is largely unknown. The aim of the project is to identify the role of organo-mineral complexes for the stabilization of organic carbon in a chronosequence of paddy soil use and thus duration of management-induced paddy soil formation. Soil profiles were sampled, including paddy sites and non-irrigated control sites. First analyses include bulk density, the TOC and total inorganic carbon (TIC) concentrations of bulk soil and the concentration of organic carbon as well as the organic carbon stocks of physical soil fractions. First results indicate distinctly different depth distributions between paddy and non-paddy (control) sites. The paddy soils are characterized by relatively low bulk densities in the puddled layer (between 0.9 and 1.3 g/cm^3) and high values in the plough pan (1.4 to 1.6 g/cm^3) and the non-paddy soils by relatively homogeneous values throughout the profiles (1.3 to 1.4 g/cm^3). In contrast to the carbonate-rich non-paddy sites, we found a significant loss of carbonates during paddy soil formation, resulting in decalcification of the upper 20 cm in 100 y old paddy soils, and decalcification of the total soil profile in 700, 1000 and 2000 y old paddy soils. The calculation of the organic carbon stocks of each horizon indicate that paddy sites have always higher values in top-soils compared to non-paddy sites, and show increasing values with increasing soil age. The capacity of fine soil fractions to preserve OC was calculated by using the formula of Hassink (1997). With increasing duration of paddy soil use, the fine fractions indicate an increasing saturation level of the potential capacity to preserve OC.

Key Words

Soil organic matter (SOM), particle size fractionation, top-soil, OC-saturation.

Introduction

Paddy soils are described as important accumulator for OM (Zhang and He 2004). In southeast China, paddy soils have the second highest OM stocks (Zhao *et al.* 1997). The paddy soil management is believed to be favourable for accumulation of organic matter, as its content in paddy soils is statistically higher than that of non-paddy soils (Cai 1996). However, the mechanism of OM storage and the development of OM distribution during paddy soil evolution are largely unknown. Soil chronosequences are valuable tools for investigating soil development processes. In the Zhejiang province (Yangtze River Delta, China), during the past 2000 years new farmland was created through consecutive land reclamation by protective dikes. The construction of the dikes is historically well-dated and provides the unique chronosequence of soil formation under agricultural use. Parts of the land were used for paddy rice, other parts for a variety of non-irrigated crops (non-paddy sites).This provides the unique opportunity to document the effect of soil redox conditions over long time periods on the evolution and distribution of soil organic matter (SOM) properties during pedogenesis.

Methods

Study area

The study sites are located around Cixi (30° 10′ N, 121° 14′ O), Zhejiang province in the eastern part of PR China. During a joint sampling campaign in June 2008, soil profiles of the following chronosequence were sampled, including paddy sites (a) and non-paddy sites (b): 50 y (a+b), 100 y (a+b), 300 y (a+b), 500 y (a+b), 700 y (a+b), 1000 y (a) and 2000 y (a). The soils are described in more detail by Cheng *et al.* (2009).

Basic soil parameters

Total carbon concentrations (C_{total}) of each soil sample were determined in duplicate by dry combustion at 950°C on a Vario EL elementar analyser (Elementar Analysensysteme, Hanau, Germany). Using the same elemental analyser, total inorganic carbon (TIC) of bulk soil material was analysed after 4 h in a muffle furnace at 550 °C to remove TOC. The TOC concentration was calculated by subtracting the concentration of TIC from the C_{total} (equation 1):

$$C_{total} - TIC = TOC\ (mg/g\ soil) \qquad (1)$$

The bulk density (bd) was calculated by dividing the mass of oven dry soil by the core volume. The organic carbon stock for each horizon of each paddy and non-paddy profile was calculated according to equation 2. For each soil profile, the carbon stocks were added up with soil depth in order to present the stocks as cumulative curves.

$$OC\ stocks\ (kg/m^2) = OC\ (g/kg) * bd\ (kg/dm^3) * depth\ (cm) * 10^{-2} \qquad (2)$$

Particle size fractionation and OC storage capacity of fine mineral fractions

Particle size fractionation was done according to Schöning *et al.* (2005); using a first ultrasonic treatment with an energy input of 60 J/ml to destroy macroaggregates (> 200 µm) and entire dispersion of microaggregates (< 200 µm) was achieved with an additional ultrasonic treatment (440 J/ml). The fraction less then 20 µm was further separated by using sedimentation in an Atterberg cylinder. Weight proportion and OC concentration for each soil fraction was determined. The OC saturation level of the particles < 20µm was calculated and compared with the potential storage capacity to preserve OC by using the formula of Hassink (1997) (equation 3):

$$OC\ in\ fraction < 20\ \mu m = 4.09 + 0.37 * \%\ particles < 20\ \mu m \qquad (3)$$

Results

Depth distribution of TIC, TOC and bulk density as well as organic carbon stocks

The 50 y old paddy site contains carbonates throughout the soil profile. However, top-soils of 100 and 300 y old paddy sites are free of carbonates but there are abrupt higher values below the plough layer. Decalcification of the total soil profiles was observed in 700, 1000 and 2000 y old paddy sites. In contrast, there is nearly no decalcification in non-paddy sites of the total soil profiles. Only the top-soil of the 700 y old non-paddy site is almost free of carbonates. Younger non-paddy sites contain carbonates throughout the soil profiles and show decreasing TIC concentrations with increasing soil age. Conclusively, decalcification requires approximately 700 years in paddy and more than 700 years in non-paddy soils. This result is can be explained by the wetland management. Carbonates were washed out by periodical flooding and drainage of the paddy soils.

Generally, there are higher concentrations of TOC in top-soils of paddy sites compared to non-paddy sites. Within the paddy soil chronosequence, increasing values in top-soils with increasing soil age (except 1000 y old paddy site) were observed. Within the non-paddy sites, there are very low TOC concentrations and slightly increasing values in top-soils with increasing soil age. Differences on TOC accumulation are caused by the paddy soil management and especially by flooding of the fields during rice growth. Under waterlogged conditions, soil OM decomposition and humification (formation of stable humic substances) proceeds at a slower rate than in well-drained, aerated soils.

Bulk densities show low values (between 0.9 and 1.3 g/m^3) in puddled top-soil layers of paddy sites, reflecting the effective soil loosening during puddling. The highest values are measured in the plough pan (1.4 to 1.6 g/m^3). Below the plough pan, slightly decreasing values with soil depth are observed. But there is no differentiation between the age groups. These results confirm a short-term formation of a compacted, permanent plough pan in order to reduce infiltration rates and to increase water use efficiency. The non-paddy sites indicate a more homogeneous distribution of bulk densities (1.3 – 1.5 g/cm^3) and additionally slightly increasing values with soil depth.

Organic carbon stocks of paddy soils

Compared to non-paddy sites, the paddy sites are always characterised by higher OC-stocks in top-soils (Figure 1). While 50 and 100 y old sites indicate relatively similar values, the 300 and 700 y old sites indicate clearly higher OC stocks in paddy compared to non-paddy sites. The 700 y old paddy soil is the site with highest values of OC stocks in sub-soil (except the 300 y old paddy site). The OC stocks of paddy soils increases with increasing soil depth. Apparently OC accumulation with soil depth is more pronounced in paddy compared to non-paddy soils.

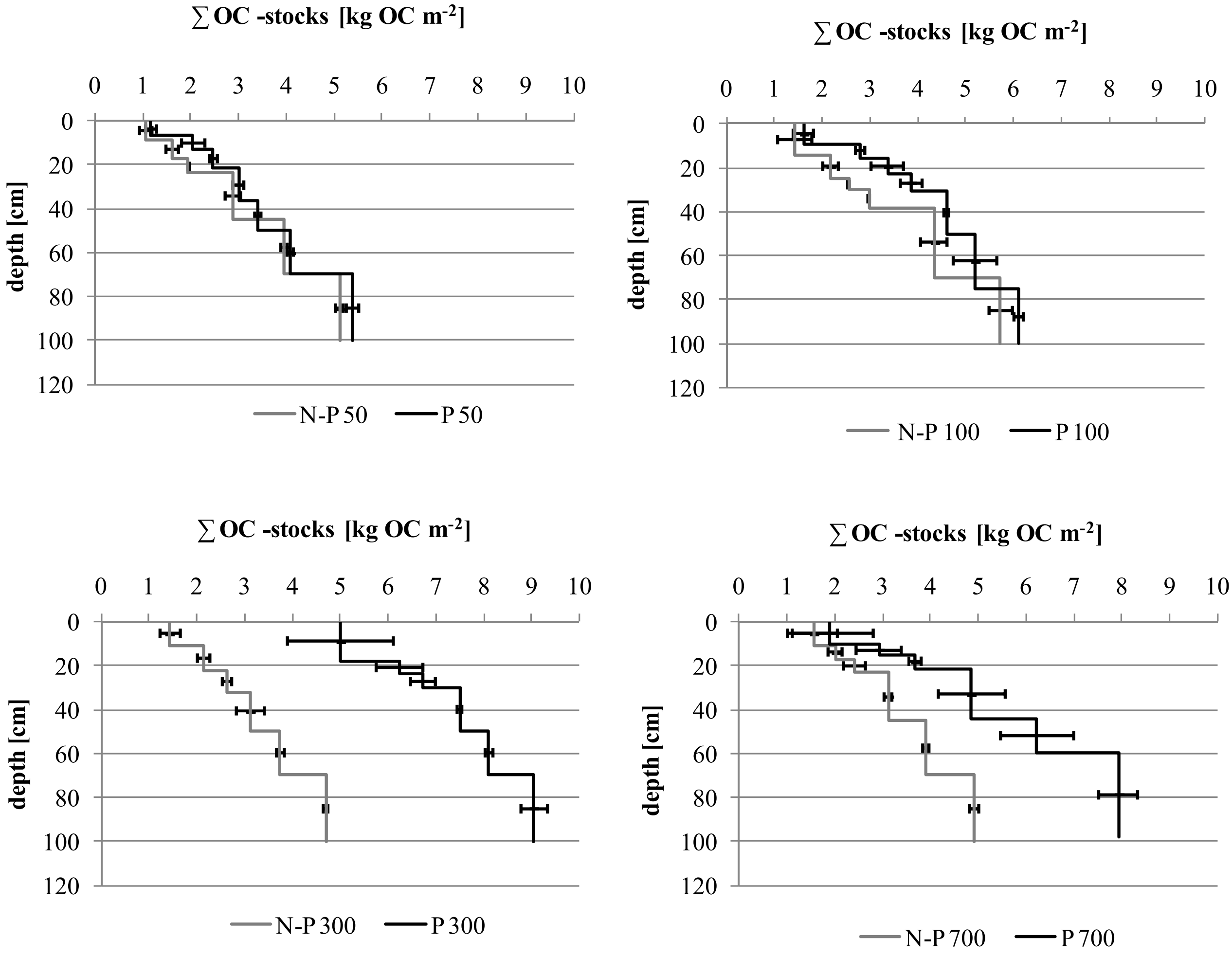

Figure 1. Cumulative OC-stocks of 50, 100, 300 and 700 y old paddy (black) and non-paddy soil profiles (grey). (Error bars show standard deviation of added up OC-stocks of 3 replicates).

Particle size distribution and storage capacity of OC in fine mineral fractions of paddy soils

The distribution of OC in different particle size classes was analysed for A horizons of paddy soils (Table1). The mass proportion of fine fractions (20 µm to < 0.2 µm) is between 70 and 80% of the total bulk soil. The OC concentration of paddy soil ranged from 2.0 in medium silt-sized classes to 55.5 mg/g in clay fractions. The fractions 2 – 0.2 µm and the < 0.2 µm fractions exhibited the highest OC concentrations in almost all age groups.

According to Hassink (1997), the potential capacity of paddy soil fraction to preserve OC is independently from soil age between 30 and 35.5 g OC/(kg soil) (Table 2). However, the calculated saturation level increases with increasing soil age from 10 to 20 g OC/(kg soil). This underlines the importance of fine fractions for increasing OC storage during paddy soil evolution.

Table 1. Particle size distribution after physical fractionation (g/kg) and OC concentrations (mg/g) of fine fractions of 50, 100, 300, 700, 1000 and 2000 y old paddy sites.

Site	Depth	6.3µm – 20µm		2µm – 6.3µm		2µm – 0.2µm		< 0.2µm	
		mass	OC	mass	OC	mass	OC	mass	OC
	(cm)	(g/kg)	(mg/g)	(g/kg)	(mg/g)	(g/kg)	(mg/g)	(g/kg)	(mg/g)
P 50	0-7	422	2.0	113	22.4	185	25.6	82	26.0
P 100	0-9	479	3.6	112	25.3	138	35.6	51	40.1
P 300	0-18	402	4.9	113	37.5	134	47.5	53.6	46.0
P 700	0-10	474	4.7	114	40.4	170	48.2	57	44.5
P 1000	0-9	521	2.2	116	16.0	148	27.6	62	29.1
P 2000	0-15	459	9.8	128	36.3	148	55.5	46.3	55.0

Table 2. Storage capacity of paddy soil fractions to preserve OC.

Site	Depth (cm)	Actual OC saturation (g OC/kg soil)	Potent. capacity to preserve OC Hassink (1997)
P 50	0-7	10.2	33.7
P 100	0-9	11.5	32.9
P 300	0-18	15.1	30.1
P 700	0-10	17.6	34.2
P 1000	0-9	8.9	35.4
P 2000	0-15	19.9	33.0

Conclusions

The faster decalcification of paddy soils compared to non-paddy soils indicates an accelerated soil development under flooding rice cultivation. This comes along with high accumulations of OC concentrations and OC stocks compared to non-paddy soils, as paddy sites indicate higher organic carbon concentrations in top-soils and show also increasing values in top-soils with increasing soil age compared to non-paddy sites. Paddy soils indicate also higher values of organic carbon stocks in top-soil compared to non-paddy sites. In the present study, A horizons are characterised by high proportions of fine mineral fractions (70 to 80% of particles < 20 µm). The calculated OC saturation levels of the fine fractions strongly increase with increasing soil age. This underlines the importance of fine fractions for increasing OC storage during paddy soil evolution. Further investigations will help to clarify how far potential OC storage capacities of fine fractions can be saturated during paddy soil development. Conclusively, paddy soil management leads to an accelerated soil development compared to non-irrigated cropland sites. In addition, increasing OC stocks, especially in the fine mineral associated OM fractions underline the relevance of paddy soil management for OC sequestration.

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