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Influence of green manure and rice straw management on soil organic carbon, enzyme activities, and rice yield in red paddy soil

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ABSTRACT

Both the quantity and quality of organic amendments can influence the accumulation of soil organic carbon (SOC) and agroecosystem functioning. However, the evidences of the effect of combination of quantity and quality of organic amendments on the paddy soil quality and rice yield are scarce. An ongoing field experiment was conducted in Hunan province of China to investigate the effect of different Chinese milk vetch (*Astragalus sinicus* L.) and rice (*Oryza sativa* L.) straw management practices on the soil biochemical properties and rice yield. The experiment consisted six treatments: applying Chinese milk vetch (MV), applying early-season rice straw (S), applying early-season and late-season rice straw (DS), applying Chinese milk vetch and early-season rice straw (SMV), applying Chinese milk vetch, early-season and late-season rice straw (DSMV), and unamended organic amendment (CK). Compared with CK, SOC content was significantly increased by 13.0%, 18.5%, 11.1%, 12.3%, and 23.0% for the MV, S, DS, SMV, and DSMV treatments, respectively. No significant correlation was found between SOC content and yearly carbon inputs. Application of organic amendments increased soil hydrolase activities (β-D-cellobiosidase, β-1,4-glucosidase, β-1,4-xylosidase, β-1,4-N-acetyl-glucosaminidase and phosphatase). The geometric mean of the assayed hydrolases followed the order: S > DSMV > SMV > DS > MV > CK. Phenol oxidase was significantly higher in CK than in the applied organic amendment treatments. The lowest ratio of β-1,4-glucosidase: phenol oxidase occurred in the S treatment, suggesting that S treatment decreased microbial substrate use efficiency. The yearly average rice yield was increased by 18.6%, 8.5%, 12.3%, 14.6%, and 24.1% for MV, S, DS, SMV, and DSMV treatment with respect to CK. There was no significant correlation between SOC content and rice yield. In general, after 4-year cultivation, our results highlight the effect of quality of organic amendments on the chemical properties of SOC and its nutrient supply. Applying high quantities of diverse organic amendments is suggested to increase SOC content and rice yield in red paddy soil.

1. Introduction

Soil organic matter (SOM) is a key factor for crop productivity due to its important role in maintaining soil physical, chemical, and biological properties (Sarker et al., 2018). Rice is the most important food crop in China, producing about 197 million tons of rice grain every year, contributing 28.7% to world rice grain production (Huang et al., 2013; Liu et al., 2014). However, the rice yield in China has stagnated (Huang et al., 2013; Liao et al., 2018). The stagnation trend of rice yield is ascribed to deterioration of soil quality through the loss of SOM (Chen et al., 2016b; Huang et al., 2013).

Application of organic amendments, such as crop residues, green manure, and livestock manure, has been considered one of the most economic and effective sustainable agriculture practices for improving

Abbreviations: SOM, soil organic matter; SOC, soil organic carbon; CBH, soil β-D-cellobiosidase; BG, soil β-1,4-glucosidase; BX, soil β-1,4-xylosidase; NAG, soil β-1,4-N-acetyl-glucosaminidase; LAP, soil leucine amino peptidase; SAP, soil phosphatase activity; POX, soil phenol oxidase

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SOM content and crop yield (Nair and Ngouajio, 2012; Sharma et al., 2017; Zhang et al., 2017). However, some studies, especially short-term studies, have reported that rice straw retention did not increase or had a negative effect on rice yield due to the quality of rice straw (Huang et al., 2013; Liao et al., 2018). The main reason is that rice straw amendment cannot reconcile the requirements of nutrients between soil microorganisms and rice, especially the demand for nitrogen, during rice straw decomposition. Decomposition rate and nutrient release are influenced by the C (carbon) : N (nitrogen) ratio and the biochemical composition of organic amendments (Kumar et al., 2018; Marschner et al., 2015). The high C : N ratio of rice straw may lead to competition for N between soil microorganisms and the crop. However, mixing low quality and high quality organic amendments provides a better strategy to match nutrient demands of the crop and soil microorganisms during decomposition of organic amendments (Kaewpradit et al., 2009; Marschner et al., 2015). Mixing high quality and low quality organic amendments changes the quality of organic C that is input into the soil, which can positively influence soil microbial activity, nutrient availability, and turnover of SOM (Marschner et al., 2015; Nair and Ngouajio, 2012; Sharma et al., 2017). Planting green manure (GM) in paddy soil during the winter period is a traditional practice in China. When legumes such as Chinese milk vetch are used as GM, they can fix atmospheric N and produce a large amount of biomass. A considerable benefit to soil quality and rice productivity can be observed when straw from legumes is incorporated into the soil (Xie et al., 2016; Yang et al., 2012). Evidence has accumulated that mixed legume and rice straw can match the N demand of rice (Kaewpradit et al., 2009). Therefore, the integration of both rice and legume straw may be a better strategy for increasing soil quality and rice yield than other soil amendments. Mixing the rice and legume straw not only influence the quality but also quantity of organic C entering the soil. Recent studies have shown that both the quality and quantity of organic amendments can affect SOC balance (Heitkamp et al., 2012; Shahbaz et al., 2017b). Liu et al. (2009) found that manipulating the quantity and type of organic amendments may improve paddy soil nutrient content and rice yield. However, more evidences are needed to evaluate the effect of combination of quantity and quality of organic amendments on soil quality and rice yield.

In the current study, we hypothesized that different rice and legume straw management practices would affect the accumulation of SOC, nutrient contents and microbial activity. The objective of this study was to try to find a more effective rice and legume straw management practices in improving red paddy soil quality and rice yield by evaluating the response of SOC, nutrient contents, soil microbial activities (by analysing soil enzyme activities involved in C, N and P cycling), and rice yield to the different rice and legume straw management practices in a field experiment.

2. Materials and methods

2.1. Study area

An ongoing field experiment was conducted in 2012 at the Red Soil Experimental Station, Chinese Academy of Agricultural Science, QiYang County in Hunan province, China (26°45′42″N, 111°52′32″E). The study site has a subtropical climate, with an annual mean temperature and precipitation of 18.3 °C and 1250 mm, respectively. The soil type is a typical red soil, derived from Quaternary red clay. The initial soil (0–20 cm) chemical properties were as follow: SOM 14.90 g kg^{-1}, total nitrogen (TN) 1.48 g kg^{-1}, available nitrogen (AN) 82.36 mg kg^{-1}, and available phosphorus (AP) 12.58 mg kg^{-1}.

2.2. Experimental design and soil sampling

The experiment was set up in a double rice-cropping system and included six treatments: (1) no organic amendment inputs (CK), in which rice straw was removed after harvest; (2) rice straw removal with application of Chinese milk vetch (MV), in which rice straw was removed after harvest and the biomass of Chinese milk vetch was returned to the soil before early-season rice was transplanted; (3) early-season rice straw retention (S), in which early-season rice straw was returned to the field after harvest; (4) early-season and late-season rice straw retention (DS), in which early-season and late-season rice straw was returned to the field after harvest; (5) early-season rice straw retention with application of Chinese milk vetch (SMV), in which early-season rice straw was returned to the field after harvest and the biomass of Chinese milk vetch was returned to the soil before early-season rice was transplanted; and (6) double season (early-season and late-season) rice straw retention and application of Chinese milk vetch (DSMV), in which early-season rice straw was returned to the field after harvest, late-season rice straw was returned to the field after harvest with standing stubble, and the biomass of Chinese milk vetch was returned to the soil before early-season rice was transplanted. Chinese milk vetch and early-season rice straw were incorporated into the soil, whereas late-season rice straw was applied such that it uniformly covered the soil surface. The experiment was conducted in a randomized complete block design, and each treatment had three replicate plots of 21 m^2 (7 m × 3 m). Each plot was separated with concrete to prevent nutrient exchange. Fertilizers were the same for all treatments and fertilizer application rates followed local farm practices. Basal fertilizer was applied with compound fertilizer (N-P_2O_5-K_2O, 18-12-10), and topdressing fertilizer was urea and potassium chloride. The basal fertilizer was applied before rice transplantation, and topdressing fertilizer was applied 6–10 days after rice transplantation. The detail of nutrients management of six treatments was given in Table 1. According to the treatment, seeds (37.5 kg ha^{-1}) of Chinese milk vetch were evenly spread on the surface at 10–15 days before late rice was harvested. No fertilizer was applied when Chinese milk vetch was planted.

Soil samples were collected from the surface soil (0–20 cm) of each plot in 11 April 2017, before field preparation. Five soil cores were randomly sampled from each plot and homogenised to reduce within-plot variability. Each soil sample was divided into two sub-samples. One sub-sample was used for analysis of soil enzymes, and the other was air-dried for analysis of soil chemical properties.

2.3. Soil chemical properties and enzyme analysis

SOC and soil TN were determined using an Elemental analyser (Vario TOC, Elementar, Hanau, Germany). The other chemical properties, including, pH, total phosphorus (TP), total potassium (TK), AN, AP, and available potassium (AK), were determined using the method described by Lu (2000).

We measured soil hydrolase and oxidase activities according to the method of Saiya-Cork et al. (2002). Soil hydrolases included the enzymes associated with the C-cycle, N-cycle, and P-cycle. The enzymes associated with the C-cycle include β-D-cellobiosidase (CBH); β-1, 4-glucosidase (BG); and β-1,4-xylosidase (BX). The enzymes associated with N-cycle acquisition include β-1,4-N-acetyl-glucosaminidase (NAG) and leucine amino peptidase (LAP). For P-cycle enzymes, we measured acidic phosphatase activity (SAP). For oxidases, we measured soil phenol oxidase (POX) activity. For each sample, the geometric mean (GMea) of the assayed hydrolases was calculated as follows (Roberto et al., 2009):

$$GMea = \sqrt[6]{CBH \times BG \times BX \times NAG \times LAP \times SAP} \quad (1)$$

Table 1
The detail of nutrient management of the six treatments in each rice season.

	N (kg ha^{-1})	P (P_2O_5, kg ha^{-1})	K (K_2O, kg ha^{-1})
Basal fertilizer	135	90	75
Topdressing fertilizer	30	0	15

Table 2
Soil chemical properties under different green manure and rice straw management practices.

Treatment	CK	MV	S	DS	SMV	DSMV
SOC (g kg^{-1})	11.60 ± 0.55c	13.11 ± 0.41b	13.75 ± 0.49ab	12.89 ± 0.44b	13.03 ± 0.74b	14.27 ± 0.28a
TN (g kg^{-1})	1.23 ± 0.12c	1.47 ± 0.06ab	1.47 ± 0.15ab	1.37 ± 0.06bc	1.47 ± 0.06ab	1.57 ± 0.06a
TP (g kg^{-1})	0.57 ± 0.09a	0.64 ± 0.05a	0.65 ± 0.06a	0.65 ± 0.04a	0.61 ± 0.07a	0.67 ± 0.02a
TK (g kg^{-1})	11.73 ± 0.93a	12.20 ± 0.6a	11.93 ± 1.29a	12.83 ± 1.55a	12.73 ± 0.81a	11.87 ± 0.59a
AN (mg kg^{-1})	122.33 ± 9.07b	135.00 ± 1.00b	145.67 ± 20.65ab	134.33 ± 10.07b	142.33 ± 10.97ab	159.67 ± 15.04a
AP (mg kg^{-1})	16.17 ± 4.70a	17.00 ± 2.26a	18.90 ± 5.22a	19.77 ± 2.15a	16.10 ± 4.25a	19.90 ± 2.62a
AK (mg kg^{-1})	66.03 ± 11.99b	62.23 ± 6.23b	87.7 ± 14.8a	89.43 ± 6.01a	69.17 ± 3.32b	77.43 ± 9.81ab
pH	5.90 ± 0.09ab	5.91 ± 0.16ab	6.02 ± 0.16a	5.93 ± 0.18ab	5.69 ± 0.02b	5.82 ± 0.14ab

CK: no organic amendment input; MV: application of green manure (Chinese milk vetch); S: early-season rice straw retention; DS: double season (early-season and late-season) rice straw retention; SMV: application of green manure and early-season rice straw; DSMV: application of green manure and double season rice straw. Different letters identify significantly differences among different treatments at $p < 0.05$. Values are the mean ± standard deviation.

2.4. Data analysis

Differences in soil chemical properties, enzyme activity, the yearly average rice yield and yearly C inputs among treatments were evaluated using one-way analysis of variance (ANOVA) in SPSS 19.0 software (SPSS Inc., Chicago, IL, USA). Differences between mean values were evaluated using Duncan's multiple range test with a probability $p < 0.05$. Pearson correlations were performed among soil chemical properties and enzyme activities, SOC content and yearly carbon input, and rice yield and SOC content using SPSS 19.0 software.

3. Results

3.1. Soil chemical properties

The influences of different treatments on soil chemical properties are shown in Table 2. Application of organic amendments significantly increased the SOC content compared to CK, ranging from 11.1 to 23.2%, with increasing magnitude following the order: DSMV > S > MV > SMV > DS. The TN contents was highest in the DSMV treatment and was increased by 27.0% compared with CK. The TN contents of MV, S, and SMV was significantly higher than in CK. The TN contents in the DS treatment was not significantly higher than in CK. Although application of organic amendments increased TP and TK contents, they did not significantly alter TP and TK contents compared to CK.

Soil AN contents was increased by application of organic amendments, but only the DSMV treatment was found to significantly increase soil AN contents compared to CK. Although application of organic amendments increased soil AP contents, there were no significant differences in AP contents among treatments. Soil AK contents was highest in DS and S treatments, followed by the DSMV treatment. Application of MV resulted in the depletion of soil available nutrients, which was offset by incorporation of MV with rice straw.

Rice straw retention increased soil pH and the S treatment had the highest soil pH compared with CK, but soil pH was not statistically different among treatments.

3.2. Soil enzyme activities

Compared to CK, application of organic amendments significantly increased soil CBH activity (Fig. 1A). The highest CBH activity was found in the S treatment, followed by the DSMV treatment. CBH activity was significantly higher under the S treatment as compared to the DS, SMV, and MV treatments. Trends similar to that for CBH activity were observed for BG and BX activity, even though differences were not significant for BG activity among DS and MV treatments and CK (Fig. 1B and C).

Soil NAG activity appeared to be significantly influenced by different organic amendment treatments (Fig. 1D). The highest NAG activity was found under the S and DSMV treatments. Soil LAP activity in the S treatment was significantly higher than other treatments. Except for the S treatment, there was no significant difference in LAP activity between CK and other organic amendment treatments (Fig. 1E).

Application of organic amendments caused significant changes in SAP activity. The highest SAP activity was found in the S treatment, followed by the SMV treatment (Fig. 1F).

Unlike the other enzyme activities, soil POX activity was highest in CK. The POX activity of organic amendment treatments was significantly lower than that of CK (Fig. 2).

Application of organic amendments significantly increased the GMea value of assayed soil hydrolases compared to CK (Fig. 3A). The GMea value was highest in the S treatment, which was significantly higher than in the MV and DS treatments (Fig. 3A). There was no significant difference in GMea value among the S, SMV, and DSMV treatments (Fig. 3A). The BG : POX ratio was highest in the DSMV treatment and lowest in the S treatment among the applied organic amendment treatments (Fig. 3B).

A correlation matrix between soil chemical and enzyme activity properties is shown in Table 3. Soil pH was significantly correlated with soil LAP activity. SOC, TN, TP, AN and AP were significantly positively correlated with one another. Except for LAP activity, SOC, TN, and AN had a strong correlation with the measured enzyme activity. AP was significantly positively correlated with soil BG activity. Except for LAP activity, POX was obviously negatively correlated with activities of assayed soil hydrolases. There was a significant positive correlation among the soil CBH, BG, BX, NAG, and SAP activities.

3.3. Rice yield

Compared with CK, all organic amendment treatments increased the yearly average rice yield, ranging from 8.5 to 23.8% (Fig. 4), with increasing magnitude following the order: DSMV > MV > SMV > DS > S. Organic C inputs includes aboveground (straw) and belowground (root) C inputs; we only measured the aboveground C inputs. The yearly C inputs followed the order of DSMV > DS > SMV > S > MV (Table 4).

4. Discussion

4.1. Effects of different C inputs on soil C sequestration

C inputs is one of the major factors controlling SOC sequestration, but the magnitude and direction of SOC sequestration varies among studies (Heitkamp et al., 2012; Li et al., 2018). Chen et al. (2016a) reported a significant correlation between C inputs and SOC content in a paddy field experiment located in southern China. We found that SOC content was increased by application of rice straw and/or MV in this study. However, SOC content was weakly correlated with yearly C inputs ($r^2 = 0.32$, $p < 0.25$). Similarly, Li et al. (2010) also indicated a weak relationship between SOC content and quantity of C inputs in

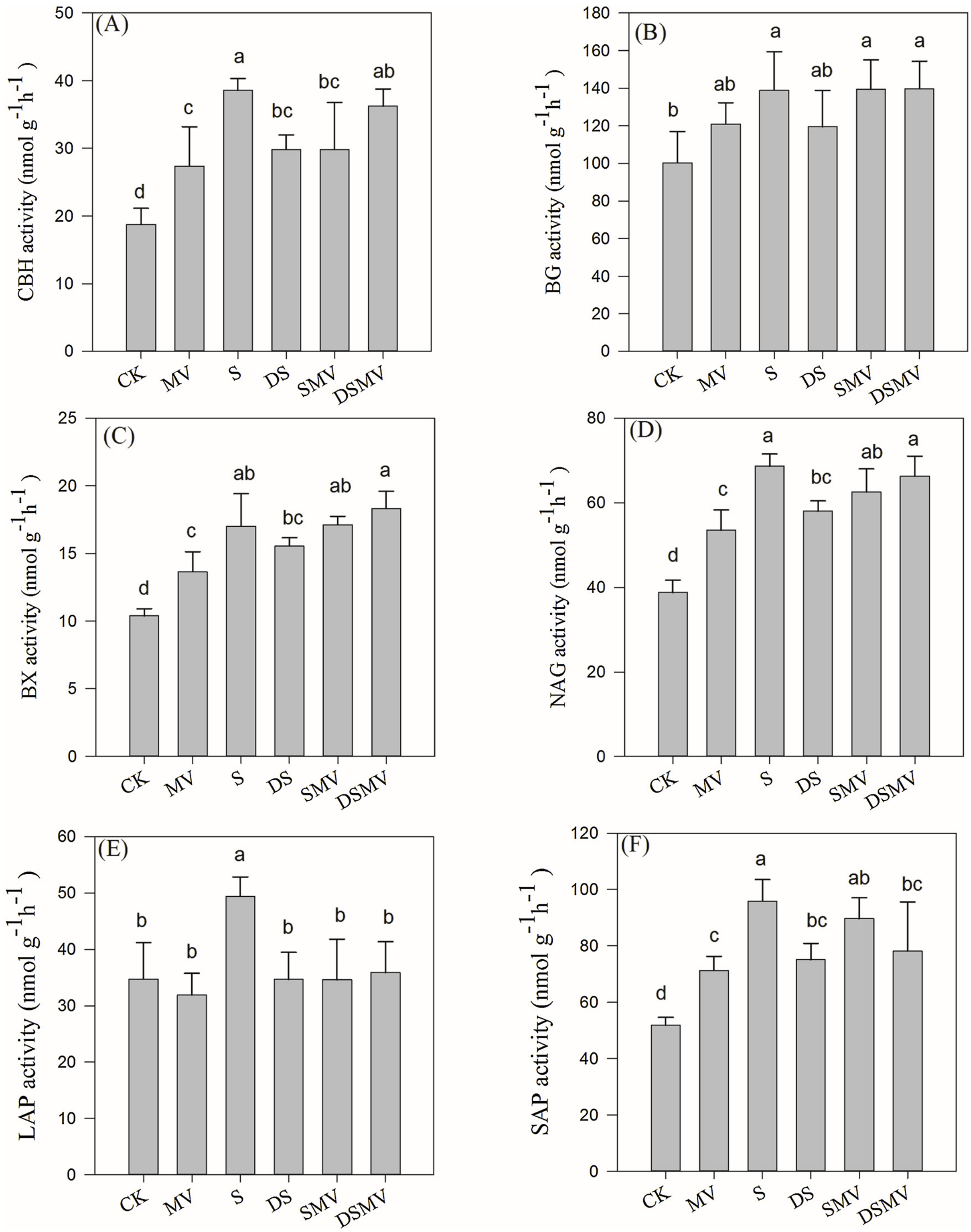

Fig. 1. Response of soil β-D-cellobiosidase (CBH) (A), β-1, 4-glucosidase (BG) (B), β-1, 4-xylosidase (BX) (C), β-1, 4-N-acetyl-glucosaminidase (NAG) (D), leucine amino peptidase (LAP) (E), and acidic phosphatase activity (SAP) (F) activities to different treatments. Different letters identify significant differences among different treatments at $p < 0.05$. Error bars represent the standard deviation. CK: no organic amendment input; MV: application of green manure (Chinese milk vetch); S: early-season rice straw retention; DS: double season (early-season and late-season) rice straw retention; SMV: application of green manure and early-season rice straw; DSMV: application of green manure and double season rice straw.

paddy soil. SOC sequestration is controlled by the following factors when organic amendments are returned to soil: (1) the quantity and quality of organic amendment (Heitkamp et al., 2012; Li et al., 2010); (2) application time and frequency (Cesarano et al., 2017; Liu et al., 2009); and (3) soil temperature, soil water regimes, soil texture, fertilizer management, and crop rotation system (Li et al., 2010; Liu et al., 2014; Wei et al., 2016; Yan et al., 2018). These factors influence the humification of added C and mineralization of native soil C, followed by the SOC content. In the present study, the quantity and quality of organic amendment and soil water regimes together influenced SOC sequestration.

The SOC content of the S treatment was higher than the DS and SMV treatments, despite the lower C inputs in the S treatment. This may indicate that the S treatment has higher C accumulation efficiency. The main reason may be that the anaerobic conditions of the continuously flooded soils decreased the decomposition rate of early-season rice

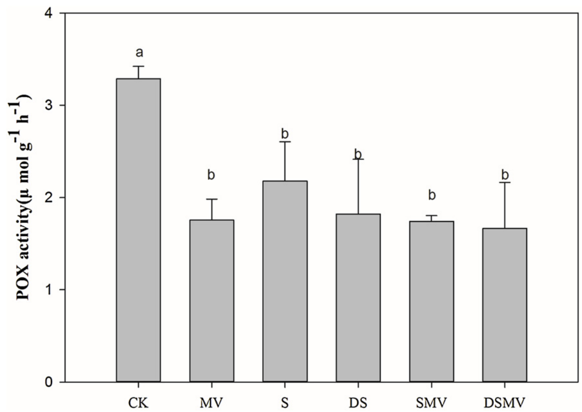

Fig. 2. Response of soil POX (soil phenol oxidase) activity to different treatments. Different letters indicate significant differences between treatments at $p < 0.05$. Error bars represent the standard deviation. Abbreviations are the same as in Fig. 1.

straw and mineralization of SOM. And, the formed SOM would then be more stable under anaerobic conditions than under aerobic conditions (Chen et al., 2018; Liu et al., 2014). For the DS treatment, the aerobic conditions of soil may increase the decomposition rate of late-season rice straw. On the other hand, the higher C : N ratio of rice straw can induce C loss by accelerating the mineralization of SOM through a priming effect (Li et al., 2018; Shahbaz et al., 2017a). The lower C : N ratio of MV, which can lead to a higher decomposition rate of MV and greater microbial activity, may be responsible for the lower SOC content of the SMV treatment. Greater microbial activity induced by application of MV can also increase rice straw mineralization because of legacy effects (Marschner et al., 2015). However, the mineralization of SOM and higher decomposition rate of added C may be beneficial to rice yield, as more available nutrients could be released during these processes. High quantity and diverse C inputs may be the main reason that the highest SOC content occurred in the DSMV treatment (Liu et al., 2009).

4.2. Response of soil enzyme activities to different C inputs

Soil enzymes have been recognized as indictors of soil fertility and soil quality, and are responsible for SOM transformation and nutrient cycling (Liu et al., 2017; Saha et al., 2008; Zhang et al., 2016). Soil enzymes decompose SOM to acquire energy for microbial growth and release nutrients for plant uptake. In our analysis we found that all measured hydrolase activities, except BG and LAP activity, were significantly increased by application of rice straw and/or MV compared to CK.

Although enzymes measured in this study have been reported to correlate with soil fertility, it is difficult to distinguish which enzymes have the strongest correlations to soil fertility (Roberto et al., 2009; Waldrop et al., 2000). However, the GMea value could give appropriate information when soil enzymes are recognized as indictors of soil fertility (Roberto et al., 2009). In the organic amendment treatments, the present study showed that the GMea value was highest in the S treatment and the lowest int the MV treatment (Fig. 3). This indicated that the low quantity and quality of rice straw (S treatment) could support higher microbial activity. It is believed that the low quality of SOC limits the microbial substrate use efficiency (SUE) (Fontaine et al., 2003; Takriti et al., 2018), therefore, the highest GMea value in the S treatment may indicate that the S treatment decreased the SUE. The BG : POX ratio has been used as an indicator of chemical recalcitrance of carbon (Robertl and Jenniferj, 2011; Takriti et al., 2018). The lowest BG : POX ratio of the S treatment also indicated lower resource availability of the S treatment compared to other treatments (Takriti et al., 2018). Therefore, the enrichment of soil enzymes in the S treatment may be a mechanism of soil microbes to maintain microbial activity with low quality SOC. These results suggested that not only quantity but also quality (chemical composition) of SOC was affected by different quality and quantity of C inputs. In addition, the soil sampling time should be considered. The soil sample was collected in April. During this time of year, the soil microbial activity may be limited by soil temperature rather than substrates (Roberto et al., 2009).

The soil POX activity showed a different pattern compared to the soil hydrolase activities, where the highest POX activity was achieved in the CK. Unlike soil hydrolase activities, evidence suggests that high POX activity limits SOM accumulation (Sinsabaugh, 2010). Therefore, a strong negative correlation between POX activity and SOC was found in this study (Table 3).

4.3. Response of rice yield to enhancement of SOC

A number of factors, including soil fertility, water supply, pests and diseases, management practices and climate condition, can influence crop yield (Chen et al., 2016b). In the present study, the yearly average rice yield was higher in the organic amendment treatments than in the CK treatment. Under the same filed management practice and climate condition, the higher rice yield in the organic amendments may have

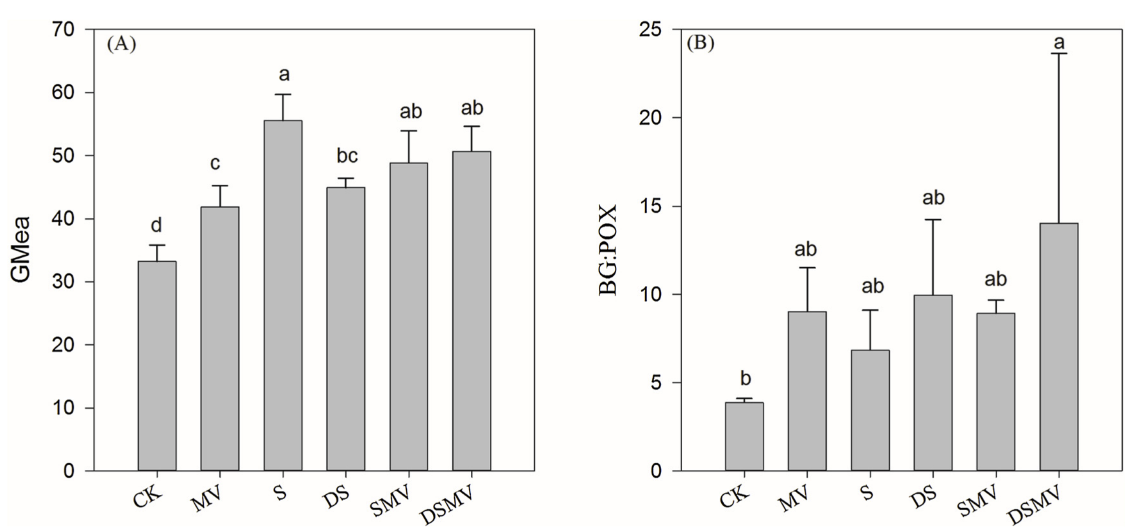

Fig. 3. The geometric mean (GMea) of the assayed soil hydrolases and the ratio of BG (β-1, 4-glucosidase) : POX (soil phenol oxidase) of different treatments. Different letters indicate significant differences between treatments at $p < 0.05$. Error bars represent the standard deviation. Abbreviations are the same as in Fig. 1.

Table 3
Pearson correlations between soil chemical properties and enzyme activities.

	pH	SOC	TN	TP	TK	A N	AP	AK	POX	CBH	BG	BX	NAG	LAP	SAP
pH	1														
SOC	−0.103	1													
TN	−0.007	0.84**	1												
TP	−0.125	0.763**	0.638**	1											
TK	−0.118	−0.173	−0.276	−0.308	1										
AN	−0.083	0.807**	0.831**	0.56*	−0.34	1									
AP	−0.040	0.608**	0.489*	0.890**	−0.461	0.566*	1								
AK	0.101	0.338	0.083	0.247	0.002	0.232	0.339	1							
POX	−0.012	−0.603**	−0.721**	−0.401	0.043	−0.588*	−0.231	−0.075	1						
CBH	0.106	0.738**	0.614**	0.428	0.069	0.625**	0.349	0.46	−0.513*	1					
BG	−0.12	0.655**	0.645**	0.434	−0.289	0.705**	0.471*	0.236	−0.637*	0.760**	1				
BX	−0.052	0.738**	0.759**	0.443	0.128	0.749**	0.314	0.348	−0.715*	0.813**	0.707**	1			
NAG	−0.07	0.789**	0.653**	0.448	−0.003	0.637**	0.29	0.471*	−0.702*	0.856**	0.771**	0.85**	1		
LAP	0.597**	0.11	0.114	−0.114	0.041	0.200	−0.071	0.293	−0.031	0.536*	0.301	0.411	0.398	1	
SAP	−0.069	0.588*	0.498*	0.343	0.135	0.505*	0.232	0.463	−0.546*	0.801**	0.708**	0.712**	0.874**	0.457	1

* $p < 0.05$.
** $p < 0.01$.

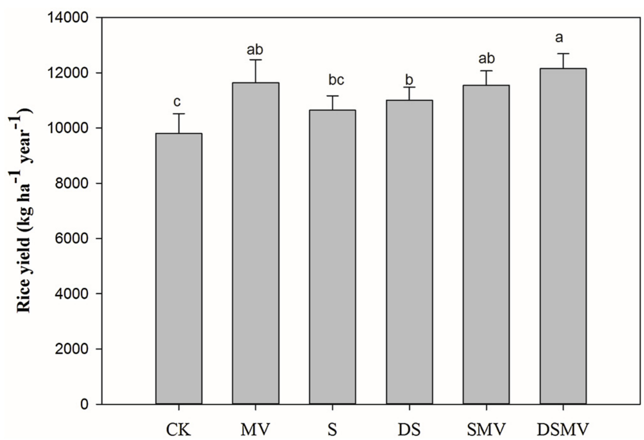

Fig. 4. Effects of different treatments on yearly average rice yield. Different letters identify significant differences among different treatment at $p < 0.05$. Error bars represent the standard deviation. Abbreviations are the same as in Fig. 1.

Table 4
The yearly average amounts of organic C inputs in each treatment.

Treatment	The yearly average amounts of organic C inputs (kg·ha⁻¹)	
	Rice straw	Chinese milk vetch straw
CK	0	0
MV	0	525.02 ± 65.03
S	651.74 ± 55.88	0
DS	1955.22 ± 84.38	0
SMV	884.04 ± 62.23	634.40 ± 136.61
DSMV	2200.42 ± 142.69	612.52 ± 100.25

The meaning of treatment is presented in Table 2.
Values are the mean ± standard deviation.

been due to the higher SOC content (Chen et al., 2016a; Pan et al., 2009). In general, the stagnation trend of rice yield is mainly due to changes in both quality and quantity of SOM, as SOM determines microbial activity and nutrient supply (Chen et al., 2016a; Cui and Holden, 2015; Sarker et al., 2018; Zhang et al., 2016). The results of the present study showed that the yearly average rice yield was significantly increased by application of rice straw and/or MV compared to CK, with the exception of the S treatment. The S treatment had the lowest rice yield in the organic amendment treatments, despite the S treatment having the second highest SOC content. This may indicate that the S treatment provides lower nutrient content than other organic amendment treatments.

Our results also indicated no significant correlations ($r^2 = 0.787$, $p < 0.06$) between SOC content and yearly average rice yield, which contrasted with the results found by Chen et al. (2016a). This difference may be caused by different qualities of SOC. As mentioned above, the quality of residue and the application time of residue (as in the S and DS treatments in the present study) may result in different composition of formed SOC (Chen et al., 2016b, 2018; Wang et al., 2017), which influence its mineralization (Fontaine et al., 2003; Takriti et al., 2018). This emphasizes the importance of the quality of SOC on nutrient supply (Fontaine et al., 2003). SOC composition influences its turnover and agroecosystem function (Sharma et al., 2017; Wang et al., 2017). Therefore, the quantity and quality of SOC should be considered.

Although there was no significant difference in the SOC and available nutrient content (except for AK), there was a trend that incorporation of MV resulted in higher rice yield compared to rice straw retention (S vs. MV; DS vs. SMV). These results highlight the importance of the quality of organic amendments on the SOM composition and nutrient supply (Ghosh et al., 2012; Sharma et al., 2017).

In the present study, we were unable to clarify the effect of quality or quantity of organic amendments on the accumulation of SOM and rice yield independently, because we did not design the independent factor. It is typically difficult to distinguish the effects of quality or quantity of organic amendments in field experiments, as there are several factors influencing the nutrient supply, such as other nutrients in organic amendments and application time of organic amendments (Liu et al., 2009).

5. Conclusions

This 4-year study suggested that application of organic amendments has a great potential to improve SOC accumulation, soil hydrolase activities, and rice yield. Compared to application of rice straw, the effects of MV are more obvious in nutrient supply and rice yield. Although it is difficult to distinguish the effects of quality or quantity of organic amendments on SOC accumulation, soil hydrolase activities, and rice yield in this study, our results suggested that the quality of C inputs exerts a stronger control than quantity of C inputs on SOC accumulation and nutrient supply. In this respect, the DSMV treatment, which has high quantity of diverse organic amendment inputs, had better performance with respect to soil chemical properties, enzyme activity, and rice yield, and is thus a more suitable regime for organic resource management practice.

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