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Effects of Land Management Practices on Labile Organic Carbon Fractions in Rice Cultivation

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Abstract: A research trial with four land management practices, i.e., traditional tillage-fallow (TTF), traditional tillage-wheat (TTW), conservation tillage-fallow (CTF) and conservation tillage-wheat (CTW), was sampled in the 15th year after its establishment to assess the effects of different management practices on labile organic carbon fractions (LOCFs), such as easily oxidizable organic carbon (EOC), dissolved organic carbon (DOC), particulate organic carbon (POC) and microbial biomass carbon (MBC) in a typical paddy soil, Chongqing, Southwest China. The results indicated that LOCFs were significantly influenced by the combination of no-tillage, ridge culture and crop rotation. And, different combination patterns showed different effectiveness on soil LOCFs. The effects of no-tillage, ridge culture and wheat cultivation on EOC, DOC, POC and MBC mainly happened at 0–10cm. At this depth, soil under CTW had higher EOC, DOC, POC and MBC contents, compared to TTF, TTW and CTF, respectively. Moreover, the contents of LOCFs for different practices generally decreased when the soil depth increased. Our findings suggest that the paddy soil in Southwest China could be managed to concentrate greater quantities of EOC, DOC, POC and MBC.
Keywords: no-tillage; rice-wheat rotation; ridge culture; labile organic carbon fraction; rice cultivation

1 Introduction

The effects of land management practices, especially tillage and crop practices, on soil labile organic carbon fractions (LOCFs) have been of great interest in recent years (Hu et al., 1997; Freixo et al., 2002), due to their vulnerability to disturbance, such as easily oxidizable organic carbon (EOC), dissolved organic carbon (DOC), particulate organic carbon (POC) and microbial biomass carbon (MBC). LOCFs are especially important, as they control the ecosystem productivity. Literatures showed that, in a relatively short time, LOCFs are more sensitive to the changes of tillage and crop practices than total organic carbon (TOC) (Blair et al., 1995; Chan et al., 2002). And, LOCFs rapidly turned, before soil TOC changed, when soil was disturbed by inappropriate practices. Therefore, soil may be either a source or a pool of carbon (C), depending significantly on land management practices changing.

Tillage induced the rapid loss of LOCFs, compared to no-tillage soils (Jacinthe et al., 2004). When soil was tilled, EOC decreased rapidly (Huang, 2005), and DOC was easily transported (Li and Shuman, 1997). Moreover, Bayer et al. (2001), Freixo et al. (2002) and Ouédraogo et al. (2005) found that POC presented an increasing trend under no-tillage. Wright et al. (2005) also observed that MBC had the lowest loss under no-tillage. The contribution of crop rotation to the concentrations of LOCFs is mainly attributed to the increased stubble, residue and roots in the soil (Freixo et al., 2002). Appropriate tillage and crop practices are essential to mitigate C loss from soil to atmosphere by managing those sensitive indictors. However, most of studies have mainly focused on upland soils. More attention also has been paid to the effects of sole tillage or crop practice. Moreover, nowadays, farmers widely adopt no-tillage, ridge culture and crop rotation in rice cultivation in China. But, very few of the effects of no-tillage, ridge culture and wheat cultivation on LOCFs in rice cultivation is known.

Disk tillage-fallow, as a traditional paddy system, is commonly found in Southwest China (Wei et al., 1989).

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This practice is not adequate to use paddy soil during winter and spring. Moreover, they require a large amount of labor resources. The combination of no-tillage, ridge culture and rice-wheat rotation, including both ancient and modern agricultural land management practices, is a rational ecology-production technique which will benefit the farmers and the ecological environment, and it has been widely used in rice cultivation in Southwest China. Some studies found that under no-tillage, ridge culture and rice-wheat rotation, crop yield increased and farming management was simplified, thus saving production costs (Xie and Chen, 2002). At the same time, soil conditions were obviously improved, in particular, soil C concentration in topsoil increased (Huang et al., 2006). Hence, to encourage farmers to adopt appropriate land management practices, the effects of different tillage and crop practices on LOCFs need to be evaluated.

At this study site, our previous research indicated that the TOC concentration in topsoil under the practices of no-tillage, ridge culture and rice-wheat rotation was 89% higher than that under disk tillage with monoculture rice (Shao et al., 2007a). The average rice yield was 10.3% greater, due to the increase of soil nutrients in the topsoil under this practice (Shao et al., 2007b). Moreover, no-tillage and ridge culture favored to increase soil aggregate stability (Wei et al., 1990). Under such conditions, soil nutrients and SOC were occluded within soil aggregates from microbial attack. Moreover, the increase of residue and root matter induced by crop rotation also contributed to the higher concentration of soil nutrients and SOC (Shao et al., 2005). The objective of this paper was to determine the effects of no-tillage, ridge culture and wheat cultivation on LOCFs in paddy soil.

2 Materials and Methods

2.1 Site description

A field experiment was established on the research farm of Southwest University (30°26′N, 106°26′E; 230m a. s. l.), Chongqing, Southwest China, in 1989. The climate is subtropical monsoon with an average annual temperature of 18.3℃, and a mean annual precipitation of 1105.4mm, of which 70% occurs in the period from May to September, and an annual frost-free period of 334d. The soil at the experimental site is paddy soil. The dominant clay mineral (<1μm) is illite (Wei et al., 1989). Characteristic chemical and physical properties of soil at 0–20cm in the experiment site are shown in Table 1, while similar measurements from soil collected during 1989–2005 were published in a book written by Xie and Chen (2002). Before setting up the experiment, the area had been cultivated with rice (*Oryza sativa*) or rice-wheat (*Triticum aestivum*) successively for 30yr under disk tillage (disk plough at 18cm depth followed by harrowing twice with light disk at 10cm depth).

Table 1 Chemical and physical properties of soils in study site

Clay (%)	pH	OM (g/kg)	Total N (g/kg)	Available N (mg/kg)	Available P (mg/kg)	Available K (mg/kg)
25.09	7.14	23.1	1.87	146	8.4	161.8

2.2 Experimental treatment

Rice-fallow and rice-wheat combining with traditional tillage and conservation tillage were used in this experiment, i.e., four land management practices of traditional tillage-fallow (TTF), traditional tillage-wheat (TTW), conservation tillage-fallow (CTF) and conservation tillage-wheat (CTW). The same rice variety was used in all plots in April, and the combination of wheat and rice was also the same in TTW and CTW. The treatment plots, 4m×5m, were arranged in a completely randomized block experimental design with four replications.

TTF: The paddy soil was disked (25–30cm deep) and harrowed with a disk-harrow three times in April, September and October of each year. The field was submerged 3cm all the year round, and the rice was cultivated. After the harvest of the rice crop, the field was re-flooded with water for fallow in winter.

TTW: Tillage was done as in TTF. The field was submerged 3cm, and rice was grown. After the harvest of the rice crop, the field was drained through ditches around the field, and wheat was grown in October. During the wheat growing season, the field was drained with ditches. After the harvest of the wheat crop, the field was submerged, disked and harrowed for rice cultivation next year.

CTF: No-tillage was performed. Ridges and furrows were made in the fields, and the total width of a ridge and a furrow was 55cm (Shao et al., 2007a). The ridges were 25cm wide on the top and the furrows were 30cm wide and 35cm deep (from the top of a ridge to the bottom of a furrow). Each plot consisted of 5 ridges. In this practice, the rice was planted on ridge tops. For 20 days since rice was planted, water surface was parallel with ridge top in the field, and during the rest in the year, water depth in furrows was 25–30cm, i.e., ridge tops protruded 5–10cm above water surface. After the harvest of the rice crop, the field lied fallow and was submerged with water without tillage.

CTW: No-tillage was performed as in CTF. Water level was similar to that of CTF during the rice growing season. After the harvest of the rice crop, water surface was lowered in furrows, mud in furrows was stacked by shovels on ridge tops, and then wheat was grown on ridge tops in October. During the wheat growing season, water surface in furrows was maintained at 5–10cm depth, i.e., ridge tops protruded 20–25cm above water surface. After the harvest of the wheat crop, the field was submerged up to ridge tops for the cultivation of rice next year.

2.3 Soil sampling

Composite soil samples were collected in September 2003 (after the rice harvest) from each plot at 0–10, 10–20, 20–30 and 30–40cm depths using a soil auger of 5cm diameter at three locations in each plot. Subsamples in each plot were mixed by depth. Subsamples were subsequently air-dried and finely ground, according to standard field study methods (Soil Survey Division Staff, 1993).

2.4 Measurement and analysis

EOC was determined by the method described by Blair et al. (1995). DOC was measured by dichromate oxidation titration (Ciavatta et al., 1991). POC was obtained following a modified procedure described by Willson (2001). And MBC was observed by the chloroform fumigation extraction (Vance et al., 1987). All statistical analyses were performed with SPSS, such as probability level (5%), standard deviation and Duncan′s Multiple Range Test (DMRT).

3 Results and Discussion

3.1 Easily oxidizable carbon (EOC)

The content of EOC at the topsoil was significantly influenced by different land management practices (Fig. 1). At 0–10cm, the contents of EOC under CTF and CTW were 2.09g/kg and 2.82g/kg, and 2.13g/kg and 2.86g/kg higher than those under TTF and TTW, respectively. Moreover, the proportion of EOC concentration at 0–10 cm soil to the total content of 0–40cm soil under CTW was greater than those under other practices. The effect of no-tillage and ridge culture on soil EOC mainly occurred in 0–10cm, similar to the findings obtained by Ni et al. (2001). However, for no-tillage and ridge culture, CTW had 0.73g/kg higher EOC content than CTF at 0–10cm. Under disk tillage, the effects of TTW on EOC was not obviously different at 0–10m, compared to TTF. Similar results were obtained by Huang (2005), who reported the effects of tillage management practices on SOC sequestration. This demonstrates that the continuous combination of no-tillage, ridge culture and rice-wheat rotation markedly increased EOC content in soil surface.

In addition, EOC contents for different practices generally decreased when the soil depth increased, and pronounced differences among different soil depths for the same practice could be detected. Moreover, different combinations of no-tillage, ridge culture and crop rota-

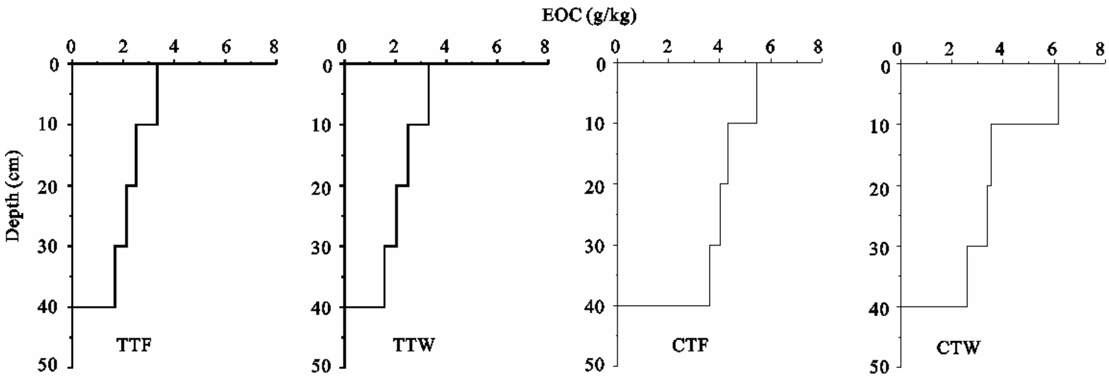

Fig. 1 Effects of land management practices on soil EOC

tion showed different effectiveness on soil EOC, regardless of the same or different soil depths. However, for conventional tillage practices, in all soil depths, the effects of TTF and TTW on EOC were not significant at P<0.05. That is, disk-tillage with single crop practices did not result in obvious differences of soil EOC content. For no-tillage and ridge culture practices, soils under CTF and CTW had pronounced different EOC concentrations at 0–10cm depth, while except for this depth, CTF presented stronger significance of effect on EOC compared with CTW. A possible reason resulted in this finding: the effectiveness of CTF and CTW on soil environment are greatly different due to the combination of no-tillage and ridge culture, despite that the difference between them is also merely from crop practices.

No-tillage and ridge culture, in some degree, improved soil microenvironment, e.g., soil structure, moisture, porosity, temperature, etc., thus further increased the activities of soil microbe and enzyme (Wei et al., 1989). These conditions favorably concentrated EOC in soil, associating with that the active layer of crop root was increased, and crop yield was heightened. Liu Shuxia et al. (2003) found that there was significant positive relation between soil EOC content and crop yield. Comparing CTF with CTW, it is found that in the non-rice growing season, the fallow field under CTF was submerged without tillage, which made microbe and enzyme activities decrease (Xie and Chen, 2002), and further led to EOC mineralization decrease. Namely, submerged water after rice harvest could have a strong protection on soil EOC. For CTW, the water table was lowered during the wheat-growing season. The exposing of topsoil to the air for a longer time led to higher soil oxidation-reduction potential (Eh) (Shao et al., 2005). Thus, high oxidation led to EOC decomposition. But, the more crop residue and stubble returned to soil under CTW apparently helped to increase EOC content yet.

3.2 Dissolved organic carbon (DOC)

As shown in Fig. 2, significant differences (P<0.05) in DOC changes between practices were observed, especially in the topsoil. At 0–10cm, the content of DOC under CTW was 0.1g/kg, 0.17g/kg and 0.09g/kg higher than those under TTF, TTW and CTF, respectively. Soil DOC content of 0–40cm under CTW was 44.9%, 153.6% and 24.6% higher than those under TTF, TTW and CTF, respectively, whilst at 0–20cm, its DOC concentration occupied 74.6% of total DOC in 0–40cm. The effectiveness of CTW on DOC was stronger than that of TTW, while the difference of effects between TTF and CTF on DOC were not prounounced. These findings indicate that the combination of no-tillage, ridge culture and wheat cultivation significantly increased soil DOC content at 0–20cm.

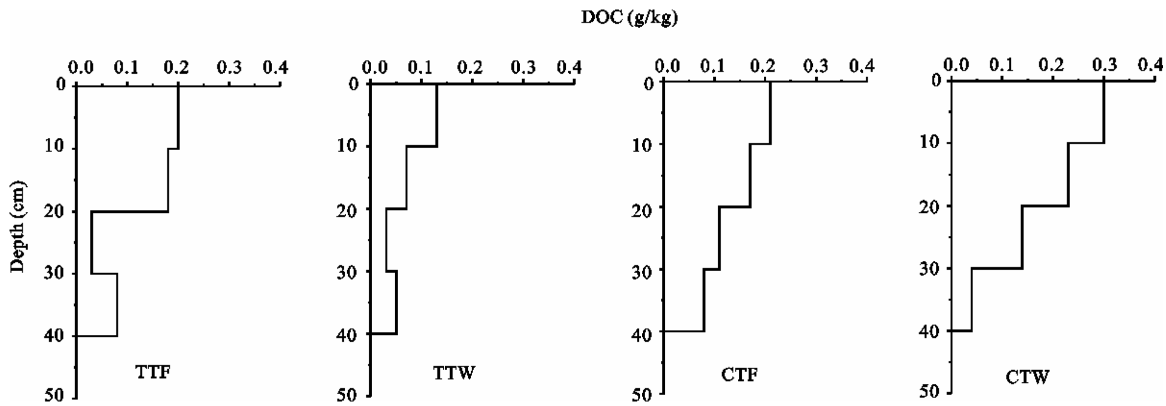

Fig. 2 Effects of land management practices on soil DOC

Paddy soil under CTW is subjected to alternating drainage and submerged conditions during non-rice and rice growing seasons. Such conditions resulted in capillary rise. And, the larger amout of DOC concentrated in the field surface due to the transport of DOC from lower soil layers to the surface. Certainly, upward movement of DOC also explained the DOC stratification in the paddy soil profile (Chan et al., 2002).

The effects of different practices on DOC were identified to three distinct groups at all depths. Similar to the distribution of EOC in soil profile, DOC concentrations were significantly different in the surface from those in the deeper layer. Under rice-wheat rotation, though CTW and TTW both presented drainage and submerged cycles, their hydrothermal conditions showed significant differences, because of different tillage practice. Regardless of the rice or non-rice growing season, soil under CTW, had higher surface soil temperature and more capillary water than those under TTW did. No-tillage and ridge culture improved soil structure, thus making observably sequestered more DOC content. But, DOC was not different between TTF and CTF. The main reasons were that no-tillage and ridge culture might increase DOC with more stubbles, plant roots and root exudates in equilibrium with DOC decomposition resulted from microbial populations and their activity increase.

For paddy soils under CTW, submerged and drainage cycles between the rice and non-rice growing season were very frequent, and soil moisture on ridge top was near field capacity conditions during the non-rice growing season. Surface soil temperature, plant residue and root matter under this practice also increased, especially in surface soil layer. Under these circumstances, the concentration of DOC was greater under CTW than CTF at 0–10cm. Soil water-stable aggregates enhanced by 20%–45% under no-tillage, ridge culture with rice-wheat rotation when compared to disk tillage (Wei et al., 1996). Thus, the improvement of soil aggregates could protect soluble soil organic matter from microbial attack. This result was different from that reported by Li et al. (2004), but was consistent with the results of Lundquist et al. (1999). The reasons resulted in this contradiction were possibly different soil types and tillage practices, e.g., Li et al. (2004) applying red paddy soil in conventional tillage.

3.3 Particulate organic carbon (POC)

POC was remarkably influenced by no-tillage, ridge culture and rice-wheat rotation, as shown in Fig. 3. Significant changes in soil POC were detected at 0–20cm, similar to the findings reported by Chan et al. (2002). At 0–10cm, the amount of soil POC under CTW was 5.33g/kg, 6.03g/kg and 5.34g/kg higher than those under TTF, TTW and CTF, respectively. At 10–20cm, it was 3.1g/kg, 4.72g/kg and 4.02g/kg higher than those under TTF, TTW and CTF, respectively. The amount of POC in 0–20cm under CTW showed 8.4g/kg, 10.8g/kg and 9.4g/kg higher POC contents, compared to TTF, TTW and CTF at the same soil depth, respectively. But, soil under single no-tillage and ridge culture or rice-wheat rotation did not concentrate POC obviously. The effects of TTW and CTF on POC at 0–10cm were not significantly different ($P<0.05$), compared to TTF, respectively. At 10–20cm, no pronounced differences occurred between CTF and TTW. Moreover, POC content presented obvious stratification, decreasing with soil depth, regardless of conversation or traditional tillage.

POC mainly affixed to plant debris and roots (Haynes, 2005). Disk tillage diluted POC, and transported it downwards. No-tillage did not disturb soil, thus soil POC was not fragmented. Crop rotation can increase the return of stubble, residue and roots, thus contributing to POC concentration in the surface soil. Moreover, the combination of no-tillage with ridge culture could effectively harmonize the soil hydrothermal, aerial and fertile periodicity balance (i.e., stabilization and slight change at time level, homogeneousness at space level), and supply nutrient for crops with stabilization, average, sufficiency and propriety. Thus, crop growth was very well, and fine root fragments and other organic debris were more adequate in topsoil. Under such conditions, POC was easily combined with soil clay and silt. Similar results on pastures were reported by Franzluebbers and Stuedemann (2002).

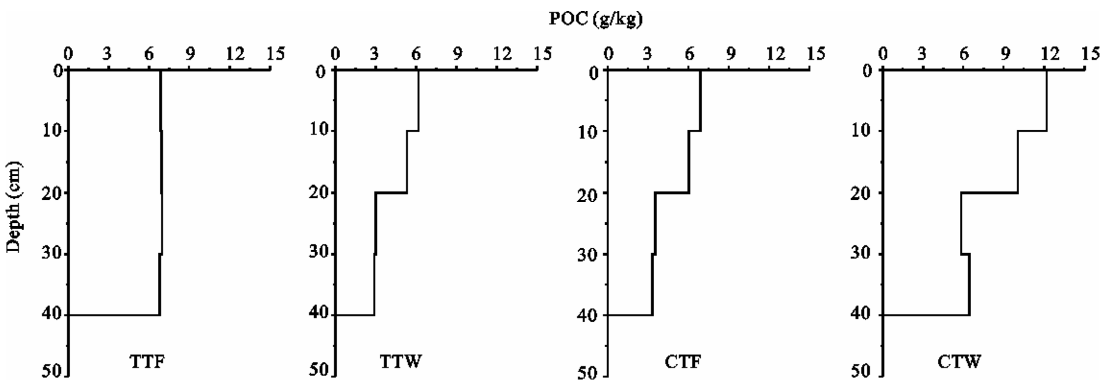

Fig. 3 Effects of land management practices on soil POC

Rotation of rice with wheat maintained continuous vegetation. This practice incorporated the alternate drainage and submerged cycles into wheat straw more effectively improved soil structure and hydrothermal conditions, and further increased POC concentration input to the soil. Yang et al. (2005) found similar results that the increase of POC concentration amounted to 32.7% under wetting and drying. Hence, the combination of no-tillage and ridge culture with rice wheat rotation helped to sequester more POC content in the topsoil. But, compared to TTF, it was found that no-tillage and ridge culture under CTF presented a potential equilibrium between POC concentration resulting from an increase of water-stable aggregates, crop debris and roots and POC decomposition induced by an augmenting of microbial populations and their activities. Consequently, no significant differences between the effectiveness of TTF, CTF and TTW on POC occurred at 0–10cm soil layer.

3.4 Microbial biomass carbon (MBC)

No-tillage, ridge culture and rice-wheat rotation significantly influenced soil MBC content (Fig. 4). This result was consistent with Wright et al. (2005) who found MBC was higher under no-tillage with crop rotation in surface soils. At 0–10cm, soil under CTW had 0.29g/kg, 0.38g/kg and 0.31g/kg higher MBC content than those under TTF, TTW and CTF, respectively. At 10–20cm, the rank of soil MBC content was CTW>CTF>TTF>TTW. However, no obvious differences occurred when compared to the effects of TTF and CTF on MBC. For no-tillage and ridge culture, there were significant differences in soil MBC observed between CTF and CTW at topsoil. Moreover, the distribution of MBC under different practices decreased with increase of soil depth as well. At 0–20cm, MBC content explained 70.0%, 57.1%, 68.8% and 81.1% of total MBC accumulation of 0–40cm under TTF, TTW, CTF and CTW, respectively. Especially, at 0–20cm, soil under CTW showed a 75.5%, 168.8% and 62.3% higher MBC concentration, as compared to TTF, TTW and CTF, respectively. Long-term continuous combinations of no-tillage, ridge culture and crop rotation could significantly increase MBC concentration at 0–20cm soil layer, because the topsoil has not been disturbed by till. Comparing to TTF and CTF, it might be detected that, although different tillage practices were adopted, their effects on MBC were not obviously different due to the same crop practice.

MBC derived from plant debris and humic acid. No-tillage and ridge culture improved soil structure and adjust soil water, heat, gas and plant nutrient cycles, thus energy for survival of soil microbe populations was supplied. These circumstances could dramatically increase soil microbial populations (Xiao et al., 2002). Certainly, soil under such conditions favorably increased the nutrient potential for crops through microbial biomass mineralizing and nutrient immobilizing. Moreover, many plant roots under shoaled cultivated horizon would be expected in surface layer (at average 0–20cm). Continuous disk tillage is a soil disturbing process, and influenced soil biological properties. Mentioned-above results also showed that single no-tillage and ridge culture or crop rotation did not cause significant differences in soil MBC in rice cultivation.

During the non-rice growing season, for CTW, water table in the furrows was lowered and wheat was grown.

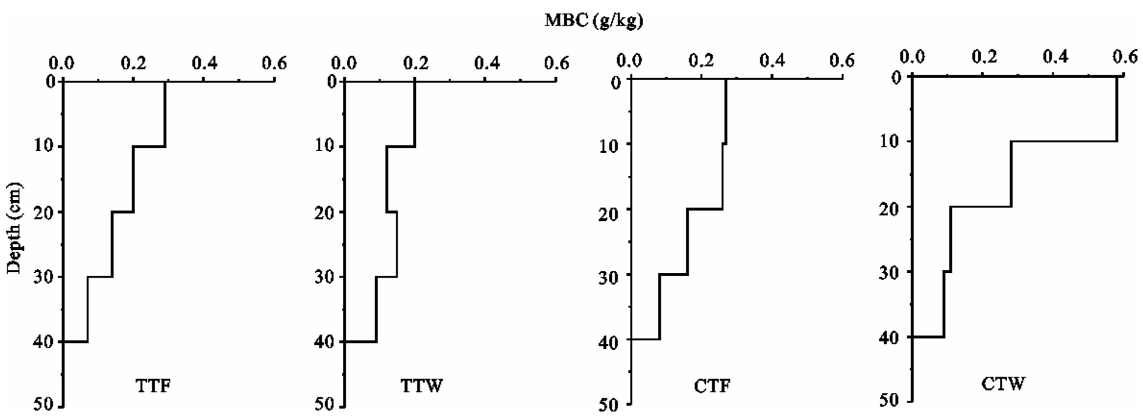

Fig. 4 Effects of land management practices on soil MBC

Continuous drainage and submerged cycles under CTW helped to enhance soil microbial populations, as it produced enough energy to maintain microbial existence, compared to CTF. Rice-wheat rotation could accumulate more dead plants, roots, and low-molecular-weight root exudates than rice-fallow. Such circumstances dramatically increased soil microbial populations, similar to results reported by Huang et al. (2006). That is, no-tillage, ridge culture and rice-wheat rotation significantly increased MBC concentration in topsoil. Liu Shoulong et al. (2003) also proposed that increasing the input of organic matter (e.g., straw and manure) was an effective way to enhance the size of the microbial biomass in paddy soils. But, the field under CTF was in fallow and submerged after the rice harvest without tillage, and this led to a decrease of MBC decomposition and mineralization, ascribed to lower temperature and microbial respiration in the surface soil, the amount of MBC decomposition was less. Thus, the effectiveness of CTW on MBC was more likely to sequester MBC at topsoil.

4 Conclusions

The results from this study indicated that appropriate land management practices could sequester more LOCFs in the topsoil. No-tillage, ridge culture and rice-wheat rotation for 15yr significantly increased soil EOC, DOC, POC and MBC concentrations in 0–20 cm soil depth, especially in 0–10cm. At 0–10cm soil depth, soil under CTW had higher EOC, DOC, POC and MBC, compared to TTF, TTW and CTF, respectively. This demonstrated that the combination of no-tillage, ridge culture and wheat cultivation was the best land management practices in rice cultivation, and it could manage paddy soil in Southwest China to sequester greater quantities of EOC, DOC, POC and MBC.

But, this study, followed up previous researches, only analyzed the effects of different combinations of no-tillage, ridge culture and crop rotation on LOCFs. Real relations among soil microenvironments, e.g., soil aggregation, primary productivity, water regime, temperature, micro biomass, nutrient, etc., induced by different practices and LOCFs were still not obtained. Moreover, this paper measured the effects of different practices on LOCFs alone, and did not understand mutual relationships among them. Certainly, there is an even poorer understanding of the complex factors and processes how to control LOCFs under appropriate land management practices in paddy soil. Future study should mainly focus on those fields.

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