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REGULAR ARTICLE

Integrated management systems and N fertilization: effect on soil organic matter in rice-rapeseed rotation

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Abstract
Aims Understanding the effects of long-term crop management on soil organic matter (SOM) is necessary to improve the soil quality and sustainability of agroecosystems.
Method The present 7-year long-term field experiment was conducted to evaluate the effect of integrated management systems and N fertilization on SOM fractions and carbon management index (CMI). Two integrated soil-crop system management (ISSM-1 and ISSM-2, combined with improved cultivation pattern, water management and no-tillage) were compared with a traditional farming system at three nitrogen (N) fertilization rates (0, 150 and 225 kg N ha^{-1}).
Results Management systems had greater effects on SOM and its fractions than did N fertilization. Compared with traditional farming practice, the integrated management systems increased soil organic carbon (SOC) by 13 % and total nitrogen (TN) by 10 % (averaged over N levels) after 7 years. Integrated management systems were more effective in increasing labile SOM fractions and CMI as compared to traditional farming practice. SOC, TN and dissolved organic matter in nitrogen increased with N fertilization rates. Nonetheless, N addition decreased other labile fractions: particulate organic matter, dissolved organic matter in carbon, microbial biomass nitrogen and potassium permanganate-oxidizable carbon.
Conclusions We conclude that integrated management systems increased total SOM, labile fractions and CMI, effectively improved soil quality in rice-rapeseed rotations. Appropriate N fertilization (N150) resulted in higher SOC and TN. Though N application increased dissolved organic matter in nitrogen, it was prone to decrease most of the other labile SOM fractions, especially under higher N rate (N250), implying the decline of SOM quality.

Keywords Soil organic matter · Labile fractions · Integrated soil-crop system management (ISSM) · N fertilization · Carbon management index (CMI)

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Introduction

Rice-upland rotations are one of the most important agricultural production systems for food security of south Asian countries and China (Yadav et al. 2000).

In China, such rotations formerly occupied a total area of about 13 million ha; they contributed 72 % of the total cereal production and 56 % of the total national calorie intake (Timsina and Connor 2001). Since the 1990s, however, the yields of rice-upland rotations showed a widespread declining or stagnating trend (Yadav et al. 2000; Timsina and Connor 2001). Moreover, the sustainability of these rotations is threatened by lower nitrogen (N) use efficiencies (Bijay-Singh et al. 2001) and shortage of irrigation water (Bouman and Toung 2001). Therefore, numerous techniques including integrated nutrient management (e.g. fertilizer, manure, residue), water conservation (e.g. non-flooded mulching, alternate drying and wetting irrigation) and novel cultivation technologies (e.g. triangular pattern cultivation) have been developed and introduced in rice-upland systems. This has been accompanied by documenting the positive effects of these managements on crop productivity, N and water use efficiency (Fan et al. 2005, 2009; Yang and Zhang 2010; Nayak et al. 2012; Bhattacharyya et al. 2012; Benbi et al. 2012).

Soil organic matter (SOM) is considered to be a key attribute of soil quality and fertility (Gregorich et al. 1994). Beyond increased C sequestration in agricultural soils has the potential to mitigate the increasing atmospheric CO_2 concentration (Lal 2004). A unique feature of rice-upland rotations is the annual conversion of soil from anaerobic to aerobic and then back to anaerobic. This creates particular difficulties for SOM conservation in rice-upland rotations. Aerobic condition in upland season is favor for SOM decomposition leading to higher CO_2 flux to the atmosphere. For example, conversion double rice to rice-maize systems caused a reduction of soil C sequestration due to 33–41 % increase in the estimated amount of mineralized C during maize season (Witt et al. 2000). It was speculated that one of the major reasons for the stagnation in yield is the decline of SOM in rice-upland rotations (Yadav et al. 2000; Timsina and Connor 2001; Nayak et al. 2012). Water conservation techniques in rice-upland rotations may lead to trade-offs between water conservation, crop yield maintenance and decreased soil C sequestration (Li et al. 2007; Tian et al. 2013a). Therefore, these call for developing and evaluating management practices on SOM conversation and build-up in rice-upland systems.

To enhance crop production and reduce environmental impacts, an integrated soil-crop system management (ISSM) strategy was introduced recently, which focus on adoption of various management practices addressing the multiple constraints to yield in existing crop varieties in crop production systems (Zhang et al. 2011; Fan et al. 2012). However, the effects of ISSM which combined water conservation techniques in rice season with higher-yield cultivation and no-tillage in both rice and upland season in rice-rapeseed rotations on SOM sequestration are still unknown.

Changes in SOM due to management practices are usually difficult to quantify because of the large background amounts of relatively stable SOM that are already present (Haynes 2005). Labile SOM fractions such as microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN), dissolved organic matter in carbon (DOM-C) and dissolved organic matter in nitrogen (DOM-N), particulate organic matter in carbon (POM-C) and particulate organic matter in nitrogen (POM-N) and potassium permanganate-oxidizable carbon ($KMnO_4$-oxidizable C) are characterized by their rapid turnover and are recommended as early indicators of the effects of management practices on soil quality (Haynes 2005; von Lützow et al. 2007). Appropriate N fertilization can boost yield levels and help avoid environment problems. Accordingly, N fertilization can increase (Russell et al. 2009), decrease (Khan et al. 2007) or have no effect (Neff et al. 2002) on total SOM. Nevertheless, we still lack a fundamental understanding of how N interacts with SOM and especially its fractions under rice-rapeseed rotation with integrated soil-crop system management. Understanding the effects of cropping systems and N fertilization on SOM levels can help to develop reasonable management strategies to optimize the productivity and sustainability of agroecosystems.

Based on a long-term field experiment, we evaluated the effects of integrated soil-crop system management and N fertilization on total SOM, its labile fractions and carbon management index (CMI) in rice-rapeseed rotation compared with traditional farming practices.

Material and methods

Study site

The field experiment was conducted on a Fluvaquent, Purple Paddy soil (Chinese soil taxonomy) at Jianyang district, Sichuan province, China (30°25′N and 104° 36′E). The region is classified as humid sub-tropical with a monsoon climate with a mean annual temperature and precipitation of 17.7 °C and 883 mm, respectively. The basic soil characteristics at the start of field experiment were: 14.3 g kg^{-1} SOC content; 1.48 g kg^{-1} TN content; 4.20 mg kg^{-1} Olsen-P,39.6 mg kg^{-1} NH_4OAc-exchangeable K, soil pH is 7.2. The soil texture is clay loam.

Field experiment

The field experiment was a rice (*Oryza sativa* L.)—rapeseed (*Brassica campestris* L.) rotation initiated in 2004. The three management systems were: two integrated management systems (ISSM-1, ISSM-2), and one traditional farming practice (FP) as control. Three N fertilizer rates: N0 (no fertilizer N for either rice or rapeseed), N150 (150 kg N ha^{-1} for rice and 150 kg N ha^{-1} for rapeseed), N225 (225 kg N ha^{-1} for rice and 225 kg N ha^{-1} for rapeseed) as urea. Treatments were laid out in a randomized complete block design in triplicate. The field plot size is 55 m^2. All plots were separated by a 20 cm-wide cement wall inserted into the soil to a depth of 60 cm.

We combined improved cultivation pattern, water management and no-tillage in integrated management systems. The details of the management information for the three systems are shown in Table 1.

Every year, rice was transplanted in late May using three seedlings per hill at 30×17 cm spacing in the FP system in rice season. Both integrated management systems were established with three seedlings in a triangular pattern with 10–12 cm spacing between the plants in rice season. Thirty-six rice seedlings in FP and 25 rice seedlings in integrated management systems were transplanted per square meter. Rapeseed was cultivated in the traditional method (two seedlings per hill at 57×33 cm spacing) in FP system in rapeseed season, while rapeseed was cultivated using the wide/narrow row method [one seedling per hill at (30+70)×25 cm] in integrated management systems. Conventional tillage (tillage depth with the plow was 15 cm) was applied in the FP system, while no-tillage in two integrated management systems in both the rice and rapeseed season.

P and K fertilizers (31 kg P ha^{-1} as calcium superphosphate and 55 kg K ha^{-1} as potassium chloride in rice and rapeseed reason) were only used as basal

Table 1 Detailed information of soil-crop system management under three systems

Systems	Crop cultivation pattern		Tillage pattern		N fertilizer management		Water management	
	Rice season	Rapeseed season	Rice season	Rapeseed season	Rice season	Rapeseed season	Rice season	Rapeseed season
FP	Traditionally cultivation	Traditionally cultivation	Conventional tillage	Conventional tillage	50 % N as basal fertilization, 50 % N was top dressing 7 days after transplanting	30 % N as basal fertilization, 20 % and 30 % N were top dressing 10 and 30 days after transplanting	Flooded	Rain feed
ISSM-1	Triangular cultivation	Narrow/wide row cultivation	No-tillage	No-tillage	100 % N as basal fertilization	50 % and 50 % N were top dressing 10 and 30 days after transplanting	Plastic film mulching	Rain feed
ISSM-2	Triangular cultivation	Narrow/wide row cultivation	No-tillage	No-tillage	30 % N as basal fertilization, 40 %, 20 % and 10 % N were top dressing 7, 14, 43 days after transplanting separately	50 % and 50 % N were top dressing 10 and 30 days after transplanting	Moisture condition irrigation	Rain feed

FP Traditional farming practice, *ISSM* Integrated soil-crop system management fertilization in all systems. Three N rates (0, 150 and 225 kg N ha^{-1}) were applied as urea for each management system. The detailed N fertilizer application was shown in Table 1.

For water management in the rice season, the plots of the FP system were irrigated every 3–5 days to maintain a 3 cm water level until 2 weeks before the rice harvest. Plastic film was used to cover the soil in the ISSM-1 system, and only limited irrigation was provided from the transplanting to the flower stage. Moisture condition irrigation was used in the ISSM-2 system: the maximum water content is saturated moisture during irrigation. When the soil moisture content fell below 70–80 % of field capacity, the plots were irrigated again.

Both rice and rapeseed residues were removed in all plots after crop harvest. There were fewer weeds in treatments with plastic film mulching, while weeds were cut manually by sickle in other treatments.

Soil sampling and analysis

Soil samples were collected from 0–5 cm, 5–12 cm and 12–24 cm soil depths after rapeseed harvest in May 2010 in each plot. Eight soil cores were taken in each plot and mixed to give one composite sample per field. A subsample was air-dried first, passed through a 2 mm sieve, then ball-milled and analyzed for soil organic carbon (SOC) and total nitrogen (TN) by dry combustion using an EA1108 CHN elemental analyzer (Fisons Instruments, Germany).

Microbial biomass carbon and nitrogen were analyzed by the chloroform fumigation extraction method (Wu et al. 1996). Briefly, fresh soil samples equivalent to 20 g air-dried soil were fumigated at 25 °C for 24 h. After removing the $CHCl_3$, C and N were extracted from the fumigated and non-fumigated samples with 80 ml 0.5 mol L^{-1} K_2SO_4 solution on a shaker for 30 min (soil/solution ratio 1:4). The filtered extracts were analyzed using a Multi 3100 N/C TOC analyzer (Analytik Jena, Germany). A K_C value of 0.45 and a K_N value of 0.54 were used to calculate the C and N content of the microbial biomass (Wu et al. 1996).

Dissolved organic matter was measured by the method recommended by Jones and Willett (2006). The field-moist soil samples (equivalent to 20 g oven-dried soil) were extracted with 100 ml 0.5 mol L^{-1} K_2SO_4 (soil/solution ratio 1:5) for 1 h. One part of the extracts was passed through a 0.45-μm membrane filter and analyzed for DOM-C and total dissolved N using a Multi 3100 N/C TOC analyzer (Analytik Jena, Germany). Another part of extracts was analyzed for NH_4^+ and NO_3^- using an autoanalyzer (TRAACS-2000, BRAN+LUEBBE, Germany); DOM-N was calculated as the difference between the total dissolved N and the combined NH_4^+ and NO_3^-.

Particulate organic matter was determined with modifications to the method described by Cambardella and Elliott (1992). Twenty grams of air-dried soil <2 mm were dispersed in 100 ml of sodium hexametaphosphate ($(NaPO_3)_6$) (5 g L^{-1}). This was shaken by hand during the first 10 min, then on a reciprocating shaker (180 r min^{-1}) for 18 h. The soil suspension was poured over a 53 μm sieve using a flow of distilled water. All material remaining on the sieve, defined as the particulate organic pool, was washed into a dry dish, oven dried at 60 °C, weighed, ball-milled and analyzed for C and N by dry combustion using an EA1108 CHN elemental analyzer (Fisons Instruments, Germany).

Potassium permanganate-oxidizable carbon ($KMnO_4$-oxidizable C) was determined according to Blair et al. (1995) and Vieira et al. (2007). Air-dried soil samples (equivalent to 15 mg C) were oxidized with 333 mM $KMnO_4$ for 1 h at 25 °C while shaking at a speed of 60 rpm. After being centrifuged, the supernatants were diluted 1:250 with deionized water. The absorbance of the diluted samples and standards was read with a spectrophotometer at 565 nm. The change in the $KMnO_4$ concentration is used to estimate the amount of C oxidized, assuming that 1 mM $KMnO_4$ is consumed (MnVII+MnII) in the oxidation of 0.75 mM or 9 mg of C.

The carbon management index (CMI) was calculated according to Blair et al. (1995) as CMI=carbon pool index (CPI)×lability index (LI)×100, where (1) CPI=[sample total C (g kg^{-1})/reference total C (g kg^{-1})], (2) lability of C (L)=(C fraction oxidized by $KMnO_4$/carbon remaining unoxidized by $KMnO_4$), and (3) LI=(lability of C in sample soil/lability of C in reference soil). FP system was used as a reference for the calculation of CMI in this study. CMI in the reference soil was 100.

Statistical analysis

The data were analyzed using a two-way analysis of variance (ANOVA) with SAS (SAS Inc. 1996). Differences were considered significant at $p<0.05$, with separation of means by the least significant difference (LSD).

Results

Soil organic carbon and total nitrogen

Since the largest differences for SOM and labile fractions were recorded in the upper 5 cm, with rare significant differences between 5–12 cm and 12–24 cm, the results presented here are only in 0–5 cm soil depth.

The SOC was influenced by the management systems, N fertilization and interactions between management systems and N fertilization (Table 2). The mean SOC content (across all N treatments) increased for management systems in the following order: FP<ISSM-1<ISSM-2 (Table 3). Among the N rates, the SOC concentrations under both ISSM systems were: N0<N1=N2.

The TN content followed a similar trend as SOC. TN under ISSM-1 and ISSM-2 was 5.7 % and 8.7 % higher (across all N treatments) than under FP (Table 3). Compared with the N0 level, N application increased the TN content under FP and ISSM-1.

Particulate organic matter

Averaged across three N levels, the particulate organic matter accounted for 16.8 %, 22.4 % and 17.2 % of the total soil mass in the FP, ISSM-1 and ISSM-2 system, respectively (Table 4). N fertilization did not affect the portion of particulate organic matter.

Compared to N fertilization, the management systems showed a higher contribution to the C and N content in POM, accounting for 58 % and 53 % variations for POM-C and POM-N, respectively (Table 2). POM-C and POM-N contents were higher in both ISSM systems than FP when averaged across all N treatments (Table 4). POM-C and POM-N contents decreased with increasing N fertilization when averaged across the three systems.

Dissolved organic matter

Management systems and N fertilization influenced DOM-C and DOM-N (Table 2). DOM-C was higher under ISSM-1 and ISSM-2 than under FP within each N level (Table 4). At the N0 level, ISSM-1 led to lower DOM-N concentration than under FP and ISSM-2. ISSM-1 resulted in a higher DOM-C/N ratio than under FP and ISSM-2 within each N level. The mean DOM-C concentration and DOM-C/N ratio across the three systems increased in the following order: N225<N150<N0. In contrast, DOM-N increased with higher N application for all systems: values were 1.8, 2.3 and 1.7 times higher with N application than without N application for the FP, ISSM-1 and ISSM-2 systems, respectively.

Soil microbial biomass carbon and nitrogen

The management systems showed dominant effects on MBC, i.e. they accounted for 86 % of the variation in MBC concentration (Table 2). ISSM-2 led to higher MBC and MBN concentrations than under FP and ISSM-1 at each N fertilizer level (Fig. 1a). In contrast to MBC, MBN changes were more dependent on N fertilization (Fig. 1b). MBN decreased with increasing N application level under FP and ISSM-2, but increased with N application level under the ISSM-1 system.

Potassium permanganate-oxidizable carbon and carbon management index

The management systems accounted for 76 % variation in $KMnO_4$-oxidizable C (Table 2). The values increased in the following order: FP<ISSM-1<ISSM-2 when averaged over all N treatments or within

Table 2 Contribution (%) of management system and N fertilization to variation of SOM and its labile fractions (two-way ANOVA)

Source of variation	SOC	TN	MBC	MBN	DOM-C	DOM-N	POM-C	POM-N	$KMnO_4$-C
Management systems	**67**	**61**	**86**	**29**	**33**	**16**	**58**	**53**	**76**
N fertilization	**12**	**9**	1	**19**	**37**	**56**	**11**	8	**8**
Interaction	**13**	9	**6**	**31**	10	2	**12**	8	4
Unexplained	8	22	7	21	19	26	18	31	12

Significant contribution at p <0.05 are shown in bold

Table 3 Effect of management system and N fertilization on soil organic carbon (SOC) and total nitrogen (TN)

Cropping system	N rate	SOC(g kg^{-1})	TN(g kg^{-1})
FP	N0	17.2±0.24 a[a]	1.95±0.02 b
	N150	17.1±0.10 a	2.02±0.01 a
	N225	17.5±0.05 a	1.97±0.01 a
ISSM-1	N0	17.1±0.43 b	1.95±0.02 b
	N150	19.2±0.07a	2.15±0.04 a
	N225	20.7±0.85 a	2.22±0.05 a
ISSM-2	N0	20.4±0.17 b	2.28±0.09 a
	N150	21.4±0.16a	2.28±0.07 a
	N225	20.8±0.27 ab	2.35±0.10 a
FP mean		17.3±0.10 C[b]	1.98±0.01 C
ISSM-1 mean		19.0±0.59 B	2.10±0.04 B
ISSM-2 mean		21.0±0.19 A	2.30±0.05 A
N0 mean		18.2±0.55 B	2.06±0.06 B
N150 mean		19.2±0.62 A	2.15±0.04 AB
N225 mean		19.7±0.59 A	2.18±0.07 A

[a] Means (n=3) followed by lower-case letters in the same column are significantly (p<0.05) different between three N rates within each management system

[b] Means (n=9) followed by upper-case letters in the same column are significantly (p<0.05) different between management systems or N rates

FP Traditional farming practice, *ISSM* Integrated soil-crop system management, *N0* No fertilizer N for either rice or rape, *N150* 150 kg N ha^{-1} for rice and 150 kg N ha^{-1} for rape, *N225* 225 kg N ha^{-1} for rice and 225 kg N ha^{-1} for rape

Standard errors of the means (n=3 or n=9) are presented as±values

each N level (Fig. 2). N225 decreased the $KMnO_4$-C when averaged across three management systems.

Integrated management systems increased the CMI to 9 % under ISSM-1 and 33 % under ISSM-2 as compared to FP (Table 5). There was only a small increase in LI (average 3 %), but a higher increase in CPI (average 18 %) under ISSM systems as compared to FP. N150 increased CMI by 7 % while N225 kept similar CMI as compared with zero N application (Data not shown).

Discussion

Effect of integrated soil-crop system management and N fertilization on total soil organic matter

Integrated soil-crop system management increased both SOC and TN contents compared with FP (Table 3). This is partially attributed to better crop growth, higher plant biomass production and large amounts of roots residues left in the ISSM systems. As reported in previous studies, higher plant biomass production usually induced higher SOM content (Sherrod et al. 2003; Russell et al. 2005). In ISSM systems, triangular plant cultivation and narrow/wide row cultivation methods alleviate the competition for light and fertilizers between individual plants, and boost total plant biomass (Lu et al. 2004; Fan et al. 2009). Additionally, no-tillage applied in ISSM systems is also responsible for increasing SOC and TN contents in the upper 0–5 cm. This supports previous studies, which have showed positive effects of no-tillage on SOC and TN contents in top soil (Franzluebbers et al. 1995; Al-Kaisi et al. 2005; Dou and Hons 2006; Chen et al. 2009). The ISSM-2 system yielded a higher SOM content compared with ISSM-1 (Table 3). This may reflect the water management, but did not appear to be associated with crop residue input because ISSM-1 and ISSM-2 had similar aboveground biomass production levels in the field (Cao 2006). We used plastic mulching in ISSM-1, but moisture condition irrigation in ISSM-2. Compared with traditional flooding system, non-flooded plastic mulching in rice was prone to lead to decrease or maintain in SOM (Li et al. 2007; Fan et al. 2005) as the higher soil temperature in earlier rice stage may accelerate SOM decomposition. In a laboratory study, we also observed that rice grown under non-flooded condition has higher root-derived respiration as compared with moisture condition irrigation (Tian et al. 2013a). Nevertheless, a more mechanistic understanding of the SOC and TN responses to water conditions is required in the future.

All systems showed increasing trends in SOC and TN contents between N0 and N150 treatments, but no difference between N150 and N225 (Table 3). These findings were in agreement with the results in previous studies (Lal et al. 1998; Jagadamma et al. 2008). Appropriate N addition can increase net primary production and thus the quantity of organic-C inputs (Gregorich et al. 1996; Russell et al. 2009; Ladha et al. 2011). However, every soil has its own C carrying capacity, and therefore C accumulation may have reached saturation and hence become less responsive to continuously increased N input (Nayak et al. 2012).

Table 4 Effect of management system and N fertilization on particulate organic matter and dissolved organic matter

Cropping system	N rate	POM/BS (%)[c]	POM-C (g kg^{-1}soil)	POM-N (g kg^{-1}soil)	DOM-C (mg C kg^{-1})	DOM-N (mg N kg^{-1})	DOM C/N
FP	N0	16.3±0.48 a[a]	3.31±0.14 a	0.26±0.02 a	54.7±4.23 a	4.92±0.84 b	12.0±2.73 a
	N150	17.3±0.87 a	3.06±0.08 ab	0.24±0.01 a	43.1±1.24 b	7.52±0.54 b	5.80±0.54 b
	N225	16.8±1.43 a	2.52±0.01 b	0.21±0.02 a	40.8±3.31 b	10.6±1.05 a	3.87±0.07 b
ISSM-1	N0	22.1±1.63 a	4.12±0.28 a	0.32±0.01 a	74.1±2.42 a	3.27±0.06 b	22.7±1.00 a
	N150	22.9±1.74 a	4.39±0.10 a	0.33±0.01 a	70.2±4.03 a	6.86±1.57 a	11.5±2.68 b
	N225	22.2±2.27 a	4.08±0.15 a	0.33±0.01 a	57.1±0.65 b	8.19±2.41 a	8.08±1.90 b
ISSM-2	N0	16.8±0.54 a	5.45±0.57 a	0.42±0.06 a	84.2±5.46 a	6.16±0.42 c	14.0±2.35 a
	N150	16.6±2.11 a	4.10±0.38 a	0.33±0.04 a	61.2±3.11 a	8.75±0.75 b	7.08±0.69 b
	N225	18.1±1.28 a	4.05±0.20 a	0.32±0.02 a	51.8±2.30 b	12.7±0.53 a	4.10±0.66 b
FP mean		16.8±0.96 B[b]	2.96±0.15 B	0.23±0.01 B	46.2±2.69 B	7.67±0.92 AB	7.22±1.47 B
ISSM-1 mean		22.4±0.52 A	4.19±0.06 A	0.33±0.004 A	67.1±2.92 A	6.11±1.11 B	14.1±2.42 A
ISSM-2 mean		17.2±0.78 B	4.54±0.30 A	0.35±0.03 A	63.2±4.20 A	9.21±1.00 A	8.39±1.70 B
N0 mean		18.3±1.08 A	4.29±0.63 A	0.33±0.05 A	71.0±8.64 A	4.78±0.83 C	16.2±1.97 A
N150 mean		19.4±1.21 A	3.85±0.40 AB	0.30±0.03 AB	58.1±7.97 B	7.71±0.55 B	8.11±1.18 B
N225 mean		18.4±1.28 A	3.55±0.51 B	0.29±0.03 B	49.9±4.94 C	10.5±1.30 A	5.35±0.93 C

[a] Means (n=3) followed by lower-case letters in the same column are significantly (p<0.05) different between three N rates within each management system

[b] Means (n=9) followed by upper-case letters in the same column are significantly (p<0.05) different between management systems or N rates.

[c] Weight percentage of particulate organic matter mass in bulk soil (BS)

FP Traditional farming practice, *ISSM* Integrated soil-crop system management, *N0* No fertilizer N for either rice or rape, *N150* 150 kg N ha^{-1} for rice and 150 kg N ha^{-1} for rape, *N225* 225 kg N ha^{-1} for rice and 225 kg N ha^{-1} for rape

Standard errors of the means (n=3 or n=9) are presented as ± values

Effect of integrated soil-crop system management and N fertilization on labile soil organic matter fractions

Higher amounts of labile SOM fractions (POM, DOM, MBC, MBN and $KMnO_4$-C), when averaged across N rates, were obtained in ISSM versus the FP system. The increase of labile SOM fractions could reflect higher C input from crops, roots and rhizodeposition, and the positive effects of no-tillage. Rhizodeposition is the C input from the living roots system into the soil and is composed of exudation, secretion, sloughing and lysis of cells and root tissue senescence (Rees et al. 2005). The higher amounts of labile SOM fractions in ISSM systems are in agreement with our earlier findings that lower rhizodeposition accompanied with less incorporation into MBC and DOM-C under continuous flooding condition as compared with non-flooded and moisture condition irrigation (Tian et al. 2013a). Additionally, frequent tillage in FP system in the current study broke down macroaggregates and exposed labile organic matter to microbial decomposition, increasing the loss of labile fractions (Six et al. 1999; Dou and Hons 2006; Chen et al. 2009). In another field experiment, Tian et al. (2013b) found non-flooded mulching cultivation in rice systems significantly influenced labile SOM fractions. The trends in the labile SOM fractions were similar to those of total SOC and TN in this study. This indicates that SOM was a major determinant of the labile fractions and those ISSM systems influenced both the quantity and quality of SOM. A positive relationship between the sustainable yield index and labile SOM fractions (MBC and POM-C) was found in a long-term rice-wheat rotation (Nayak et al. 2012). Similarly, Liebig et al. (2002) reported enhanced nutrient cycling in a corn-soybean-clover system due to a higher portion of POM being present as SOM. CMI<100 indicates a negative impact of management practices on SOM and soil quality (Blair et al. 1995). Our results clearly

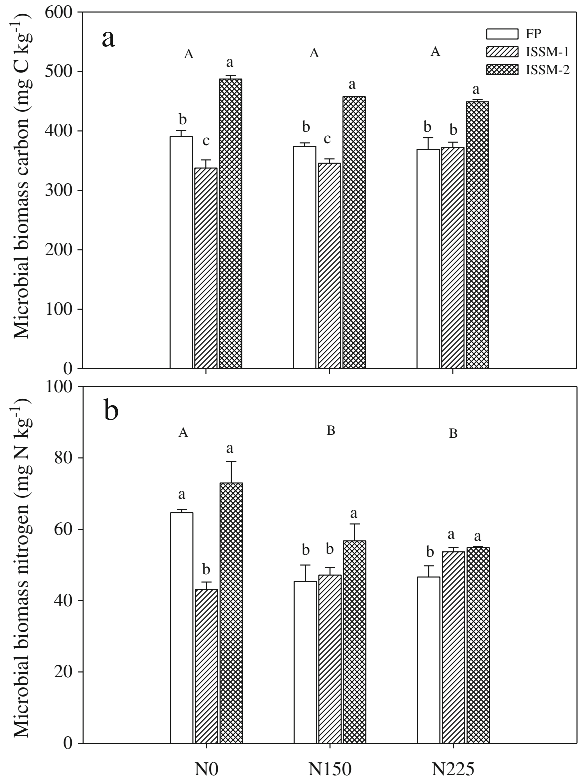

Fig. 1 Effect of management system and N fertilization on microbial biomass carbon (**a**) and microbial biomass nitrogen (**b**). Means (n=3) followed by different lower-case letters are significantly (p<0.05) different between three systems within same N rate. Means (n=9) followed by different upper-case letters are significantly (p<0.05) different between three N rates averaged across three management systems. *FP* Traditional farming practice, *ISSM* Integrated soil-crop system management, *N0* No fertilizer N for either rice or rapeseed, *N150* 150 kg N ha^{-1} for rice and 150 kg N ha^{-1} for rapeseed, *N225* 225 kg N ha^{-1} for rice and 225 kg N ha^{-1} for rapeseed. Standard errors of the means (n=3) are presented as ± values

indicate that ISSM systems may have a higher potential for improving soil quality. A small increase in LI (average 3 %), but a higher increase in CPI (average 18 %) under ISSM systems as compared to FP, indicating that they may contribute to the formation of more stable organic compounds that work as a soil reservoir for C and nutrients (Blair et al. 1995; Sousa et al. 2012). Accordingly, higher amounts of labile SOM fractions and CMI in ISSM systems suggest that integrated soil-crop management may enhance nutrient cycling, soil structure stability, biological productivity and finally soil quality.

Labile SOM fractions are major substrates and energy source for microorganisms. For example, close

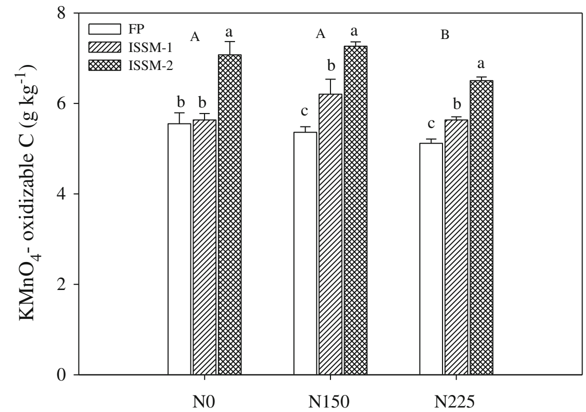

Fig. 2 Effect of management system and N fertilization on $KMnO_4$-oxidizable C. Means (n=3) followed by different lower-case letters are significantly (p<0.05) different between three systems within same N rate. Means (n=9) followed by different upper-case letters are significantly (p<0.05) different between three N rates averaged across three management systems. *FP* Traditional farming practice, *ISSM* Integrated soil-crop system management *N0* No fertilizer N for either rice or rapeseed, *N150* 150 kg N ha^{-1} for rice and 150 kg N ha^{-1} for rapeseed, *N225* 225 kg N ha^{-1} for rice and 225 kg N ha^{-1} for rapeseed. Standard errors of the means (n=3) are presented as ± values

relationship has been reported between microbial activity and DOM concentration (Marschner and Kalbitz 2003; Tian et al. 2012). POM is also major source of substrate and energy for the heterotrophic microbial biomass, and overall soil microbial activity is greatly affected by POM additions (Haynes 2005). Meanwhile, compared with flooded rice system, non-flooded and controlled irrigation rice systems increased the roots-derived respiration and rhizodeposition, thus may cause a positive priming effect in these water conservation system (Tian et al. 2013a). Bhattacharyya et al. (2012)

Table 5 Effect of management system on $KMnO_4$-oxidizable C and carbon management index (CMI)

Management system	$KMnO_4$-oxidizable C (g kg^{-1})	Carbon pool index (CPI)	Lability index (LI)	Carbon management index (CMI)
FP	5.34±0.10 c[a]	1.00	1.00	100
ISSM-1	5.82±0.14 b	1.11	0.99	109
ISSM-2	6.95±0.15 a	1.25	1.07	133

[a] Means (n=9) followed by lower-case letters are significantly (p<0.05) different between management systems

FP Traditional farming practice, *ISSM* Integrated soil-crop system management

Standard errors of the means (n=9) are presented as±values observed a higher CH_4, CO_2 and N_2O emission, together with higher MBC, $KMnO_4$-C amounts following the application of rice straw+green manure as compared with control treatment. Based on this consideration, higher labile SOM fractions in ISSM systems may result in a trade-off between its positive effects on nutrient cycling and negative effects on fuelling greenhouse gas production. This hypothesis needs to be tested in future work.

N fertilization decreased POM when averaged across three systems, especially under N225 (Table 4). Liebig et al. (2002) observed that POM content was highest under zero N application in three cropping systems. POM-N decreased with N fertilization beyond 180 kg N ha^{-1} (Coulter et al. 2009). POM represents finest roots and sand-sized organic matter in soil (Haynes 2005). The decrease of POM with increasing N fertilization may have increased the N concentration in the crop residue, thereby stimulating the decay of POM (Haynes 2005; Coulter et al. 2009). The drop in DOM-C with increasing N fertilization was explained by increased DOM-C consumption by microorganisms along with immobilization of added N (Chantigny et al. 1999; Chantigny 2003). In contrast to DOM-C, we observed an inverse pattern for DOM-N concentration with increasing N application (Table 4). Similar result was reported by Mercik and Németh (1985) for N amendment agricultural field experiment in which DOM-N concentrations increased with N amendments. Nonetheless, the studies of repeated N applications on DOM-N are not always consistent in the field study: others reported no effects of N on DOM-N or even an inverse trend (Chantigny 2003; Filep and Rékási 2011). MBN was lower in N-fertilized versus unfertilized soils. This agrees with previous studies that showed a primary effect of accompanying increased soil acidification on microorganisms (Ajwa et al. 1999; Wallenstein et al. 2006). In our field experiments, however, soil pH in N fertilized plots was similar to that of control plots (7.54 vs. 7.49) after 7 years of N application. Presumably, microbial biomass may be suppressed by reducing rhizodeposition as a substrate for microorganisms with N application (Kuzyakov et al. 2002; Haase et al. 2007). Overall, considering the cost of most SOM fractions, our study indicates that N fertilization especially under higher rate is not a prerequisite to build up the organic matter fractions and it may even negatively affect nutrient cycling and SOM quality in our long-term field experiment.

Conclusions

The SOC, TN and labile SOM fractions were affected by management systems and N fertilization. Management systems had greater effects on total SOM and its fractions than did N fertilization. Compared with traditional farming practices, the two ISSM systems increased SOC, TN, labile SOM fractions and CMI. Appropriate N fertilization application (N150) resulted in higher SOC and TN. Though N application increased DOM-N, it was prone to decrease most of the other labile SOM fractions (POM-C, POM-N, DOM-C, MBN, $KMnO_4$-oxidizable C), especially under higher N rate. Our study indicates that those recently developed integrated soil-crop system management in rice-rapeseed rotation was suitable for improving soil organic matter. N rate is a key factor in affecting labile SOM fractions. There need to evaluate the long-term integrated soil-crop management and N fertilization for the environmental effects (e.g. greenhouse gas production) in rice-rapeseed rotations.

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References

Ajwa HA, Dell CJ, Rice CW (1999) Changes in enzyme activities and microbial biomass of tallgrass prairie soil as related to burning and nitrogen fertilization. Soil Biol Biochem 31:769–777

Al-Kaisi MM, Yin X, Licht MA (2005) Soil carbon and nitrogen changes as influenced by tillage and cropping systems in some Iowa soils. Agr Ecosyst Environ 105:635–647

Benbi DK, Toor AS, Kumar S (2012) Management of organic amendments in rice-wheat cropping system determines the pool where carbon is sequestered. Plant Soil 360:145–162

Bhattacharyya P, Roy KS, Neogi S, Adhya TK, Rao KS, Manna MC (2012) Effect of rice straw and nitrogen fertilization on greenhouse gas emission and carbon storage in tropical flooded soil planted with rice. Soil Till Res 124:119–130

Bijay-Singh, Bronson KF, Yadvinder-Singh, Khera TS, Pasuquin E (2001) Nitrogen-15 balance and use efficiency

as affected by rice residue management in a rice-wheat system in Northwest India. Nutr Cycl Agroecosyst 59:227–237
Blair GJ, Lefroy RDB, Lise L (1995) Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. Aust J Agr Res 46:1459–1466
Bouman BAM, Toung TP (2001) Field water management to save water and increase its productivity in irrigated lowland rice. Agr Water Manage 49:11–30
Cambardella CA, Elliott ET (1992) Particulate soil organic-matter changes across a grassland cultivation sequence. Soil Sci Soc Am J 56:777–783
Cao GL (2006) Effect of different cultivation modes on crop productivity and nitrogen utilization in rice-rapeseed rotation system. China Agricultural University. Beijing (master thesis, in Chinese)
Chantigny MH (2003) Dissolved and water-extractable organic matter in soils: a review on the influence of land use and management practices. Geoderma 113:357–380
Chantigny MH, Angers DA, Prevost D, Simard RR, Chalifour FP (1999) Dynamics of soluble organic C and C mineralization in cultivated soils with varying N fertilization. Soil Biol Biochem 31:543–550
Chen HQ, Hou RX, Gong YS, Li HW, Fan MS, Kuzyakov Y (2009) Effects of 11 years of conservation tillage on soil organic matter fractions in wheat monoculture in Loess Plateau of China. Soil Till Res 106:85–94
Coulter JA, Nafziger ED, Wander MM (2009) Soil organic matter response to cropping system and nitrogen fertilization. Agron J 101:592–599
Dou FG, Hons FM (2006) Tillage and nitrogen effects on soil organic matter fractions in wheat-based systems. Soil Sci Soc Am J 70:1896–1905
Fan MS, Liu XJ, Jiang RF, Zhang FS, Lu SH, Zeng XZ, Christie P (2005) Crop yields, internal nutrient efficiency, and changes in soil properties in rice-wheat rotations under non-flooded mulching cultivation. Plant Soil 277:265–276
Fan MS, Lu SH, Jiang RF, Liu XJ, Zhang FS (2009) Triangular transplanting pattern and split nitrogen fertilizer application increase rice yield and nitrogen fertilizer recovery. Agron J 101:1421–1425
Fan MS, Shen JB, Yuan LX, Jiang RF, Chen XP, Davies WJ, Zhang FS (2012) Improving crop productivity and resource use efficiency to food security and environmental quality in China. J Exp Bot 63(1):13–24
Filep T, Rékási M (2011) Factors controlling dissolved organic carbon (DOC), dissolved organic nitrogen (DON) and DOC/DON ratio in arable soils based on a dataset from Hungary. Geoderma 162:312–318
Franzluebbers AJ, Hons FM, Saladino VA (1995) Sorghum, wheat and soybean production as affected by long-term tillage, crop sequence and N fertilization. Plant Soil 173:55–65
Gregorich EG, Carter MR, Angers DA, Monreal CM, Ellert BH (1994) Towards a minimum data set to assess soil organic matter quality in agricultural soils. Can J Soil Sci 74:367–385
Gregorich EG, Ellert BH, Drury CF, Liang BC (1996) Fertilization effects on soil organic matter turnover and corn residue C storage. Soil Sci Soc Am J 60:472–476
Haase S, Neumann G, Kania A, Kuzyakov Y, Römheld V, Kandeler E (2007) Elevation of atmospheric CO_2 and N-nutritional status modify nodulation, nodule-carbon supply, and root exudation of *Phaseolus vulgaris* L. Soil Biol Biochem 39:2208–2221
Haynes RJ (2005) Labile organic matter fractions as central components of the quality of agricultural soils: an overview. Adv Agron 85:221–268
Jagadamma S, Lal R, Hoeft RG, Nafziger ED, Adee EA (2008) Nitrogen fertilization and cropping system impacts on soil properties and their relationship to crop yield in the central Corn Belt, USA. Soil Till Res 98:120–129
Jones DL, Willett VB (2006) Experimental evaluation of methods to quantify dissolved organic nitrogen (DON) and dissolved organic carbon (DOC) in soil. Soil Biol Biochem 38:991–999
Khan SA, Mulvaney RL, Ellsworth TR, Boast CW (2007) The myth of nitrogen fertilization for soil carbon sequestration. J Environ Qual 36:1821–1832
Kuzyakov Y, Siniakina SV, Rühlmann J, Domanski G, Stahr K (2002) Effect of nitrogen fertilisation on below-ground carbon allocation in lettuce. J Sci Food Agr 82:1432–1441
Ladha JK, Reddy CK, Padre AT, van Kessel C (2011) Role of nitrogen fertilization in sustaining organic matter in cultivated soils. J Environ Qual 40:1756–1766
Lal R (2004) Soil carbon sequestration impacts on global climate change and food security. Science 304:1623–1627
Lal R, Kimble JM, Follett RF, Cole CV (1998) The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect. Ann Arbor Press, Chelsea
Li YS, Wu LH, Zhao LM, Lu XH, Fan QL, Zhang FS (2007) Influence of continuous plastic film mulching on yield, water use efficiency and soil properties of rice fields under non-flooding condition. Soil Till Res 93:370–378
Liebig MA, Varvel GE, Doran JW, Wienhold BJ (2002) Crop sequence and nitrogen fertilization effects on soil properties in the western Corn Belt. Soil Sci Soc Am J 66:596–601
Lu SH, Ren GJ, Zeng XZ, Liu XJ, Zhang FS (2004) Effect of different transplanting periods on the growth and yield of high-quality hybrid rice in the system of rice intensification. Chinese Journal of Eco-Agriculture 12:138–139 (In Chinese)
Marschner B, Kalbitz K (2003) Controls of bioavailability and biodegradability of dissolved organic matter in soils. Geoderma 113:211–235
Mercik S, Németh K (1985) Effects of 60-year N, P, K and Ca fertilization on EUF-nutrient fractions in the soil and on yields of rye and potato crops. Plant Soil 83:151–159
Nayak AK, Gangwar B, Shukla AK, Mazumdar SP, Kumar A, Raja R, Kumar A, Kumar V, Rai PK, Mohan U (2012) Long-term effect of different integrated nutrient management on soil organic carbon and its fractions and sustainability of rice-wheat system in Indo Gangetic Plains of India. Field Crops Res 127:129–139
Neff JC, Townsend AR, Gleixnerk G, Lenmans SJ, Turnbull J, Bowman WD (2002) Variable effects of nitrogen additions on the stability and turnover of soil carbon. Nature 419:915–917
Rees RM, Bingham IJ, Baddeley JA, Watson CA (2005) The role of plants and land management in sequestering soil carbon in temperate arable and grassland ecosystems. Geoderma 128:130–154
Russell AE, Laird DA, Parkin TB, Mallarino AP (2005) Impact of nitrogen fertilization and cropping system on carbon

sequestration in Midwestern mollisols. Soil Sci Soc Am J 69:413–422
Russell AE, Cambardella CA, Laird DA, Jaynes DB, Meek DW (2009) Nitrogen fertilizer effects on soil carbon balances in Midwestern U.S. agricultural systems. Ecol Appl 19:1102–1113
Sherrod LA, Peterson GA, Westfall DG, Ahuja LR (2003) Cropping intensity enhances soil organic carbon and nitrogen in a no-till agroecosystem. Soil Sci Soc Am J 67:1533–1543
Six J, Elliott ET, Paustian K (1999) Aggregate and soil organic matter dynamics under conventional and no-tillage systems. Soil Sci Soc Am J 63:1350–1358
Sousa FP, Ferreira TO, Mendonca ES, Romero RE, Oliveira JGB (2012) Carbon and nitrogen in degraded Brazilian semi-arid soils undergoing desertification. Agr Ecosyst Environ 148:11–21
Tian J, Fan MS, Guo JH, Marschner P, Li XL, Kuzyakov Y (2012) Effects of land use intensity on dissolved organic carbon properties and microbial community structure. Eur J Soil Biol 52:67–72
Tian J, Pausch J, Fan M, Li X, Tang Q, Kuzyakov Y (2013a) Allocation and dynamics of assimilated carbon in rice-soil system depending on water management. Plant Soil 363:273–285
Tian J, Lv SH, Fan MS, Li XL, Kuzyakov Y (2013b) Labile soil organic matter fractions as influenced by non-flooded mulching cultivation and cropping season in rice-wheat rotation. Eur J Soil Biol 56:19–25
Timsina J, Connor DJ (2001) Productivity and management of rice-wheat cropping systems: Issues and challenges. Field Crops Res 69:93–132
Vieira FCB, Bayer C, Zanatta JA, Dieckow J, Mielniczuk J, He ZL (2007) Carbon management index based on physical fractionation of soil organic matter in an Acrisol under long-term no-till cropping systems. Soil Till Res 96:195–204
von Luetzow M, Koegel-Knabner I, Ekschmitt K, Flessa H, Guggenberger G, Matzner E, Marschner B (2007) SOM fractionation methods: Relevance to functional pools and to stabilization mechanisms. Soil Biol Biochem 39:2183–2207
Wallenstein MD, McNulty S, Fernandez IJ, Boggs J, Schlesinger WH (2006) Nitrogen fertilization decreases forest soil fungal and bacterial biomass in three long-term experiments. Forest Ecol Manag 222:459–468
Witt C, Cassman KG, Olk DC, Biker U, Liboon SP, Samson MI, Ottow JCG (2000) Crop rotation and residue management effects on carbon sequestration, nitrogen cycling and productivity of irrigated rice systems. Plant Soil 225:263–278
Wu J, Brookes PC, Jenkinson DS (1996) Evidence for the use of a control in the fumigation-incubation method for measuring microbial biomass carbon in soil. Soil Biol Biochem 28:511–518
Yadav RL, Dwivedi BS, Prasad K, Tomar OK, Shurpali NJ, Pandey PS (2000) Yield trends, and changes in soil organic-C and available NPK in a long-term rice-wheat system under integrated use of manures and fertilisers. Field Crops Res 68:219–246
Yang J, Zhang J (2010) Crop management techniques to enhance harvest index in rice. J Exp Bot 61:3177–3189
Zhang FS, Cui ZL, Fan MS, Zhang WF, Chen XP, Jiang RF (2011) Integrated soil-crop system management: reducing environmental risk while increasing crop productivity and improving nutrient use efficiency in China. J Environ Qual 40:1051–1057