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保护性耕作对稻田土壤有机质的影响

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摘要：研究使用常规犁耕-休闲 (DTF), 常规犁耕-小麦 (DTW), 保护耕作-休闲 (CTF), 保护耕作-小麦 (CTW) 4 个处理, 评价连续实验 10a 后保护性耕作对稻作区 SOM 的影响。结果表明：垄作、免耕和小麦种植的结合是稻作区一种较好的保护性耕作实践。它不仅显著增加 SOM 在土壤表层的聚集, 而且它也通过改变 SOM 的组成和结构显著影响土壤胡敏酸的光谱和热解特性。相比其他处理, 垄作免耕(稻麦)在 0 ~ 10 cm 土层拥有最多的 SOM 含量, 但随着土层厚度的增加, 这一含量下降的也较为迅速。垄作免耕(稻麦)土壤胡敏酸在波长 665 nm 处的光密度为 0.122, 465 nm 处为 0.705, 而常规平作(中稻)在这两个波长处却分别为 0.062 和 0.321。垄作免耕土壤胡敏酸 DTA 曲线在 360 ~ 365 ℃处放热峰的焓变值比常规平作低, 1000 ~ 1050 cm^{-1} 吸收峰常规平作也比垄作免耕强。垄作免耕土壤腐殖质的氧化稳定系数增高, 表明长期垄作免耕土壤腐殖酸的缩合度增高, 芳构化程度增强。通过保护性耕作和作物实践可以管理稻田土壤, 维持充分的 SOM 积累, 缓解土壤有机碳的丢失。

关键词：保护性耕作；小麦耕作；土壤有机质；稻作区

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Effects of conservation tillage on soil organic matter in paddy rice cultivation

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Abstract: In this study, the effect of conservation tillage on soil organic matter (SOM) in paddy rice cultivation after 10 yr was investigated. Four treatments, disk till-fallow (DTF), disk till-wheat (DTW), conservation till-fallow (CTF) and conservation till-wheat (CTW) were used. The results indicated that the combinative application of no tillage, ridge culture and wheat cultivation was a sound conservation practice in paddy rice cultivation. It not only significantly increased the concentration of SOM in the topsoil, but also further affected humic acids (HA) optical and pyrolysis characteristics through changing the composition and structure of SOM. At 0 —10 cm, the greatest SOM content was in CTW, but declined sharply with depth, while in DTF, DTW and CTF was not as high at the surface as in CTW, but the SOM content did not decline as fast as in CTW. The oxidation stabilization of SOM was generally greater in no tillage and ridge culture than that of disk till. The HA optical density in CTW at wavelength 665 nm and 465 nm was 0.122 and 0.705, while in DTF was 0.062 and 0.321, respectively. E_4/E_6 ratios in CTW were higher than that of in the other treatments. The enthalpy

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capacity of exothermal peak (360—365 ℃) for HA DTA curve in no tillage and ridge culture was lower than that of in disk till, while the HA absorption peaks in 1000—1050 cm^{-1} presented the reverse trend. The oxidation stabilization coefficient of HA in no tillage and ridge culture was higher than those in disk till, indicating that polycondensation degree and aromatization of HA were stronger. Those findings suggest that it may be possible to manipulate paddy soils through conservational tillage and crop practices and thereby maintain adequate SOM concentrations, mitigate soil organic carbon loss from soil to atmosphere.

Key Words: conservation tillage; wheat cultivation; soil organic matter; paddy rice cultivation

1　Introduction

Recently, a number of studies have shown that the amount of soil organic matter (SOM) increased at 0—20 cm soil depth with the application of conservation tillage [1,2]. Frequently tillage destroys SOM fractions [3], and urges the transfer of SOM to depth soil layer [4]. The elimination of tillage favored accumulation of SOM [5]. But, these studies have mainly focused on drylands soil, and few have considered paddy soils. No tillage and ridge culture is a special conservation tillage method, i. e., the combinative application of no tillage and ridge culture. Ridges are reformed atop the planted row by cultivation, and the ensuing row crop is planted into ridges formed the previous growing season. No-till was zero or little tillage. However, the effects of no tillage and ridge culture on SOM are still hardly understood, especially in paddy rice cultivation. Moreover, the increase of mean SOM content is also primarily related to the return of straw to soil when crop harvested [6,7]. But the effects of drought-drought cultivation on SOM have been of great interest, and few documents have recorded the changes of SOM, when flood-drought cultivation has been made. In China, paddy fields play a significant role in the overall agricultural ecosystems. The total area of paddy fields reached 30 Mhm^2 in the mid-1980s (23% of the world's total irrigated lands) [8]. Paddy fields produce one-quarter of grains for China's market, approximately accounting for 36% of world total rice yield [9]. Paddy fields had unique laws in movement, accumulation and transformation of SOM, due to paddy fields controlled by long-term seasonal oxidation-reducible interaction. Currently, no tillage, ridge culture and flood-drought cultivation have been widely adopted by farmers, including smallholders. The objective of this research was to evaluate the effects of conservation tillage on SOM in paddy rice cultivation, and to ensure the long-term health of soils.

2　Materials and methods

2.1　Site description

Soil samples were collected in April or September every year from a field experiment that was established on the research farm of Southwest University (106°26′ E, 30°26′ N; alt. 230 m), Chongqing, China, in 1989. The climate is subtropical monsoon with a yearly average temperature of 18.3 ℃, a mean annual rainfall of 1105.4 mm, of which 70% occurs in the period from May to September, and an annual frost-free period of 334 d. The soil at the experimental site is gray brown purple paddy soil (Hapli-Stagnic Anthrosols in Chinese Soil Taxonomy) developed from the purple parent material of Mesozoic J_2s. The dominant clay mineral (< 1 μm) is illite. Chemical and physical properties of soil at 0 — 20cm in the experiment field are reported in Table 1. Before setting up the experiment, the area had been cultivated with a rice (*Oryza sativa* L.) or rice-wheat (*Triticum aestivum* L.) succession for 30 yr under disk till (disc plough at 18 cm depth followed by harrowing twice with light discs at 10 cm depth).

Table 1 Chemical and physical properties of the soils

Clay (%)	pH	O. M. (g kg^{-1})	Total N (g kg^{-1})	Available N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})
25.09	7.14	23.1	1.87	146	8.4	161.8

2.2 Experiment treatments

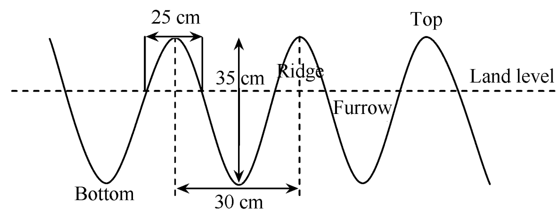

Fig. 1 The type of bulleting for ridge culture

The four treatments in this experiment were: disk till-fallow (DTF), disk till- wheat (DTW), conservation till-fallow (CTF) and conservation till-wheat (CTW). The same rice varieties were used in all plots in April, while the combination of wheat was also the same in DTW and CTW in October. DTF: The field was submerged, 3 cm below water lever all the year round. The paddy soil was disked (25 — 30 cm depth) and harrowed with a disk-harrow three times in April, September and October of each year, respectively. DTW: Tillage was done as in DTF. The field was submerged, 3 cm below water lever, and rice was grown. After the harvest of the rice crop, the field was drained through ditches around, and wheat was grown. During the wheat growing season, the field was drained with ditches. After the harvest of the wheat crop, the field was submerged and disked and harrowed for rice cultivation. CTF: no-till was performed. Ridges and furrows were made in the fields, and the wide width of ridge and furrow was 55 cm (Fig. 1). The ridges were 25 cm wide on the top and the furrows were 30 cm wide and 35 cm deep (from top of ridge to bottom furrow). Each plot consisted of 5 ridges. From the beginning of rice transplanting, water surface was paralleled with ridge top in the field, and during the rest year, water depth in furrows was 25 — 30 cm, i. e., ridge tops protruded 5 — 10 cm from water surface. After the harvest of the rice crop, the field was in fallow submerged with water without tillage. CTW: Tillage was done as in CTF. Water level was similar to CTF during the rice growing season. After the harvest of the rice crop, water stable was lowered in furrows, mud in furrows was stacked by shovel on ridge tops, and then wheat was grown. During the wheat growing season, water level in furrows was maintained at 5 — 10 cm depth, i. e., ridge tops protruded 20 — 25 cm from the water surface. After the harvest of the wheat crop, the field was submerged up to ridge top for the cultivation of rice. The treatment plots, 4 m × 5 m, were arranged in a complete randomized block experimental design with four replications.

2.3 Soil sampling

Composite soil samples were collected in April or September in 1999 from each plot at 0 — 10, 10 — 20, 20 — 30cm and 30 — 40 cm depths using a soil auger of 5 cm diameter at three locations within each plot, from the upper, middle and lower one-third segments of the plot. Samples were taken using a bricklayer's trowel sowed them at 0 — 10, 10 — 20, 20 — 30cm and 30 — 40 cm depths. Subsamples in each plot were composited by depth. Subsamples (< 3 cm) were subsequently air-dried and finely ground (< 2 mm). SOM inter-annual variation was analyzed using collected composite soil samples in April or September from 1990 to 1999.

2.4 Data measurement

The pH, SOM, total N, total P, total K, available N, available P and available K were measured using the routine soil sample lab analytical method according to Foster [0].

SOM oxidation was performed at room temperature by suspending 1 — 2 g of soil in 10 — 20 ml of 30% H_2O_2. After the end of the intense initial reaction, samples were heated to 40 ℃. Fresh H_2O_2 was added daily until frothing was no longer visible [1]. This was usually achieved after 20 — 40 d. After oxidation the samples were washed twice with demonized water, freeze-dried and analyzed for the remaining SOM concentration.

Humic acids (HA) were extracted, purified, dialyzed and lyophilized by conventional procedures [2]. Briefly, 2 g of air-dried and finely ground samples were extracted under N_2 with 100 ml of 0.5 mol/L NaOH and stirred for 24 h. The suspension was centrifuged at 5000 g for 30 min and then filtered through a 0.45 μm filter using a Minitan S System (Millipore, Bedford, MA-USA). The solution was acidified with 5 mol/L HCl to pH < 2 to precipitate the HA and was subsequently centrifuged at 5000 g for 20 min in order to eliminate the supernatant. The HA were dissolved with NaOH 0.5 mol/L to produce a Na-humate. The Na-humates were dialyzed against Millipore water, using tubing (Cellu Sep H1-USA) with a cut-off of 1000 Da, until a neutral pH was achieved, and were then freeze-dried.

HA optical density, following a procedure based on modifications to the method described by Nascimento *et al.* [3], was determined on all subsamples. HA sampling was dissolved for 0.136 mg C ml^{-1} using heat 0.02 mol/L $NaHCO_3$ solution. And then HA optical density was measured at wavelengths 726, 665, 619, 574, 533, 496 and 465 nm through spectrophotometer (721) based on 0.02 equivalent sodium bicarbonate ($NaHCO_3$) solution reference. For HA evaluation, extinction coefficient (E) was employed. E_4 and E_6 from E_4/E_6 was HA optical density at wavelengths 465 and 665 nm, respectively.

HA infrared spectrogram analysis was carried out through KBr electrolyte solutions [4]. 0.5 mg HA was mixed with 150 mg KBr. Spectrogram analysis was measured by an infrared spectrophotometer (HTTACH 1260-10, Japan).

HA thermal analysis (DTA) were performed with using a TG DTA92 instrument (SETARAM, France) as described by Francioso *et al.* [2]. About 10 mg of lyophilized HA was weighed on an alumina (Al_2O_3) crucible and isothermally heated to 30 ℃ for 10 min under air flow (8 L min^{-1}), and then heated from 30 to 700 ℃ in a static air atmosphere. The heating rate was 10 ℃ min^{-1}. Indium was used as reference standard. Calcined caolinite was used as the reference material.

2.5 Statistical analysis

Data were analyzed statistically by analysis of variance (ANOVA) procedure. Duncan's New Multiple Range Test (DMRT) was employed to assess differences between the treatment means. The effects of conservation tillage were declared as significant at 5% probability levels. Standard deviations were calculated for means values of all the determination. All statistical analyses were performed with SPSS statistical package.

3 Results and discussion

3.1 SOM content and oxidation stabilization

Soil organic matter (SOM) content, at 0—20 cm soil depth, was higher in CTW than that of in DTF, DTW and CTF during a continuous 10 yr observation, as shown in Fig. 2. After the harvest of the rice crop in 1999, SOM content was 89.02% higher amounting to 4.75% in CTW, compared to that of in 1989, while was 36.43%, 56.62% and 47.76% greater in DTF, DTW and CTF, respectively. No tillage and ridge culture improved soil microenvironment, including enhancing soil temperature of ridge top, protecting soil from erosion, accelerating thermal exchange between soil and atmosphere, and further enhancing crop bioaccumulation [5]. The application of wheat cultivation increases the return of crop residues to soil. As a result, soil in CTW had greater SOM concentration than that of in DTF, despite the perviousness in CTW was strengthened thus SOM being decomposed quickly. DTW also returned plentiful crop residues, but SOM concentration in DTW was less than that of in CTW, due to that the accumulation of crop residues in DTW was lower than that of in CTW. When compared among DTF, DTW and CTF, the results found that DTW applied wheat cultivation and CTF combined no tillage and ridge culture, SOM accumulation was not pronounced different, because of mutually exclusive among their habitat characteristics. That is, soil environment built by DTF, DTW and CTF, favorable SOM concentration was almost in equilibrium with available SOM decomposition and mineralization.

SOM content in CTW showed pronounced stratification, and decreased with soil depth (Fig. 3). At 0 — 10 cm, SOM content was the greatest in CTW, but declined sharply with depth. SOM content in DTF, DTW and CTF was not as high at the surface as in CTW, but did not decline as fast as in CTW. At 20 — 30 cm, SOM content in CTW was even lower than that of in DTF and DTW, while at 30 — 40 cm, SOM content in four treatments was not obvious different. At the topsoil, the ranks of SOM content along the decreasing sequence were CTW, DTF, CTF and DTW, while at the subsoil, was DTF, CTF, DTW and CTW. In permanent no tillage and ridge culture, SOM are no longer mixed into the subsoil. Moreover, the application of wheat cultivation collected the more crop residues in soil surface. This finding was similar to those of Al-Kaisi *et al.* [6] who reported reducing tillage intensity and increasing crop diversity could be effective in improving SOM.

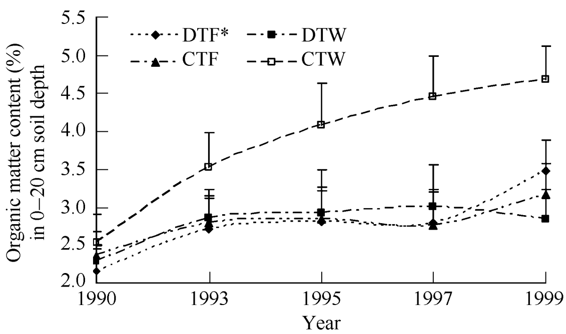

Fig. 2 Soil organic matter change from 1990 to 1999 under different conservation tillage

* DTF: disk till fallow; DTW: disk till wheat; CTF: conservation till fallow; CTW: conservation till-wheat

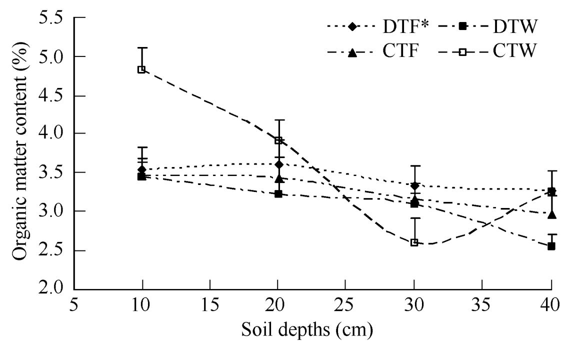

Fig. 3 SOM content under different conservation tillage

* See note beneath Fig. 2

The oxidation stabilization coefficient of SOM was significant different ($P < 0.05$) (Fig. 4), but they were less than 1. The oxidation stabilization of SOM was generally greater in no tillage and ridge culture than that of disk till. In contrast to the topsoil, the subsoil SOM has much higher oxidation stabilization. The oxidation stabilization of organic compound was closely relation to its corresponding molecule structure, and was higher when comparing with that of aliphatic compound. Humus was the polymeric composite material of complex multi-condensation, including polyhydroxybenzene aromatic compound and aminobenzene nitrogen-containing compound. In humus, molecular weight for every compound was different, and their aromaticity was also different. Compared fulvic acid compound, the molecular weight of humic acid compound was greater, and their aromaticity was stronger. The oxidation stabilization of SOM in different treatments was pronounced different, thus practically showing the different SOM composing. That is, no tillage and ridge culture and wheat cultivation can affects SOM composing and structure. This result was consistent with those described by Neufeldt *et al.* [7] on

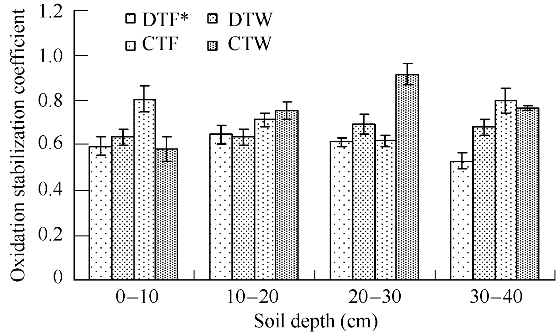

Fig. 4 SOM oxidation stabilization coefficient under different conservation tillage

See note beneath Fig. 2

soil texture and land management practice effects on SOM.

3.2 HA optical characteristics

Significant differences between effects of different treatments on HA optical density occurred, as shown in Fig. 5. The greatest HA optical density was CTW, the following was DTW, and the least was DTF. These findings indicated that no tillage and ridge culture with wheat cultivation favored the formation of humus, which showed the greater molecular weight and the more complex structure. The molecular complexity is the higher, and HA optical density value is the greater. Aromatic core has higher condensation degree due to the more radicel. However, the much single HA with lower aromaticity has the more side bonds, and the less optical density. A number of studies showed that composition of humus and HA optical characteristics depended on tillage systems and crop practices [8]. Tillage, to some degree, influenced composition of soil humus. The proportion of HA to fulvic acid was greater in paddy rice than that of in wasteland or grassland, but just the reverse was the rate of labile HA. No tillage and ridge culture with wheat cultivation enhanced the exchange of soil surface moisture, heat and gas, concentrates more biomass and organic matter. Under these circumstances, the greater molecular weight humus was created easily.

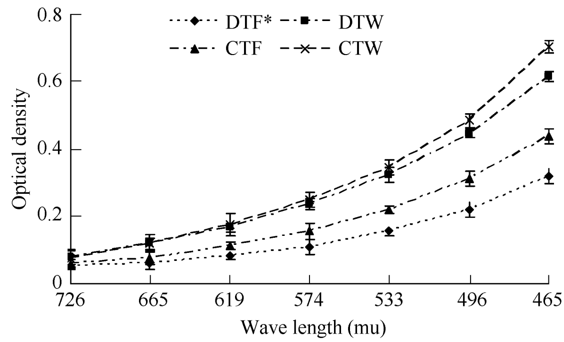

Fig. 5 HA optical density under different conservation tillage

Notes: * See note beneath Fig. 2

E_4 and E_4/E_6 ratios were higher in CTW, when compared with that of in other treatments. E_4/E_6 values enhance associated with the increase of soil fertility. But, the differences were not pronounced. No tillage and ridge culture with wheat cultivation reduced the human disturbance to soil, increased the return of biomass to soil, and further enhanced soil nutrient-providing and nutrient-holding capacities. Thus, the polymeric of soil humic substances raised, the atomic groups of aromatic nucleus increased. The aromaticity and complexity of aromatized molecules and humification all went up, and the quality of humic substances became better. E_4/E_6 ratios are closely relation to the aromaticity. But, Tan and Giddens [9] found that E_4/E_6 values are the results of the coupling of complex factors, no correlation could be found between HA optical characteristics and aromaticity of HA. Moreover, he also reported that HA optical characteristics could determine relatively the complexity of humus and the content of color function groups.

Table 2 HA E_4, E_6 and E_4/E_6 under different conservation tillage

Treatments	E_4	E_6	E_4/E_6
DTF *	0.321d	0.062c	5.18
DTW	0.616b	0.120a	5.13
CTF	0.439c	0.079b	5.56
CTW	0.705a	0.122a	5.78

Notes: * See note beneath Fig. 2; The data in table were expressed as Means; means for the same measurement followed the same letter are not significantly different ($P < 0.05$) by Duncan's multiple range test

Four treatments had the following characteristics of soil HA absorption peaks (Fig. 6): 3350 — 3450 cm^{-1} (hydrogen bonding OH), 2800 — 2900 cm^{-1} (aliphatic C—H stretching) and 2200 — 2400 cm^{-1}, 1695 — 1700 cm^{-1} (carboxyl and ketone C=O stretching), 1550 — 1630 cm^{-1} (aromatic C=C and carboxyl conjugated double bond), 1350 — 1400 cm^{-1} (carboxyl CH_2 bending and O—H stretching) and 1000 — 1050 cm^{-1}. Despite the peaks of HA from every soil samples presented obvious differences, the regular variation did not occur. In contrast to CTW and DTW, the adsorption peaks DTF and CTF at 1000 — 1050 cm^{-1} were much stronger. The reason for these was that the return of crop residues to soil in DTF and CTF was the less thus the application of organic materials decreasing, compared with that of in DTW and CTW. The decrease of the return of crop residues to soil resulted in the increase of HA infrared spectrogram value. Dou *et al.* [10] found application of organic materials led to the decline of soil HA adsorption optical value. In addition, the return of crop residues to soil was different between DTF and CTF or DTW and CTW, while their adsorption peaks was very similar.

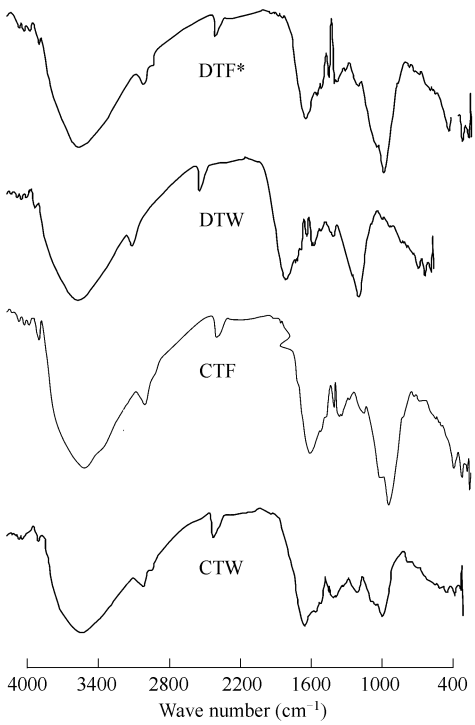

Fig. 6 HA infrared spectrogram under different conservation tillage

* See note beneath Fig. 2.

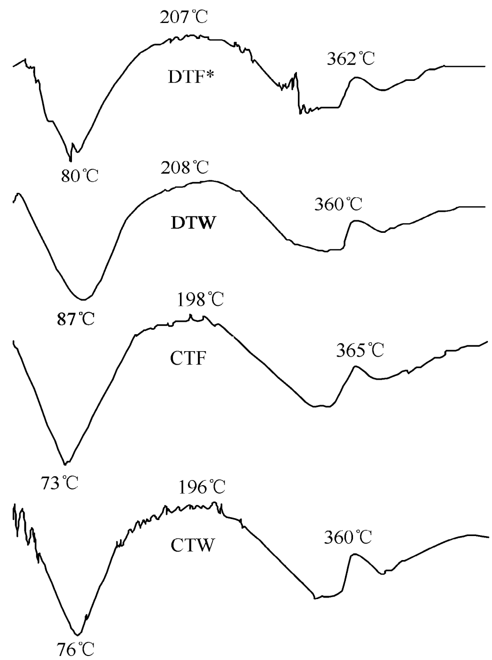

Fig. 7 HA DAT curve under different conservation tillage

* See note beneath Fig. 2

3.3 HA pyrolysis characteristics

Soil HA DTA curve from four treatments were similar (Fig. 7). There was a consensus on two basic features. That is, the adsorption peaks occurred at 73 — 87 ℃, and the exothermic peaks happened at 360 — 365 ℃. Similar DTA curve showed that there existed in the commonness of chemical compositions and structural features of soil HA between treatments. The characteristics of the humic extracted from the different soils were generally similar to those of humic materials originating from soils formed under widely different geographic and pedologic conditions. Compared with Fig. 7 and Table 3, there was some variations besides some commonness. There are () the enthalpy capacity of adsorption and exothermic peaks; (i) the ranks of the enthalpy capacity of endothermic peaks with DTW > CTF > CTW > DTF; (ii) the ranks of the enthalpy capacity of exothermal peaks with DTF > DTW > CTF > CTW. The energy state of soil HA is consolidation degree itself. The energy state of soil HA was the higher, the

Table 3 The enthalpy capacity of DTA curve of HA (H) under different conservation tillage

Treatments	Endothermic peak (73 ~ 87 ℃)		Exothermal peak (360 ~ 365 ℃)	
	Peak temperature (℃)	H (J g^{-1})	Peak temperature (℃)	H (J g^{-1})
DTF *	80	159.93c	362	125.60a
DTW	87	181.42a	360	120.20b
CTF	73	172.60b	365	118.25c
CTW	76	170.38b	360	114.57d

* See note beneath Fig. 2; The data in table were expressed as Means; means for the same measurement followed the same letter are not significantly different ($P < 0.05$) by Duncan's multiple range test

condensation of HA became lower, and further the aliphatic side chain was the more. Otherwise, the energy state of soil HA was the lower, and the aliphatic side chain was relatively the less. No tillage and ridge culture resulted in the decrease of the enthalpy capacity of exothermal peak value. The condensation of soil HA under no tillage, ridge culture was higher, and the aromatization of SOM was improving. Dorado *et al.* [11] also found that soil management substantially affects the accumulation mechanisms of the HA fraction.

4 Conclusions

The combinative application of no tillage and ridge culture and wheat cultivation was a sound conservation practice in paddy rice cultivation. It not only significantly increased the concentration of SOM in the topsoil, but also further affected HA optical and pyrolysis characteristics through changing the composition and structure of SOM. Those findings suggest that it may be possible to manipulate paddy soils through conservational tillage and crop practices and thereby maintain adequate SOM concentrations, mitigate soil organic carbon loss from soil to atmosphere.

References:

[1] Stockfisch N, Forstreuter T, Ehlers W. Ploughing effects on soil organic matter after twenty years of conservation tillage in Lower Saxony, Germany. Soil Till. Res., 1999, 52 (-2): 91－101.

[2] Wright A L, Hons F M, Matocha Jr J E. Tillage impacts on microbial biomass and soil carbon and nitrogen dynamics of corn and cotton rotations. Applied Soil Ecology, 2005, 29 (): 85－92.

[3] Hernanz J L, López L R, Navarrete L, *et al.* Long-term effects of tillage systems and rotations on soil structural stability and organic carbon stratification in semiarid central Spain. Soil Till. Res., 2002, 66 (2): 129－141.

[4] Shan Y H, Yang L Z, Yan T M, *et al.* Downward movement of phosphorus in paddy soil installed in large-scale monolith lysimeters. Agric. Ecosyst. Environ., 2005, 111 (-4): 270－278.

[5] Duiker S W, Beegle D B. Soil fertility distributions in long-term no-till, chisel/disk and moldboard plow/disk systems. Soil Till. Res., 2006, 88 (-2): 30－41.

[6] Dick W A, Blevins R L, Frye W W, *et al.* Impacts of agricultural management practices on C sequestration in forest-derived soils of the eastern Corn Belt. Soil Till. Res., 1988, 47 (3-4): 235－244.

[7] Fullen M A, Booth C A, Brandsma R T. Long-term effects of grass ley set-aside on erosion rates and soil organic matter on sandy soils in east Shropshire, UK. Soil Till. Res., 2006, 89 (): 122－128.

[8] Pan G X, Li L Q, Wu L S, *et al.* Storage and sequestration potential of topsoil organic carbon in China's paddy soils. Global Change Biology, 2003, 10: 79－92.

[9] Tong C L, Hall C A S, Wang H Q. Land use change in rice, wheat and maize production in China (961－1998). Agric. Ecosyst. Environ., 2003, 95 (2-3): 523－536.

[10] Foster H L. Rapid routine soil and plant analysis without automatic equipment. I. Routine soil analysis East Africa. Agriculture and Forest Journal, 1971, 37: 160－170.

[11] Eusterhues K, Rumpel C, Kögel-Knabner I. Stabilization of soil organic matter isolated via oxidative degradation. Organic Geochemistry, 2005, 36 (1): 1567－1575.

[12] Francioso O, Montecchio D, Gioacchini P, *et al.* Thermal analysis (TG－DTA) and isotopic characterization (^{13}C－C^{15}N) of humic acids from different origins. Applied Geochemistry, 2005, 20 (3): 537－544.

[13] Nascimento V M, Almendros G, Fernandes F M. Soil humus characteristics in virgin and cleared areas of the paran river basin in Brazil. Geoderma, 1992, 54 (-4): 137－150.

[14] Tan K H. Complex formation between humic acid and clays as revealed by gel filtration and infrared spectroscopy. Soil Biology and Biochemistry, 1976, 8 (3): 235－239.

[15] Wei C F, Che F C, Gao M, *et al.* Soil aggregate and soil moisture-thermal regime in paddy field under no-tillage and ridge culture. Acta

Pedologica Sinica, 1990, 27 (2), 173－178.

[6] Al-Kaisi M M, Yin X H, Licht M A. Soil carbon and nitrogen changes as influenced by tillage and cropping systems in some Iowa soils. Agric. Ecosyst. Environ., 2005, 105 (4): 635－647.

[7] Neufeldt H, Resck D V S, Ayarza M A. Texture and land-use effects on soil organic matter in Cerrado Oxisols, Central Brazil. Geoderma, 2002, 107 (3-4): 151－164.

[8] Slepetiene A, Slepetys J. Status of humus in soil under various long-term tillage systems. Geoderma, 2005, 127 (3-4): 207－215.

[9] Tan K H, Giddens J E. Molecular weights and spectral characteristics of humic and fulvic acids. Geoderma, 1972, 8 (4): 221－229.

[10] Dou S, Chen E F, Xu X C, *et al*. Effect of application of organic manures on the structural characteristics of humic acids in soils: the optical properties of HAs. Acta Pedologica Sinica, 1995, 32 (1): 41－49.

[11] Dorado J, Gonz lez-Vila F J, Zancada M C, *et al*. Pyrolytic descriptors responsive to changes in humic acid characteristics after long-term sustainable management of dryland farming systems in Central Spain. Journal of Analytical and Applied Pyrolysis, 2003, 68－69: 299－314.

参考文献：

[5] **魏朝富，车福才，高明，等. 垄作免耕下稻田土壤团聚体和水热状况变化的研究. 土壤学报**，1990，27 (2)：172～178.

[10] **窦森，陈恩凤，须湘成，等. 施用有机物料对土壤胡敏酸结构特征的影响-胡敏酸的光学性质. 土壤学报**，1995，32 (1)：41～49.