Soil & Tillage Research 163 (2016) 64–70

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Changes in soil organic carbon fractions under integrated management systems in a low-productivity paddy soil given different organic amendments and chemical fertilizers

Wenhai Mi[a,b], Lianghuan Wu[a,b,*], Philip C. Brookes[c], Yanling Liu[a,b], Xuan Zhang[a,b], Xin Yang[a,b]

[a] Ministry of Education Key Laboratory of Environmental Remediation and Ecosystem Health, College of Environmental and Resource Sciences, Zhejiang University, Hangzhou 310058, China
[b] Zhejiang Provincial Key Laboratory of Subtropical Soil and Plant Nutrition, College of Environmental and Resource Sciences, Zhejiang University, Hangzhou 310058, China
[c] Institute of Soil & Water Resource and Environmental Sciences, College of Environmental and Resource Sciences, Zhejiang University, Hangzhou 310058, China

ARTICLE INFO

Article history:
Received 30 October 2015
Received in revised form 12 May 2016
Accepted 12 May 2016
Available online 28 May 2016

Keywords:
Organic amendments
Labile organic carbon
Carbon management index
Low-productivity paddy soil

ABSTRACT

Labile soil organic carbon fractions are important indicators of soil C dynamics, which is affected by different management practices. However, few studies have reported the short-term effect of a wide range of organic materials mulching on the distribution of soil total organic C (TOC) and its labile C pools in a low-productivity paddy soil. Our objective was quantify TOC and labile organic C fractions down a 0–30 cm soil profile in a 4-year field experiment receiving four organic amendments (spent mushroom compost, green manure, cattle manure and rice straw residues). Soil samples were taken from the 0–5 cm, 5–10 cm, 10–20 cm and 20–30 cm soil depths. Soil total organic carbon (TOC), total nitrogen (TN), microbial biomass C (MBC), particulate organic C (POC), potassium permanganate-oxidizable C ($KMnO_4$-C) and dissolved organic C (DOC) were measured. Carbon management index (CMI) was also calculated. Among the four organic amendments, cattle manure showed the most profound effect on TOC, TN and labile organic C fractions and produced the highest 4-year average rice grain yield (9.67 t ha^{-1}). The cattle manure combined with NPK resulted in the highest level of TOC (19.2 g kg^{-1}) and TN (1.86 g kg^{-1}) in the surface soil (0–5 cm). Additionally, $KMnO_4$-C and MBC concentrations in the cattle manure plus NPK treatment were 1.3 and 1.5 times higher at the 0–5 cm depth, 1.4 and 1.6 times higher at the 5–10 cm depth, 1.2 and 1.4 times higher at the 10–20 cm depth compared to NPK fertilizer alone, respectively. However, POC was not sensitive to different management practices in the deeper soil layer (10–20 cm). DOC was not significantly affected by fertilization in the 0–20 cm soil layer, suggesting it was unsuitable as an early indicator of soil quality. Overall, the integrated use of cattle manure and NPK fertilizers is the most efficient management practice in improving carbon sequestering under current soil conditions. A long-term assessment is needed to confirm the most effective and sustainable management practice for improving rice grain yield and soil quality.

1. Introduction

Soil organic C is a key factor in soil quality assessment due to its important role in modifying soil physical, chemical and biological properties. High levels of soil total organic C (TOC) have beneficial effects on crop productivity (Rasmussen and Parton, 1994; Pan et al., 2003; Yang et al., 2012). Hence, TOC dynamics monitoring in agricultural soils is very important. However, short-term changes in TOC are difficult to measure against the large background of relatively stable organic C in soil (Haynes, 2005). Labile organic C is another fraction of TOC. It generally includes dissolved organic C (DOC), microbial biomass C (MBC), particulate organic C (POC) and potassium permanganate-oxidizable C ($KMnO_4$-C) (Haynes, 2005). This labile organic C fraction represents a small proportion of TOC, and is characterized by rapid turnover times and responds more

* Corresponding author at: Ministry of Education Key Laboratory of Environmental Remediation and Ecosystem Health, College of Environmental and Resource Sciences, Zhejiang University, Hangzhou 310058, China.
E-mail address: finm@zju.edu.cn (L. Wu).

http://dx.doi.org/10.1016/j.still.2016.05.009
0167-1987/

quickly to changes than TOC (Blair et al., 1995; Needelman et al., 1999). Hence, these fractions have been used as early indicators of changes in soil organic C. The carbon management index (CMI) combining labile and non-labile C fractions, originally proposed by Blair et al. (1995), is a discerning tool for assessing soil quality in response to soil management practices.

Numerous studies have examined the long-term effects of residue managements and fertilization on TOC and labile organic C fractions. Yan et al. (2007) reported 25-year application of manure increased the TOC, MBC and POC contents in the 0–15 cm soil depth. Yang et al. (2012) found that 20-year application of NPK with straw resulted in no marked improvement on the TOC and POC, but significantly increasing MBC contents in the 0–20 cm as compared to the NPK treatments. However, many researchers concentrated on the effect of only one or two kinds of organic manures on the soil organic carbon fractions. Little attention has been paid to the short-term effects of a wide range of organic manures mulch on the distribution of TOC and labile organic C fractions.

Yellow clayey paddy soil is a typical low-yielding soil in southern China and covers about 1.3 million ha (Liu et al., 2014). Its poor soil quality limits rice production and decreases local food supply. In order to both increase crop yield and soil quality in such soils, sustainable agricultural practices should be developed.

In this study, a 4-year field experiment with various fertilization treatments was conducted in a low-productivity paddy soil. We aimed (1) to investigate the distribution of TOC and labile organic C in the four depths (0–5 cm, 5–10 cm, 10–20 cm and 20–30 cm) under mulching four different organic manures including spent mushroom compost, green manure, cattle manure and rice straw; (2) to evaluate soil quality using the Carbon Management Index (CMI); (3) to derive an effective fertilization model in a low-productivity paddy soil.

2. Materials and methods

2.1. Climate and experimental site

The experiment was located in Langya town (29°1′N, 119°27′E), Zhejiang province, China. The climate is typical subtropical monsoon with mean annual precipitation of 1424 mm and a mean temperature of 17.5 °C. The soil of the experiment is a yellow clayey paddy soil. Initially, the soil in the plow layer (0–20 cm) contained 15.3 g kg^{-1} soil organic carbon, 1.53 g kg^{-1} total nitrogen, 108.5 mg kg^{-1} available nitrogen, 17 mg kg^{-1} Bray-P, 97 mg kg^{-1} NH_4OAc-exchangeable K and the soil pH was 5.14.

2.2. Experiment details

The experiment began in 2011 with a single cropping rice system. Rice (cultivar Liangyoupeijiu) was transplanted on June 20th in 2011–2012, June 18th in 2013 and June 15th in 2014 at hill spacings of 19.8 cm × 19.8 cm with two seedlings per hill. The corresponding harvest dates were October 10th in 2011–2012, October 1st in 2013 and October 7th in 2014. The fields remained fallow between harvest and planting.

Six treatments were applied: (1) no fertilizer (CK), (2) inorganic fertilizer (F), (3) F plus spent mushroom compost (FR), (4) F plus fresh green manure (FG), (5) F plus fresh cattle manure (FM), (6) F plus straw residue (FS). Each treatment was replicated three times using a randomized block design with 50 m^2 (5 m × 10 m) plots. The N fertilizer was prilled urea at 180 kg ha^{-1} $year^{-1}$, P as calcium superphosphate at 90 kg ha^{-1} $year^{-1}$, K as potassium chloride at 120 kg ha^{-1} $year^{-1}$. The P and K fertilizers were broadcast before transplanting. Urea was used as a split-application at three development stages: 40% as basal, 30% at tillering stage and 30% at booting stage. Treatments (2)–(6) used the same rates of chemical fertilizer. In order to increase soil fertility, treatments (3)–(6) also used different organic manures every year.

The soil was ploughed to 15 cm depth. Then all organic materials were applied to the soil surface, one day before rice transplanting. The fresh green manure and rice straw were applied as intact plants. Rice straw from all treatments was removed at harvest. The mean annual application rates of organic materials and total C are shown in Table 1.

2.3. Soil sampling and analytical methods

Soil samples at four different depths (0–5 cm, 5–10 cm, 10–20 cm, 20–30 cm) were collected by randomly taking six cores on October 10th, 2014 (after rice harvest) from each plot. The six soil cores were bulked to form a composite soil sample. One portion was sieved moist (<2 mm) then kept at 4 °C for dissolved organic C and microbial C analysis. The other portion was air-dried and kept at room temperature.

Total organic C was determined by oxidation with potassium dichromate (Walkley and Black, 1934) and soil total nitrogen with a Kjeldahl auto-analyser. Microbial biomass C was measured by fumigation-extraction (Vance et al., 1987; Wu et al., 1990).

Dissolved organic C was determined as described by Jones and Willett (2006). The moist soil (equivalent to 10 g oven-dried soil) was extracted with 50 ml 0.5 mol L^{-1} K_2SO_4 for 1 h. The extracts were filtered through a 0.45-μm membrane filter and analyzed for dissolved organic C using a Multi 3100 N/C TOC analyzer (Analytik Jena, Germany). Particulate organic C was determined with modifications of the method described by Cambardella and Elliott (1992). Twenty g of air-dried soil was dispersed in 100 ml of sodium hexametaphosphate (5 g L^{-1}) with shaking on a reciprocating shaker (100 r min^{-1}) for 18 h. The soil suspension was passed through a 53-μm sieve using a flow of distilled water to ensure particle separation. All materials remaining on the sieve were washed into a dry dish and then dried at 60 °C for 48 h, weighed, and ground to measure the C content. Potassium permanganate-oxidizable C ($KMnO_4$-C) was measured as described by Blair et al. (1995). Soil samples containing approximately 15 mg C were oxidized with 25 ml 333 mM $KMnO_4$ after shaking for 1 h. After shaking, the tubes were centrifuged for 5 min. Then the supernatant was diluted 1:500 with deionized water. The absorbance of diluted supernatants and standards were read at 565 nm. The change of $KMnO_4$ concentration was used to estimate the amount of C oxidized, assuming that 1 mM $KMnO_4$ is consumed in the oxidation of 0.75 mM or 9 mg of C.

Table 1
Average annual application rates of different organic materials.

Organic amendments	Amount based on oven-dried weight (kg ha^{-1})	C (kg ha^{-1})	N (kg ha^{-1})	C/N Ratio
Spent mushroom compost	1500	742	15	48
Green manure	3600	1372	60	23
Cattle manure	4725	1364	98	14
Straw residue	3000	1313	26	52