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Impacts of Rice Field Winter Planting on Soil Organic Carbon and Carbon Management Index

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ABSTRACT

To tackle with the problem of prevailing farmland abandonment in winter, 5 treatments includes Chinese milk vetch-double cropping rice (CRR), rape-double cropping rice (RRR), garlic-double cropping rice (GRR), winter crop multiple cropping rotation (ROT), winter fallow control (WRR) were set up. By measuring soil total organic carbon, active organic carbon and its components and calculating the soil carbon pool management index in 0~15 cm and 15~30 cm soil layers in the early and late rice ripening stage. The effects of different winter planting patterns on the changes of soil organic carbon and carbon pool management index were discussed. In order to provide theoretical basis for the optimization and adjustment of winter planting pattern of double cropping rice field in the middle reaches of Yangtze River. The results showed that soil total organic carbon, active organic carbon and its components in different winter cropping patterns were increased, and ROT and CRR treatments were more beneficial to the accumulation of soil total organic carbon, active organic carbon and its components as well as the improvement of soil carbon pool management index, which should be preferred in the adjustment of cropping patterns.

1. Introduction

Soil carbon pool is the largest in terrestrial ecosystem, which has an important impact on global climate change and sustainable development of ecological environment. Soil carbon pool is composed of organic carbon pool and inorganic carbon pool, of which the former accounts for a large proportion [1]. The global soil organic carbon pool reserves are about 1500 Pg (1 Pg = 10^{15} g), accounting for about 2/3 of the whole terrestrial ecosystem, about twice the atmospheric carbon pool and three times the terrestrial vegetation carbon pool. Therefore, small changes can lead to large fluctuations in atmospheric CO_2 concentration and have a profound impact on the global climate environment [2,3]. Moreover, as the basis of soil fertility soil organic carbon has a direct impact on cultivated land quality and crop yield [4]. Soil organic carbon are often divided into the inactive organic carbon and active organic carbon, the latter one includes readily oxidizable organic carbon, dissolved organic carbon, mineralizable organic carbon and microbial biomass

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carbon. The proportion of active organic carbon is very small, but it is responsive to the agricultural management measures, and was used as a predictor of soil total organic carbon tendency [5]. Carbon Pool Management Index (CPMI) is often combined with soil organic carbon to represent soil organic carbon changes under different agricultural management measures, which can better reflect the impact of agricultural management measures on soil quality [6]. The middle and lower reaches of the Yangtze River is the main rice producing area in China, which supplies 1/4 of the grain and more than 1/2 of the rice in China. It is a veritable "grain depot" and "barn" in China and has a strategic position that cannot be ignored [7]. However, in the middle and lower reaches of the Yangtze River, farmland abandonment is common, especially in winter. In addition, the utilization rate of crop straw is not high in the middle and lower reaches of the Yangtze River, while straw returning is an important soil fertilizer cultivation measure. It is one of the important measures for the green and sustainable development of double cropping rice field in the middle reaches of Yangtze River to realize the multiple cropping rotation pattern of "raising the field with the field" by planting green manure in winter. Therefore, it is necessary to explore suitable planting pattern and make full use of winter fallow land to plant green manure or cash crops. At present, there have been many studies on winter crop planting. Yang Binjuan et al. [8] showed that the soil total organic carbon content and active organic carbon content increased by 22.2% and 26.7% on average when Chinese milk vetch was returned to the field. Yuan Miaomiao et al. [9] showed that spring rape overturn to the field could significantly improve the content of soil humus components, hot water- soluble organic matter and carbon pool management index. However, these studies are mainly limited to "Chinese milk vetch-rice" and "rape-rice", which are common winter planting patterns in southern China, but there are few studies on other winter planting patterns and winter crop multiple cropping rotation. Therefore, in this study, 5 treatments includes Chinese milk vetch-double cropping rice (CRR), rape-double cropping rice (RRR), garlic-double cropping rice (GRR), winter crop multiple cropping rotation (ROT), winter fallow control (WRR) were set up to measure the content of soil total organic carbon, active organic carbon and its components, soil carbon pool management index. The effects of different winter planting patterns on soil organic carbon pool in double cropping rice fields were analyzed, looking forward to provide theoretical basis for the optimization and adjustment of winter planting pattern of double cropping rice field in the middle reaches of Yangtze River.

2. Materials and Methods

2.1 Overview of Experiment Site

The experiment was conducted from October 2019 to October 2020 in the experimental field (28° 41′ N, 116° 55′ E) of Institute of Agricultural Sciences in Wannian County, Jiangxi Province, a typical double cropping rice area in Northeast Jiangxi. The experimental site is the transition zone between the residual vein of Huaiyu mountain system and Poyang Lake Plain, which belongs to subtropical monsoon climate, with four distinct seasons: humid climate, abundant rainfall, sufficient sunshine and abundant light and heat resources. During the experiment period, the annual average temperature is 18.6 ºC, the extreme maximum temperature is 38.3 ºC, the extreme minimum temperature is -5 ºC, the annual average rainfall is 1908.4 mm, the annual average sunshine duration is 1662.65 h, the annual average wind speed is 1.3 $m\cdot s^{-1}$, and the annual frost free period is 260 days. The tested soil is a hydrogric soil developed by the fourth Red Clay parent material. Before the experiment, the fertility of topsoil (0 ~ 15 cm) was pH 6.08, organic matter 41.81 $g\cdot kg^{-1}$, total nitrogen 1.97 $g\cdot kg^{-1}$, available phosphorus 16.38 $mg\cdot kg^{-1}$ and available potassium 130.00 $mg\cdot kg^{-1}$.

2.2 Experimental Design

A single factor randomized block design was adopted in the experiment. A total of 5 treatments were set up: Chinese milk vetch-double cropping rice (CRR), rape-double cropping rice (RRR), garlic-double cropping rice (GRR), winter crop multiple cropping rotation (ROT), winter fallow control (WRR). The winter crops of ROT treatment have been rotated between potato, Chinese milk vetch and rape since the winter of 2012. The winter crops of this treatment were Chinese milk vetch in 2020. A

Table 1. Design of rice field winter planting patterns

Crop rotation treatment	Treatment code	Note
Winter fallow control	WRR (CK)	Winter fallow
Chinese milk vetch- double cropping rice	CRR	Continuous planting of Chinese milk vetch in winter and returning to the field at maturity stage
rape- double cropping rice	RRR	Continuous planting of rape in winter, and the straw was crushed and overturned to the field after seed collection at maturity stage
garlic- double cropping rice	GRR	Continuous cropping of garlic in winter and the stems are harvested
winter crop multiple cropping rotation	ROT	Winter crop rotation, which is the rotation of potato, garlic, rape and Chinese milk vetch, and the corresponding straw returning to the field

protective belt with a width of 1.5 m has been set around the experiment plot for isolation. The area of each plot is 66.0 m^2. Five treatments were set for three repetitions, 15 experiment plots in total. The soil fertility status of each area is basically the same before the experiment (Table 1).

2.3 Crop Varieties and Field Management

The variety of Chinese milk vetch was "Chinese milk vetch No. 1", and the sowing time was September 28, 2019; The rape variety was "March yellow" and the garlic variety was "Shandong Jinxiang". The sowing time of rape and garlic was November 2, 2019. Before planting, ditch, border and rake are opened, and the plant row spacing was 18 × 5 cm. Winter crops were applied with "Sanyuan" brand compound fertilizer (N: P_2O_5: K_2O = 15%: 15%: 15%). After sowing, some late rice straw were covered to ensure the normal growth of winter crops. All winter crops were harvested on April 15, 2020 and the straw were turned over and returned to the field. The early rice variety was "Zhongzao 37" and the late rice variety was "Jingliangyouhuazhan". The amount of fertilizer applied to early and late rice in each plot was the same, including urea (converted into N, 46%) 135.58 $kg·hm^{-2}$, calcium superphosphate (converted into P_2O_5, 12%) 50.91 $kg·hm^{-2}$ and potassium chloride (converted into K_2O, 60%) 122.73 $kg·hm^{-2}$. All phosphorus fertilizer were applied as base fertilizer before rice transplanting. Potassium fertilizer and nitrogen fertilizer were applied as base fertilizer, tiller fertilizer and panicle fertilizer respectively. The ratio of base fertilizer, tiller fertilizer, panicle fertilizer was 2:2:1. Tiller fertilizer was applied 5 ~ 7 days after transplanting, and panicle fertilizer was applied when the young panicle of main stem is 1 ~ 2 cm long. The planting method of early and late rice was artificial planting, and the plant row spacing is 20 × 20 cm. The sowing time of early rice was April 1, 2020, transplanting on May 8 and harvesting on July 15. The sowing time of late rice is June 11, 2020, transplanting on July 17 and harvesting on October 24. After the harvest of early rice, all straw were chopped, turned and pressed back to the field, and half of the straw were returned to the field after the harvest of late rice. Other management measures were the same as conventional field production.

2.4 Sample Collection and Determination

After the harvest of early rice and late rice in 2020, soil samples in 0 ~ 15 cm and 15 ~ 30 cm layers were collected by soil drill in the paddy field. The field experiment includes 5 treatments and there were 3 replicates for each treatment. For each replicate, same amount of soil taken from 5 sites were collected by "S-shaped sampling method" and mixed evenly to become one. After picking out plant residues and sundries, samples were separated into two parts: one part was naturally air dried and sieved by 0.25 mm for determination of total organic carbon, active organic carbon, readily oxidizable organic carbon; the other part was stored in -4 ºC refrigerator for the determination of soil microbial biomass carbon and dissolved organic carbon. Total organic carbon was determined by potassium dichromate volumetric method dilution heat method; active organic carbon was determined by potassium permanganate oxidation colorimetry; the readily oxidizable organic carbon was determined by potassium permanganate external heating method; microbial biomass carbon was determined by Chloroform Fumigation K_2SO_4 extraction method; available phosphorus was determined by $NaHCO_3$ extraction molybdenum antimony anti absorption spectrophotometry; available potassium was determined by NH_4OAc extraction flame spectrophotometry; soil total nitrogen was determined by semi micro Kjeldahl method. In addition, before the harvest of the early and late rice, the yields of all plots were measured, the rice is weighed after threshing, headed in the oven at 105 ºC for 30 minutes, then adjusted to 80 ºC and weighed after drying, and the moisture content is calculated. Taking the surrounding abandoned farmland soil as a reference, the soil carbon pool management index is calculated according to the following formula：

Carbon pool management index (CPMI) = carbon pool index × Carbon pool activity index × 100% (1)

Carbon pool index (CPI) = soil organic carbon content / reference farmland soil organic carbon content (2)

Carbon pool activity (CPA) = soil active organic carbon / steady- state carbon (3)

Steady state carbon = total soil organic carbon − active organic carbon (4)

Carbon pool activity index (CPAI) = sample carbon pool activity / reference soil carbon pool activity (5)

2.5 Data Processing

Microsoft Excel 2019 software was used for data processing, SAS 9.4 statistical analysis software was used for one- way ANOVA and Origin was used for plotting.

3. Results

3.1 Effects of Rice Field Winter Planting on Rice Yield

The early and late rice yields of each winter planting treatment were increased when compared with the winter fallow treatment (Table 2). In terms of early rice yield, all treatments were 7.91~10.7% higher than the control (P<0.05), among which ROT treatment was the highest, but showed no significant difference from other treatments except the control treatment. The early rice yield of each treatment was 3.57~6.89% higher than that of the control, respectively, and the highest was GRR (8515.42 kg·hm^{-2}), followed by RRR, which were significantly different from that of the control treatment (P<0.05). In terms of annual rice yield, there was significant difference between winter planting treatments and the control treatments (P<0.05). GRR treatment had the highest yield performance, which increased by 7.86% compared with the control, but there was no significant difference between GRR treatment and other winter planting treatments. According to the above analysis, all winter planting patterns are beneficial to increase the yield of early and late rice as well as the annual yield.

3.2 Effects of rice field winter planting patterns on soil organic carbon pool

3.2.1 Effects of Rice Field Winter Planting Patterns on Soil TOC, AOC, ROC, DOC, MBC

The content of TOC, AOC, ROC, DOC, MBC in 0~15 cm soil layer under each treatment is generally higher than that in 15~30 cm soil layer (Figure 1). For soil TOC content, in terms of early rice ripening stage, the TOC content in both 2 soil layers of different winter planting treatments was 13.99~17.97% and 18.62~23.72% higher than that of the winter fallow, respectively (P<0.05). In the late rice ripening stage, the TOC content of CRR and GRR treatments in 0~15 cm soil layer was higher than that of control by 7.11% and 7.42% (P<0.05), respectively (Figure 1a). The AOC content of the winter planting treatments is significantly higher than that of the control (P<0.05). Moreover, among all winter planting patterns, ROT treatment had the highest AOC content in both 0~15 cm and 15~30 cm soil layers at early and late rice ripening stages, indicating winter multiple cropping rotation pattern was the most beneficial to soil AOC accumulation (Figure 1b).

While for soil ROC content, there was no significant difference between the treatments in 0~15 cm soil layer at both the early and the late rice rippening stage. In 15~30 cm soil layer, the ROC content of winter planting treatments was significantly higher than that of the control (P<0.05) (Figure 1c). For soil DOC content, CRR and ROT treatments had the higher DOC content in 0~15 cm soil layer at both the early and the late rice rippening stage. For 15~30 cm soil layer, DOC content in CRR treatment was significantly higher than other treatmentsl (P<0.05) (Figure 1d). The soil MBC content is highest in ROT treatment in both soil layers at the early rice rippening stage and 0~15 cm layer of the late rice rippening stage. In 0~15 cm soil layer at early rice ripening stage, MBC content of ROT treatment was 479.3 mg·kg^{-1}, which was 38.45% and 18.4% higher than that of WRR and GRR, respectively (P<0.05). While the CRR treatment had the highest MBC content in 15~30 cm soil layer at the late rice rippening stage (Figure 1e).

3.2.2 Effects of Different Winter Planting Patterns on Soil Carbon Pool Management Index

All the carbon storage management indexes in the winter planting pattern tend to be higher than those in the winter fallow treatment, and all the carbon storage management indexes in the 0~15 cm soil layer are generally greater than 15~30 cm (Table 3). In terms of early rice ripening stage, all winter planting treatments in 0~15 cm soil layer significantly increased soil stable carbon, carbon pool index and carbon pool management index (P<0.05), among which the highest carbon pool management index was ROT treatment, which had significant differences with GRR and RRR treatment (P<0.05). Compared with WRR treatment, it increased by 16.07%. In the 15~30 cm soil layer, soil carbon pool indexes

Table 2. Impacts of winter planting patterns on rice yield (kg·hm^{-2})

Treatments	Early rice yield	Late rice yield	Annual rice yield
WRR (CK)	5201.15±122.59b	7968.16±373.43b	13169.31±323.64b
CRR	5612.45±135.42a	8252.73±566.20ab	13865.18±430.80a
RRR	5682.49±379.63a	8493.54±492.90a	14176.03±656.11a
GRR	5688.89±203.67a	8515.42±427.29a	14204.31±234.02a
ROT	5757.45±94.39a	8405.97±430.64ab	14163.42±337.05a

Note: Data is averaged ± SE of 3 replicates. The difference letter in same column indicated significantly at 5% levels.

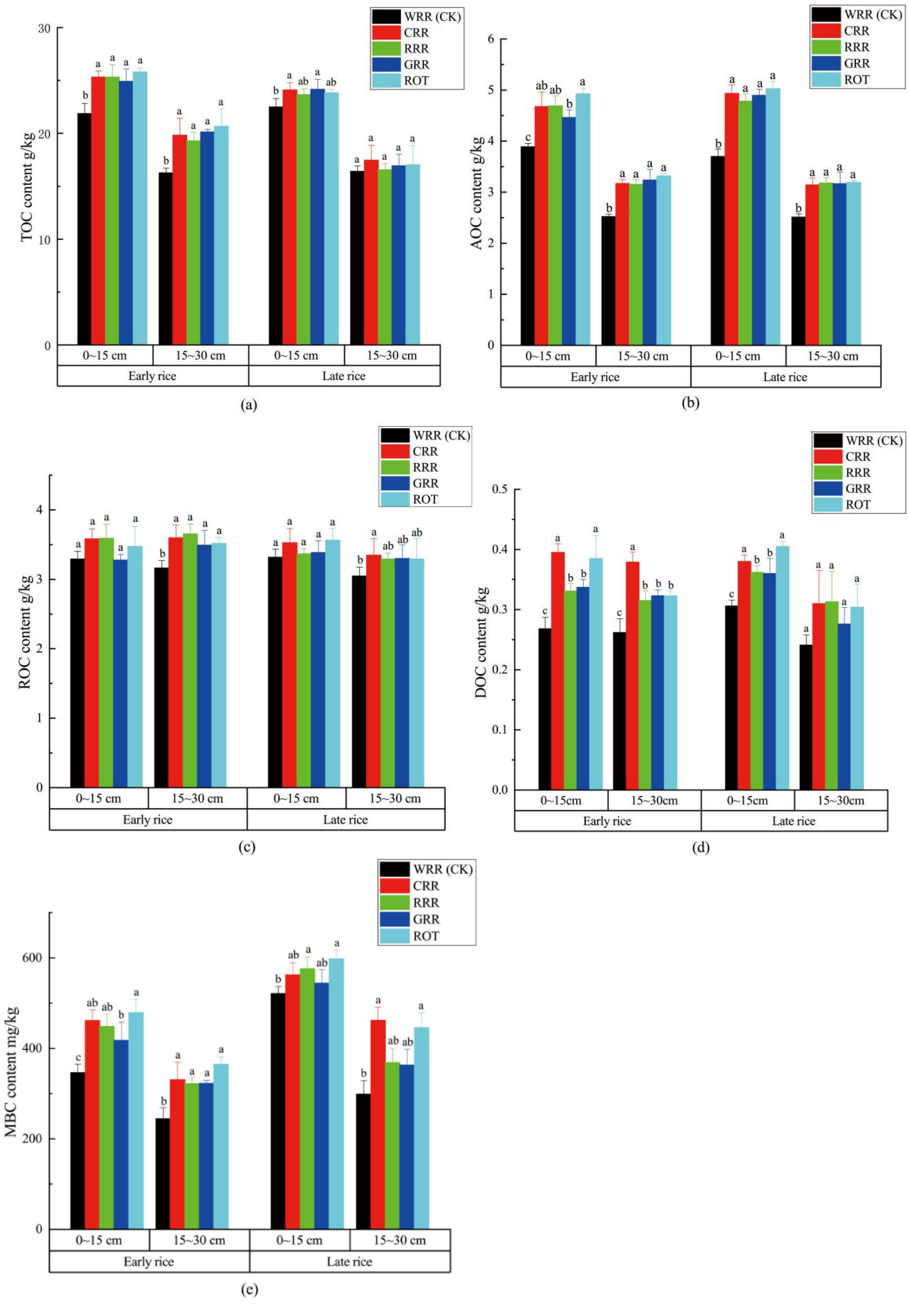

Figure 1. Effects of rice field winter planting patterns on (a) soil total organic carbon (TOC), (b) soil active organic carbon (AOC), (c) soil readily oxidizable organic carbon (ROC), (d) soil dissolved organic carbon (DOC) and (e) soil microbial biomass carbon. The vertical bars are showing the mean of three replications with ± SE. The different lower case letters show that treatments differ at p≤ 0.05. Abbreviations: CRR, Chinese milk vetch- double cropping rice; RRR, rape- double cropping rice; GRR, garlic- double cropping rice; ROT, winter crop multiple cropping rotation; WRR, winter fallow control.

Table 3. Impacts of rice field winter planting on carbon management index

Sampling stage	Soil layer	Treatments	Stable carbon (g/kg)	Carbon pool index	Carbon pool activity index	Carbon pool management index
Early rice ripening stage	0~15 cm	WRR	17.98±0.99b	1.24±0.05b	1.19±0.07a	147.34±3.60c
		CRR	20.66±0.66a	1.44±0.03a	1.24±0.10a	178.66±13.63ab
		RRR	20.64±1.15a	1.44±0.07a	1.25±0.09a	179.25±9.14ab
		GRR	20.47±1.3a	1.41±0.07a	1.20±0.11a	169.39±8.41b
		ROT	20.87±0.36a	1.46±0.02a	1.30±0.04a	189.55±5.17a
	15~30 cm	WRR	13.74±0.48b	0.92±0.03b	1.01±0.05a	92.98±2.30b
		CRR	16.66±1.53a	0.13±0.09a	1.05±0.07a	117.49±1.94a
		RRR	16.15±0.87a	1.10±0.05a	1.08±0.07a	117.4±4.95a
		GRR	16.90±0.14a	1.14±0.01a	1.05±0.07a	120.09±8.90a
		ROT	17.35±1.67a	1.17±0.09a	1.06±0.12a	123.28±4.00a
Late rice ripening stage	0~15 cm	WRR	17.80±0.73b	1.22±0.05b	1.14±0.05b	138.98±6.02b
		CRR	19.17±0.64a	1.37±0.04a	1.41±0.06a	193.11±7.71a
		RRR	18.89±0.46ab	1.34±0.03a	1.39±0.04a	186.44±6.51a
		GRR	19.27±0.95a	1.37±0.05a	1.40±0.08a	191.21±6.01a
		ROT	18.81±0.45ab	1.35±0.02a	1.47±0.07a	198.34±7.80a
	15~30 cm	WRR	13.55±0.47a	0.91±0.03a	1.01±0.02b	92.74±2.12b
		CRR	14.32±1.29a	0.99±0.08a	1.21±0.06ab	119.33±4.17a
		RRR	13.39±0.48a	0.94±0.03a	1.30±0.01a	122.49±3.95a
		GRR	14.23±1.20a	0.99±0.06a	1.22±0.16ab	120.75±0.11a
		ROT	13.84±1.83a	0.97±0.10a	1.28±0.17a	122.62±0.05a

Note: Data is averaged ± SE of 3 replicates. The difference letter in same column indicated significantly at 5% levels.

showed a similar trend to those in the 0~15 cm soil layer. The soil stable carbon, carbon pool index and carbon pool management index of all winter planting treatments were significantly higher than those of the control treatment, showing the trend of ROT>GRR>CRR>RRR, and ROT treatment increased 26.27% compared with WRR treatment. As for the late rice ripening stage, in the 0~15 cm soil layer, the stable carbon content of GRR and RRR treatments was 19.27 and 18.89 $g \cdot kg^{-1}$, respectively. All the treatments improved the carbon pool index, and the carbon pool activity index, carbon pool activity index and carbon pool management index were significantly different from those of WRR treatment. In the 15~30 cm soil layer, RRR and ROT treatments significantly increased the carbon pool activity index by 22.31 and 21.1% compared with WRR treatments, respectively. Soil carbon pool management index was significantly increased by 22.28~24.37% ($P<0.05$) (Table 3).

4. Discussion

4.1 Effects of Rice Field Winter Planting Patterns on Soil Organic Carbon and Its Fractions

It is generally believed that winter crop multiple cropping rotation can increase TOC content. On the one hand, this is due to the direct input of organic carbon into soil by returning straw of winter crops [10], on the other hand, returning winter crop straw to the field can potentially improve the nutrient supply state of farmland soil and increase crop rhizosphere sediment, thus increasing TOC content [11]. Yuan Jiaxin et al. [12] showed that compared with winter planting of Chinese milk vetch, winter planting of rape and winter planting of potato increased soil organic carbon content. Wang Shubin et al. [13] believed that winter planting of Chinese milk vetch and rape increased soil organic carbon content compared with winter fallow treatment. The results of this study show that planting different winter crops can significantly increase soil organic carbon content, which is similar with the conclusions of previous studies [13,14]. This may be due to the straw returning of Chinese milk vetch and rape, which increased the input of organic carbon. In addition, winter multiple planting potentially improved nutrient availability and promoted the growth of subsequent rice crops, thereby increasing the rhizosphere biomass remaining in the soil and the amount of straw returned to the field. Many studies have shown that soil organic carbon content decreases with the deepening of soil depth

[15-17]. In this study, a similar conclusion was drawn that TOC content in 0~15 cm soil layer was generally higher than that in 15~30 cm soil layer, mainly because crop litter, crop roots and fertilization mainly acted on the surface soil, meanwhile the surface soil structure was loose, which was conducive to TOC accumulation. The soil organic carbon content in 15~30 cm soil layer under different winter planting patterns was significantly higher than that under winter fallow treatments, which further indicated that different winter planting patterns firstly increased the soil organic carbon content in the surface layer, and then transported the organic carbon to the deep soil through leaching and infiltration.

TOC content is not sensitive to the change of agricultural management measures comparing with the active organic carbon pool,which is more sensitive to predict the variation trend of soil organic carbon [18]. The active organic carbon pool consists of readily oxidizable organic carbon, dissolved organic carbon and microbial biomass carbon. Yang Binjuan et al. [8] showed that after two years of planting green manure in winter and returning green manure to the field, the content of soil AOC increased by 26.7% compared with that without fertilization. Zhang Junhua et al. [19] compared different planting system patterns based on farmland with more than 100 years of farming history in Heihe River Basin, and found that TOC, AOC and inert organic carbon in soil profile showed the trend of rapeseed field > common corn field > seed corn field > wheat field. This study showed that the content of AOC in different soil layers of all winter treatments was significantly higher than that of winter fallow treatments, which was similar with the results of previous studies [8,19]. This may be due to the fact that returning straw of winter plants provided a reaction substrate for microorganisms, which increased the activity of soil microorganisms, accelerated the turnover rate of organic carbon, and stimulated the increase of AOC in different soil layers. In the study, ROT performance was better because the chemical properties of straw and residual roots in winter crop multiple cropping rotation were different each year, which affected the carbon and nitrogen metabolism of soil microorganisms. Many studies have shown that ROC and MBC are sensitive to fertilization measures [8,20,21], and straw returning can significantly increase ROC and MBC content. This study showed that different winter treatments significantly increased soil MBC content, which further verified previous studies. However, ROC did not increase significantly in 0~15 cm soil layer of early and late rice, but significantly increased in 15~30 cm soil layer, which was inconsistent with previous studies. This may be because the surface soil is greatly affected by management measures, and the management measures of early and late rice are the same, while ROC is sensitive to management measures [21], therefore, the ROC content of surface soil is mainly affected by management measures. In contrast, the accumulation of ROC in deep soil is more obvious under winter planting treatment. DOC can be extracted by water and salt solution, mainly from soil humus, plant litter and root exudates [22]. Straw contains a large amount of organic matter easily decomposed by microorganisms, which can significantly increase the DOC content [23]. This study showed that CRR and ROT treatments showed high performance in all soil layers of early and late rice, and DOC content between the two treatments was generally close. This may be due to the fact that this year, Chinese milk vetch is the winter crop of both CRR and ROT treatment, and the C/N of Chinese milk straw is low. Straw with low C/N usually degrades quickly after being applied to soil, and can improve microbial biomass and activity, which is conducive to the accumulation of soil DOC [24]. Similarly, Gao et al. [25] showed that winter green manure rapeseed and Chinese milk vetch increased the aromatic degree, humification degree and average molecular weight of DOM, making DOM more stable in red rice soil.

4.2 Effects of rice field winter planting patterns on soil carbon pool management index

Soil carbon pool management Index (CPMI) represents the ability of soil to reflect soil nutrient supply under different agricultural management measures, and the improvement of CPMI is conducive to the accumulation of organic carbon and its active components [26]. CPMI is a sensitive and effective indicator reflecting the dynamic change of soil carbon, which can be used to measure soil management level and fertilizer supply capacity, and is an important basis for the variation of soil organic carbon led by agricultural management measures [27]. Many studies have shown that CPMI value is closely related to management measures such as straw returning and crop planting pattern [8,13,28-30]. Cao et al. [31] pointed out that compared with the early- late rice planting pattern, the spring corn- late rice planting pattern was conducive to the increase of carbon pool activity (CPA) and carbon pool activity index (CPAI) in each soil layer. Wu et al. [32] showed that returning rice straw to field can lead to the improvement of soil carbon content of different forms as well as carbon pool management index. Zhao et al. [33] believed that returning wheat and maize to the field significantly increased the carbon pool management index of each soil layer. Xiao et al. [34] believed that stubble return of Chinese milk vetch had better performance in improving soil carbon pool activity index, carbon pool index and soil carbon pool management index. In this study, it was found that soil carbon pool indexes were improved in different winter planting patterns compared with winter fallow treatment. In each soil layer of early and late rice, each winter planting treatment significantly increased the carbon pool index except for the carbon pool activity index in 0~15 cm soil layer, because the management measures such as fertilization and straw returning mainly affected the surface soil. At the early rice ripening stage, the CPMI value of winter crop multiple cropping rotation treatment was the highest, which was significantly higher than that of winter garlic treatment. Meanwhile, the AOC content of 0~15 cm soil layer of early rice in winter crop multiple cropping rotation treatment was the highest, indicating that winter multiple cropping rotation can increase the CPMI value of early rice ripening stage by increasing soil AOC content. At the ripening stage of late rice, carbon pool indexes of all winter treatments increased significantly in 0~15 cm soil layer, and the stable carbon content of GRR and CRR treatments was higher, suggesting that the stability of soil carbon pool can be improved under CRR, GRR planting patterns. As for 15~30 cm soil layer, RRR and ROT treatments shows higher CPAI value and the difference with those of control were significant. CPMI values of each winter planting treatment were significantly higher than those of winter fallow control. Although RRR and ROT treatments shows higher AOC/TOC proportion in the 15~30 cm soil layer at the ripening stage of late rice, the CPMI value was mainly affected by TOC content. In terms of CPMI of both layers of early and late rice, ROT treatment was the highest, so winter crop multiple cropping rotation was the most favorable planting pattern for the enhancement of CPMI.

5. Conclusions

The content of TOC, AOC and its components in different winter planting patterns were increased, and ROT and CRR treatments showed better performance. The content of organic carbon, active organic carbon, dissolved organic carbon, microbial carbon and soil carbon pool management index in 0~15 cm soil layer were higher than those in 15~30 cm soil layer. Different planting patterns of winter crops increased soil carbon pool management index and carbon pool activity index, and ROT treatment was the most beneficial winter crop planting pattern for the accumulation of organic carbon and its active components. In conclusion, CRR and ROT treatment is more beneficial to the accumulation of soil organic carbon and active organic carbon, as well as the improvement of soil carbon pool management index, and should be preferred during the adjustment of planting pattern.

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