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Fertilization increases paddy soil organic carbon density*

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Abstract: Field experiments provide an opportunity to study the effects of fertilization on soil organic carbon (SOC) sequestration. We sampled soils from a long-term (25 years) paddy experiment in subtropical China. The experiment included eight treatments: (1) check, (2) PK, (3) NP, (4) NK, (5) NPK, (6) 7F:3M (N, P, K inorganic fertilizers+30% organic N), (7) 5F:5M (N, P, K inorganic fertilizers+50% organic N), (8) 3F:7M (N, P, K inorganic fertilizers+70% organic N). Fertilization increased SOC content in the plow layers compared to the non-fertilized check treatment. The SOC density in the top 100 cm of soil ranged from 73.12 to 91.36 Mg/ha. The SOC densities of all fertilizer treatments were greater than that of the check. Those treatments that combined inorganic fertilizers and organic amendments had greater SOC densities than those receiving only inorganic fertilizers. The SOC density was closely correlated to the sum of the soil carbon converted from organic amendments and rice residues. Carbon sequestration in paddy soils could be achieved by balanced and combined fertilization. Fertilization combining both inorganic fertilizers and organic amendments is an effective sustainable practice to sequestrate SOC.

Key words: Soil organic carbon (SOC), SOC density, Long-term fertilization, Paddy soil
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1 Introduction

Recently, much attention has been focused on soil organic carbon (SOC) sequestration because of its possible impact on global climate change (Lal, 2004; Li and Zhang, 2007; Pan *et al*., 2009; Bhattacharyya *et al*., 2010; Li Z.P. *et al*., 2010). Globally, soils are estimated to contain 1 500 to 1 600 Pg carbon (C) in the top 100 cm alone, being more than the sum of C in the plant and atmospheric pools (Jobbágy and Jackson, 2000). In China, rice (*Oryza sativa* L.) cropping is very important, and on average paddy soil contains about 9 Mg/ha more topsoil SOC than upland soil due to its anaerobic condition (Pan *et al*., 2004; 2010).

Fertilization influences SOC content. However, reported evidence is contradictory. Compared to no fertilization, some studies suggested that SOC content increases under inorganic fertilization, especially for inorganic nitrogen (N) fertilizers (Majumder *et al*., 2007; Reid, 2008; Tong *et al*., 2009; Batlle-Bayer *et al*., 2010). López-Bellido *et al*. (2010) and Luo *et al*. (2010) suggested that the SOC content does not change, and others suggested that the SOC content decreases (Manna *et al*., 2006; Khan *et al*., 2007; Li and Zhang, 2007). Inorganic N fertilizers improve the

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crop residues in the soil, and thus improve the SOC. N fertilizers, however, have been shown to promote the decomposition of crop residues and soil C, a process which may offset the possible increase in C from crop residues (Nayak *et al*., 2009). Thus, N fertilization may decrease or not change the SOC. In addition, N fertilizer has a C cost [C:N: about 0.50 to 1.74 (w/w)] for its manufacture, distribution, and application (West and Marland, 2002; Franzluebbers, 2005). Many reports indicate that it would be beneficial to sequestrate SOC through organic amendments, which themselves contain C (Sainju *et al*., 2008). Bhattacharyya *et al*. (2010) observed that the rate of conversion of the applied C to SOC was approximately 19%. However, Cai and Qin (2006) suggested that compost alone had a reverse effect on SOC. The increased incorporation of organic matter could not compensate for the rapid decomposition of the original SOC. An increase or decrease of SOC may be related to its initial value (Bolinder *et al*., 2010). Most studies have shown that combined application of both inorganic fertilizers and organic amendments sequestrates SOC (Zhang S.L. *et al*., 2006; Hao X.H. *et al*., 2008). In this article, "combined" refers to the "combined application of both inorganic fertilizers and organic amendments", except where noted. Combined fertilization is an effective sustainable practice for SOC sequestration (Cai and Qin, 2006; Pan *et al*., 2009; Zhang W.J. *et al*., 2009).

The SOC density is the total C at a certain depth. The total C is the product of the SOC content and the soil weight. The soil weight is the product of soil bulk density and soil volume. In general, a higher SOC content occurs with a lower soil bulk density. For estimating the SOC density of paddy soil, the top 100 cm of soil is generally considered. Paddy SOC density to a depth of 100 cm ranged from 89 to 97 Mg/ha in the Tai Lake region, compared with an average SOC density of 44 Mg/ha in the top 30 cm in China (Pan *et al*., 2004). The SOC density tends to increase as the ratio of inorganic fertilizers to organic amendments decreases (Hao X.Y. *et al*., 2003; Rasool *et al*., 2007; Sainju *et al*., 2008; Pan *et al*., 2009; Bhattacharyya *et al*., 2010). The increase in SOC density values ranged from <0 to >8 Mg/(ha·a), with an average of 0.33 Mg/(ha·a) (Franzluebbers, 2005; West and Six, 2007; López-Bellido *et al*., 2010).

Organic amendments and rice residues (rice stubble and root) are the main C sources converted to soil C in paddy field ecosystems (Li Z.P. *et al*., 2010). Organic amendments are the external C sources and rice residues are the internal C sources. The application of higher organic amendments may induce higher rice yields, and thus higher rice residues (Li Z.Z. *et al*., 2006). Soil C converted from seeds, algae, and rhizodeposition was neglected because their biomass plays a minor role in total C and is difficult to quantify. Annual residues were estimated to be 3690–4105 kg/(ha·a) (Li Z.P. *et al*., 2010). Li Z.P. *et al*. (2010) argued that the SOC sequestration rate was weakly correlated with soil C converted from residues or from organic amendments. In contrast, Pan *et al*. (2006) reported a close relationship between SOC sequestration rate and the sum of soil C converted from rice residues and organic amendments in paddy soil in a long-term experiment.

Inappropriate disposal of organic amendments is a major concern because of contamination of surface water and groundwater through N leaching and phosphorus (P) runoff. These are serious problems in China, especially in relation to pig manure (Li S. *et al*., 2009). In this experiment, green manure and pig manure were used as organic amendments. In recent years, there has been a large increase in the use of inorganic fertilizers with a concomitant decrease in the use of organic amendments, so non-point pollution concerns have been increasing. The co-benefits of enhancing C storage in soil include enhanced wildlife habitats, reduced erosion, and concomitant loss of nutrients such as N and P that otherwise may contribute to the eutrophication of rivers and other bodies of water (Feng *et al*., 2007).

Most studies have focused on the top 30 cm or less of soil. We sampled the soil profile to 100 cm. In light of SOC sequestration, the environmental concerns about fertilization, and some contradictory results, SOC was examined in field experiments. Our objectives were: (1) to study the effects of fertilization on SOC sequestration, and (2) to recommend appropriate fertilization treatments to effectively sequestrate C and minimize unintended environmental consequences in the paddy wetland ecosystem.

2 Materials and methods

2.1 Site description

The field experimental site was located in Nanchang County (115°56′ E, 28°34′ N), Jiangxi Province, China. The climate there is subtropical. In this area, the annual mean temperature is 18.4 °C and annual mean precipitation is 1632 mm.

The paddy field experiment started in 1984 and has continued for 27 years. The cropping system was of a rice-rice-fallow pattern. The early rice was transplanted in April and harvested in July. The late rice was transplanted in July and harvested in October. The fallow season was from October to April of the following year. Each year from 1984 to 1993, tillage was conducted in the plow layer during the fallow period after the harvest of late rice. Before tillage, soil samples of the plow layer were collected and analyzed. Since 1994, tillage has not been conducted after the late rice harvest. Soil samples of the plow layer were collected and analyzed once every five years. Some related data have been published (Li Z.Z. *et al.*, 2006; Bi *et al.*, 2009).

The experimental field has been used continuously for rice cropping for more than 700 years (Li Z.Z. *et al.*, 2006). The soil was classified as Stagnic Anthrosols (IUSS Working Group WRB, 2006). It has a hydragic paddy soil system (i.e., loam clay, mixed, quaternary sub-red soil parent material). Initial samples of the plow layer (0–20 cm), collected in February 1984, had the following characteristics: pH, 6.5; SOC, 14.8 g/kg; total N, 1.36 g/kg; alkali hydrolyzable N, 172.3 mg/kg; total P, 0.49 g/kg; available P, 20.8 mg/kg; available K, 35.0 mg/kg; and cation exchange capacity (CEC), 7.54 cmol/kg (Li Z.Z. *et al.*, 2006).

2.2 Fertilization treatments and management

Three parallel rows were constructed for 24 plots (each measuring 33.3 m^2). Barriers, 50 cm wide at the base and 25 cm high, were constructed with concrete. Non-experimental guard plots were established to reduce edge effects. The experiment included eight treatments arranged in a randomized complete block design with three replications. The eight treatments maintained were as follows: (1) check (CK); (2) PK; (3) NP; (4) NK; (5) NPK; (6) 7F:3M, N, P and potassium (K) inorganic fertilizers and partial substitution of inorganic N by organic N at a rate of 30%; (7) 5F:5M, N, P and K inorganic fertilizers and partial substitution of inorganic N by organic N at a rate of 50%; (8) 3F:7M, N, P and K inorganic fertilizers and partial substitution of inorganic N by organic N at a rate of 70% (Table 1). Urea, calcium superphosphate,

Table 1 Treatments and annual N, P, and K fertilizers applied

Treatment	Fertilizer (kg/ha)						
	Crop	CF-N	GM-N/PM-N	CF-P_2O_5	GM-P_2O_5/PM-P_2O_5	CF-K_2O	GM-K_2O/PM-K_2O
CK	Early rice	0	0	0.0	0.0	0.0	0.0
	Late rice	0	0	0.0	0.0	0.0	0.0
PK	Early rice	0	0	60.0	0.0	150.0	0.0
	Late rice	0	0	60.0	0.0	150.0	0.0
NP	Early rice	150	0	60.0	0.0	0.0	0.0
	Late rice	180	0	60.0	0.0	0.0	0.0
NK	Early rice	150	0	0.0	0.0	150.0	0.0
	Late rice	180	0	0.0	0.0	150.0	0.0
NPK	Early rice	150	0	60.0	0.0	150.0	0.0
	Late rice	180	0	60.0	0.0	150.0	0.0
7F:3M	Early rice	105	45	49.1	10.9	118.7	31.3
	Late rice	126	54	37.2	22.8	78.0	72.0
5F:5M	Early rice	75	75	41.8	18.2	97.4	52.6
	Late rice	90	90	22.0	38.0	29.9	120.1
3F:7M	Early rice	45	105	34.6	25.4	76.8	73.2
	Late rice	54	126	6.8	53.2	0.0	168.0

CF: chemical fertilizers; Urea, calcium superphosphate, and potassium chloride were used as chemical N, P, and K fertilizers, respectively. GM: green manure (*Astragalus*); For the early rice season, green manure contained N 33.0 g/kg, P_2O_5 8.0 g/kg, and K_2O 22.9 g/kg in dry weight. PM: pig manure; For the late rice season, pig manure contained N 15.0 g/kg, P_2O_5 6.3 g/kg, and K_2O 20.0 g/kg in dry weight and potassium chloride were used as chemical N, P, and K fertilizers, respectively. Urea was applied in three split doses (the basal fertilizer/first topdressing/ second topdressing ratio was 3:1:1). Potassium chloride was topdressed twice at a first topdressing/ second topdressing ratio of 1:1. Calcium superphosphate and organic amendments were applied as basal fertilizers. Green manure was used for the early rice season and pig manure was used for the late rice season as organic amendments. The green manure was *Astragalus* brought from outside of the experimental plots. For dry weight, green manure was applied annually at a rate of 0, 0, 0, 0, 0, 1.36, 2.27, and 3.18 Mg/ha, and pig manure at 0, 0, 0, 0, 0, 3.60, 6.01, and 8.40 Mg/ha for CK, PK, NP, NK, NPK, 7F:3M, 5F:5M, and 3F:7M, respectively (Li Z.Z. *et al.*, 2006; Bi *et al.*, 2009).

Rice hill spacing was 20 cm×20 cm. The rice cultivars selected were the local dominant cultivars. Field practices, such as field preparation, tillage, puddling, irrigation, and weed control, were carried out according to the local farming practices. Before the stage of rice grain maturity, the level of irrigation water was maintained at 5–8 cm above the ground.

2.3 Soil sampling and analysis

In 2008, after the harvest of early rice (in July) and of late rice (in October), seven soil samples in each plot were collected with a hand probe from the plow layers (from 0 to 5 cm and from 5 to 20 cm). The soil samples from each plot were mixed to produce a composite sample. In February 2009, in each plot, seven 3 cm-diameter soil cores were taken from the following depth intervals: 0–5, 5–20, 20–40, 40–70, and 70–100 cm. The first three soil core samples were used to determine bulk density by dividing the constant mass of the oven-dried sample at 105 °C by the volume of the probe, as described by Sainju *et al.* (2008) and Bhattacharyya *et al.* (2010). The other four soil core samples were mixed to produce a composite sample which was used to determine the SOC content. After all the visible residues were picked out, soil samples were air-dried and then passed through a 0.15-mm sieve to determine the SOC content. The SOC content was determined using the wet oxidation method with $K_2Cr_2O_7$ and concentrated H_2SO_4 (Sparks *et al.*, 1996). As fertilization and soil C change are closely related to the sampling depth, the plow layer was divided into two layers: a 0–5 cm layer for the surface layer, and a 5–20 cm layer for the subsurface layer.

2.4 Data analysis

The SOC density of the whole profile (100 cm) was estimated as the sum of the SOC densities of the 0–5, 5–20, 20–40, 40–70, and 70–100 cm layers.

Soil C converted from organic amendments was estimated using Eq. (1):

$$T_m=Q_{gm}\times C_{gm}\times H_{gm}\times 25+Q_{pm}\times C_{pm}\times H_{pm}\times 25, \quad (1)$$

where T_m is the total C converted from organic amendments (Mg/ha), Q_{gm} is the rate of green manure and Q_{pm} the rate of pig manure [Mg/(ha·a)], C_{gm} is the C content in green manure (300 g/kg) and C_{pm} the C content in pig manure (370 g/kg), H_{gm} is the humification coefficient (0.20) for green manure and H_{pm} the humification coefficient (0.25) for pig manure (He and Ni, 1996; Pan *et al.*, 2006), and 25 is the number of experimental years from 1984 to 2009.

Soil C converted from rice residues was estimated using Eq. (2):

$$C_c=Y_r\times C_r\times H_r, \quad (2)$$

where C_c is C converted from rice residues (Mg/ha), Y_r is the total rice yield (Mg/ha) for 25 years (from 1984 to 2009), C_r is the C coefficient (0.3) of rice residues of the rice grain yield (He and Ni, 1996), and H_r is the humification coefficient (0.4) (Pan *et al.*, 2006).

Data were analyzed using EXCEL and SPSS 15 for Windows. One-way analysis of variance (ANOVA) was conducted to analyze the differences between treatment means. Statistical differences among individual treatments were determined using Duncan's least significant difference (LSD) test at the probability level of 0.05 or 0.01. Linear regression analyses of the dependent variables (SOC density) against the independent variables (soil C converted from organic amendments or from rice residues) were performed.

3 Results and discussion

3.1 SOC content in the plow layers

Fertilization increased SOC content in the plow layers (0–5 and 5–20 cm) after the harvest of early rice and of late rice in 2008 compared to the CK (no fertilization) (Fig. 1). The effect of treatments with combined fertilizers was greater than that of those with only inorganic fertilizers. There was no significant difference in SOC content between treatments with only inorganic fertilizers and the CK, except for PK in the 0–5 cm layer and NP and NPK in the 5–20 cm layer. The SOC content in combined treatments (7F:3M, 5F:5M, and 3F:7M) was significantly higher than that of the CK.

Fertilization improves crop residues in the soil, and thus improves the SOC (Li Z.Z. *et al.*, 2006; Bi *et al.*, 2009). However, N fertilizer promotes the decomposition of crop residues and soil C, so treatments with N inorganic fertilizers improved SOC content less than other fertilizer treatments. Combined treatments significantly increased the SOC content compared to the CK because the organic amendments themselves contained C (Zhang W.J. *et al.*, 2009; Bhattacharyya *et al.*, 2010). The SOC content of the 0–5 cm layer was higher than that of the 5–20 cm layer, which was consistent with other studies (Pan *et al.*, 2006).

3.2 SOC in the 0–100 cm profiles

3.2.1 SOC content

Fertilization affected the SOC content of the plow layers in February 2009 (Table 2). The change trend was similar to the results after the harvest of early rice and of late rice in 2008. The highest SOC content was found in winter (February 2009), followed by autumn (October 2008), and the lowest in summer (July 2008). The rates of SOC mineralization and accumulation are closely related to temperature (Tsuji *et al.*, 2006). Compared to the CK and treatments with imbalanced inorganic fertilizers (PK, NP,

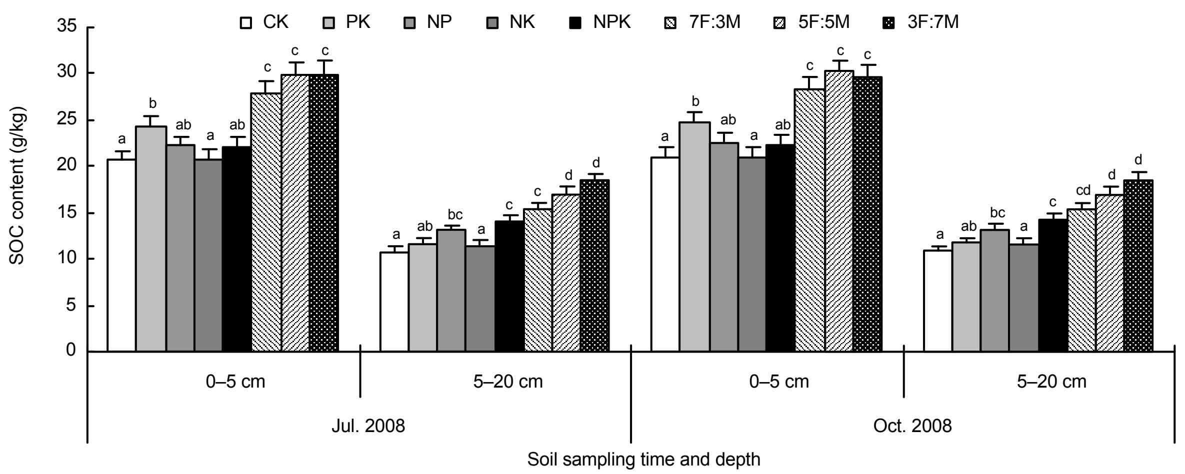

Fig. 1 SOC content after the harvest of early rice (in July) and of late rice (in October) in 2008
Values with the same letters do not differ significantly (*P*>0.05, Duncan's LSD test) between treatments at the same depth and the same sampling time

Table 2 SOC contents in the 0–100 cm profiles in February 2009

Depth (cm)	SOC content (g/kg)							
	CK	PK	NP	NK	NPK	7F:3M	5F:5M	3F:7M
0–5	21.50a	25.06b	23.05ab	21.52a	22.78ab	28.77c	30.74c	30.00c
5–20	11.01a	11.95ab	13.31bc	11.82a	14.49c	15.54c	17.18d	18.77d
20–40	5.63a	5.81a	5.62a	5.41a	6.66b	6.55b	6.53b	6.69b
40–70	2.58b	2.71b	2.44ab	2.37a	2.37a	2.23a	2.24a	2.44ab
70–100	2.16a	1.96a	2.44b	2.17a	2.17a	1.82a	2.72b	2.51b

Values with the same letters do not differ significantly (*P*>0.05, Duncan's LSD test) between treatments at the same depth and NK), combined treatments (7F:3M, 5F:5M, and 3F:7M) and treatment with balanced inorganic fertilizers (NPK) significantly increased the SOC content in the 20–40 cm layer (Table 2). In the 40–70 and 70–100 cm layers, there was no significant difference in SOC content between treatments, suggesting that fertilization did not influence SOC content in the 40–100 cm layer. The SOC content decreased with increasing soil depth.

3.2.2 SOC density

Fertilization also affected soil bulk density in the plow layers in February 2009 (Table 3). The correlation coefficient (r) between soil bulk density and SOC content was −0.926, reaching the 0.01 probability level ($r_{0.01,\,38}$=0.393).

At each depth, SOC density was determined from the SOC content and the soil bulk density. In February 2009, the SOC density in the top 100 cm varied from 73.12 Mg/ha in the CK to 91.36 Mg/ha in the 3F:7M treatment (Fig. 2). This was close to the result of Pan *et al.* (2006), who found 89 to 97 Mg/ha in the top 100 cm of paddy soil. The SOC densities of all the fertilizer treatments were greater than that of the CK. Those treatments that combined inorganic fertilizers and organic amendments had greater SOC densities compared to those receiving only inorganic fertilizers. This was consistent with the results of other studies (Hao X.Y. *et al.*, 2003; Rasool *et al.*, 2007; Sainju *et al.*, 2008; Pan *et al.*, 2009; Bhattacharyya *et al.*, 2010).

Between 1984 and 2009, as the 24 plots were under the same conditions except for fertilization, fertilization effects on SOC density were evaluated by comparison to the CK. Compared to the CK, SOC sequestration was 5.85, 8.18, −0.32, 11.68, 13.01, 16.24, and 18.24 Mg/ha, with average SOC sequestration rates of 0.23, 0.33, −0.01, 0.47, 0.52, 0.65, and 0.73 Mg/(ha·a) in the PK, NP, NK, NPK, 7F:3M, 5F:5M, and 3F:7M treatments, respectively. This was

Table 3 Soil bulk densities of different layers (0–100 cm) in February 2009

Depth (cm)	Soil bulk density (Mg/m^3)							
	CK	PK	NP	NK	NPK	7F:3M	5F:5M	3F:7M
0–5	0.89b	0.96c	1.01c	0.88b	1.01c	0.97c	0.73a	0.78a
5–20	1.40b	1.41b	1.37b	1.38b	1.40b	1.31ab	1.25a	1.26a
20–40	1.63a	1.70a	1.69a	1.65a	1.65a	1.69a	1.65a	1.62a
40–70	1.49a	1.50a	1.50a	1.52a	1.46a	1.54a	1.48a	1.52a
70–100	1.62a	1.65a	1.68a	1.57a	1.61a	1.69a	1.76a	1.51a

Values with the same letters do not differ significantly (P>0.05, Duncan's LSD test) between treatments at the same depth

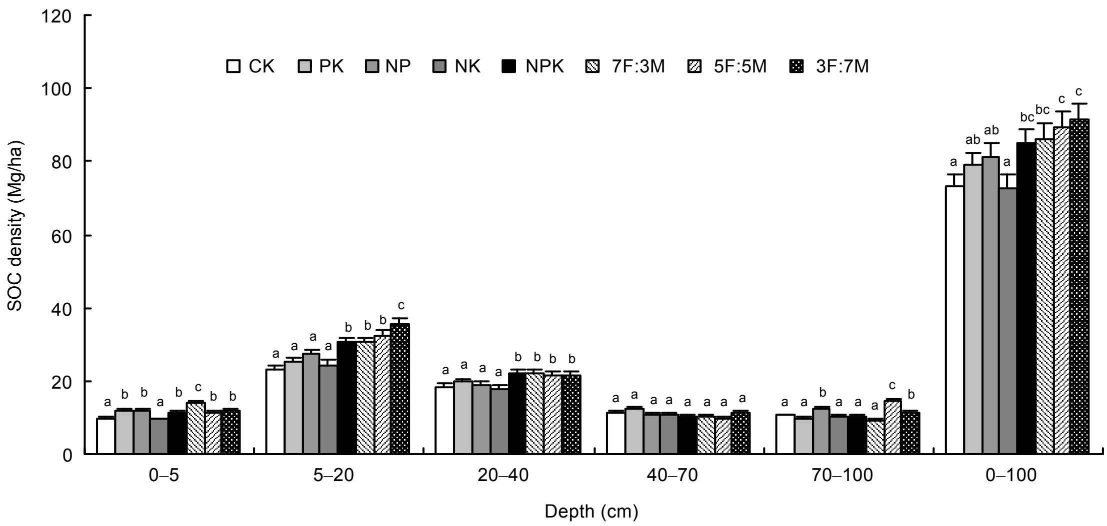

Fig. 2 SOC density in the 0–100 cm profiles in February 2009

SOC density values with the same letters do not differ significantly (P>0.05, Duncan's LSD test) between treatments at the same depth within the range of increase of from <0 to >8 Mg/(ha·a), with an average of 0.33 Mg/(ha·a) found in other studies (Franzluebbers, 2005; West and Six, 2007; López-Bellido *et al.*, 2010).

3.3 Correlation between SOC density and soil C converted

Organic amendments and rice residues were the main sources of soil C converted in this experimental field (Li Z.Z. *et al.*, 2006). For the CK, PK, NP, NK, and NPK treatments, without organic amendments applied, the soil C converted from the external C sources from organic amendments in these treatments was 0. Therefore, the soil C converted from organic amendments for 25 years (from 1984 to 2009) was 0, 0, 0, 0, 0, 10.40, 17.30, and 24.20 Mg/ha in CK, PK, NP, NK, NPK, 7F:3M, 5F:5M, and 3F:7M treatments, respectively.

The amount of soil C converted from the rice residues was related to the rice grain yield. Total rice grain yield for the 25-year period was 172.5, 197.5, 267.5, 230.0, 282.5, 300.0, 292.5, and 300.0 Mg/ha in the CK, PK, NP, NK, NPK, 7F:3M, 5F:5M, and 3F:7M treatments, respectively. The total soil C converted from the internal C sources from rice residues for the period was estimated to be 20.70, 23.73, 27.75, 31.95, 33.95, 36.08, 35.00, and 36.15 Mg/ha in the CK, PK, NP, NK, NPK, 7F:3M, 5F:5M, and 3F:7M treatments, respectively. The sum of soil C converted from organic amendments and rice residues for the period was estimated to be 20.70, 23.73, 27.75, 31.95, 33.95, 46.48, 52.30, and 60.35 Mg/ha in the CK, PK, NP, NK, NPK, 7F:3M, 5F:5M, and 3F:7M treatments, respectively. Apparently, soil C converted from rice residues was greater than that from organic amendments. The significance of fertilization to increasing SOC density was that it could increase rice biomass yield and, as a result, increase the rice residues and SOC density. Similarly, treatments with organic amendments also increased rice yield and rice residues. Consequently, soil C converted from the rice residues and the sum of soil C converted in treatments with organic amendments were much greater than those in treatments without organic amendments. Therefore, the SOC density in the whole profile was significantly greater in treatments with organic amendments than in those without organic amendments (Fig. 2).

In February 2009, the SOC density in the whole profile was significantly correlated with the amount of soil C converted, reaching the 0.05 probability level ($r_{0.05,\ 6}$=0.707) for the soil C converted from organic amendments and for the soil C converted from rice residues, and reaching the 0.01 probability level ($r_{0.01,\ 6}$=0.834) for the sum of soil C converted (Table 4). In the 0–5 cm layer, the SOC density was not related to the amount of soil C converted (Table 4), possibly because the soil surface is the vital interface that changes rapidly (Franzluebbers, 2002; Li Z.P. *et al.*, 2010). In the 5–20 cm layer, the SOC density was markedly related to soil C converted, reaching the 0.05 probability level for the soil C converted from rice residues, and reaching the 0.01 probability level for the soil C converted from organic amendments and the sum of soil C converted (Table 4). The SOC of the 5–20 cm layer in the NK treatment was higher than that in the CK. This may be related to the amount of soil C converted from rice residues. In the 20–40 cm layer, the SOC density was markedly related to the amount of soil C converted, reaching the 0.05 probability level for the soil C converted from rice residues, and the 0.01 probability level for the soil C converted from organic amendments and the sum of soil C converted (Table 4). No significant correlation between SOC density and soil C converted was observed in the 40–100 cm layer.

Table 4 Regression equations of SOC density and soil C converted from organic amendments or rice residues in February 2009

Depth (cm)	Regression equation		
	Soil C converted from organic amendments	Soil C converted from rice residues	Sum of soil C converted from organic amendments and rice residues
0–5	–, R^2=0.110	–, R^2=0.187	–, R^2=0.163
5–20	y=0.379x+26.152, R^2=0.741	y=0.592x+10.458, R^2=0.679	y=0.276x+18.364, R^2=0.855
20–40	y=0.114x+19.549, R^2=0.507	y=0.213x+13.777, R^2=0.518	y=0.089x+16.987, R^2=0.526
0–100	y=0.586x+78.428, R^2=0.665	y=0.871x+55.550, R^2=0.550	y=0.419x+66.670, R^2=0.740

Number of samples: n=8. y: SOC density (Mg/ha) at different depths; x: soil C converted (Mg/ha) during 25 years; R: correlation coefficient between SOC density and soil C converted. The regression equation presented in "–" was not valid because the correlation coefficient was less than 0.707 ($r_{0.05,\ 6}$=0.707)

4 Conclusions

The results suggest that fertilization affected the SOC content in the plow layers. Fertilization, especially with combined inorganic fertilizers and organic amendments, increased the SOC density compared to the CK. The SOC density at 100 cm varied from 73.12 Mg/ha in the CK to 91.36 Mg/ha in the 3F:7M treatment. The SOC density was correlated with the sum of soil C converted from organic amendments and rice residues. Treatments combining inorganic fertilizers and organic amendments gave greater SOC densities compared to those with inorganic fertilizers alone. Organic amendments applied in paddy wetland ecosystems could partially substitute for inorganic fertilizers to turn non-point pollution sources into nutrients and to save resources to minimize unintended environmental consequences. Combined fertilization with inorganic fertilizers and organic amendments is an effective sustainable practice to sequestrate SOC and to improve soil fertility and quality.

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