Mechanisms of Soil Aggregates Stability in Purple Paddy Soil under Conservation Tillage of Sichuan Basin, China

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Xiaohong Tang [1,*], Youjin Luo[2], Jiake Lv[2], Chaofu Wei [2]

[1]College of Urban and Rural Development, Sichuan Agricultural University, 611830 Sichuan, China
[2] College of Resource and Environment, Southwest University, 400716 Chongqing, China

Abstract: Ridge culture is a special conservation tillage method, but the long-term influence of this tillage system on soil aggregate-size stability in paddy fields is largely unknown in southwest of china. The objectives of this paper are to evaluate soil aggregates stability and to determine the relationship between SOC and soil aggregate stability. Soil samples at 0-20 cm layer were adopted from a long-term (16 yr) field experiment including conventional tillage: plain culture, summer rice crop and winter upland crop under drained conditions (PUR-r), and conservation tillage: ridge culture without tillage, summer rice and winter fallow with floodwater layer annually (NTR-f), and winter upland crop under drained conditions (NTR-r), and wide ridge culture without tillage, summer rice crop and winter upland crop under conditions (NTRw-r), respectively. The determination of aggregate-size stability distribution involves the assumptions that soil aggregates can be categorized in terms of their size and water stability (slaking resistance). Experimentally this procedure involves the slaked and capillary-wetted pretreatments; and a subsequent slaking treatment of aggregates >0.250 mm in size. WSMA and NMWD were applied to simulate the breakdown mechanisms of aggregates for studying soil stability based on aggregate resistance to slaking in paddy soil. The results showed that the amount of aggregates-size was greatly observed in the fraction of 2~6.72 mm under ridge culture in paddy soil (more than 50%) under slaking and capillary-wetting pretreatment. The proportion of soil macro-aggregates (＞0.25 mm) in conservation tillage was greatly higher than that in conventional tillage under subsequent slaking treatment. Minimal differences of aggregate stability between slaking and wetting were observed, while significant differences were found between ridge culture and plain culture. The aggregates stability under slaking treatment ranked in the order of NTR-r＞NTRw-r＞NTR-f＞PUR-r, while under wetting was NTRw-r＞NTR-r＞NTR-f＞PUR-r, respectively. There was a positive correlation between the aggregates stability and SOC concentrations under wetting, and low correlation was observed under slaking pretreatment. Soil exposure with tillage and lack of rice/rape-seed stubble inputs caused declines in aggregation and organic carbon, both of which make soil susceptible to water erosion. Adoption of ridge culture with no-tillage integrated with crop rotation and stubble mulch significantly alter soil organic concentration, suggesting it was a valuable conservation practice for soil aggregation and soil organic carbon sequestration on paddy soil.

Key words: ridge culture; rotation; aggregate stability; organic carbon; paddy soil

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* Corresponding author. *E-mail address*: jianglj_2003@163.com

1. Introduction

Soil organic carbon (SOC) plays a crucial role in sustaining crop production and environmental soil services. A loss of SOC due to inappropriate land use or soil management practices can affect soil properties and lead to CO_2 emissions into atmosphere. On the other hand, appropriate land use and soil management can lead to an increase in SOC, improve soil properties and partially mitigate the rise in atmosphere CO_2 (Christensen, 1996; Lal and Kimble, 1997; Bernoux et al., 2006). Among the numerous strategies that permit sequestering atmospheric carbon in agroecosystems, ridge culture practices have been well documented (Halvorson et al., 2002; Franzluebbers, 2005). But the impacts of no-tillage practices on soil aggregates composition and its stability can vary drastically with soil properties and no-tillage practices (Puget et al., 1999; Bernoux et al., 2006). Conventional tillage systems enhance SOC mineralization; soil aeration and water fluctuation (Balesdent et al., 2000). Conventional tillage also can disrupt soil aggregates and expose physically protected SOC to microbial decomposition, decreasing SOC content and soil aggregate stability. Conversely, conservation tillage accumulate residues on the soil surface as much and reduce soil mixing and disturbance and promotes soil aggregation through enhanced binding of soil particle as a result of greater SOM content and. Soil aggregation can increase SOC storage by reducing loss by erosion and from mineralization (Paustian et al., 2000; Six et al., 2002a, 2002b). Soil organic matter (SOM) can be physically protected from microbial mineralization through sorption to clay minerals (Hassink et al., 1993; Beare et al., 1994a; 1994b) and enclosure within soil aggregates (Tisdall and Oades, 1980; 1982). Soil structure and soil organic matter (SOM) are two of the most dynamic properties that are extremely sensitive to crop and soil management. Soil aggregates are used for structural unit, which is a group of primary soil particles that cohere to each other more strongly than other surrounding particles. SOM is a major resource that links the chemical, physical and biological properties of soils, and is considered a major binding agent that stabilizes soil aggregates. Soil structure moderates soil and plant functions and is the framework for water, air, and nutrient flow to plants. Plants, in turn, furnish the soil with fresh residues and roots for aggregate structure development. The nature and properties of aggregates are thus determined by the quantity and quality of coarse residues and humus material and by the degree of their interaction with soil particles (Jastrow et al., 1996; Haynes and Francis, 1993; Elliott, 1986). Plant roots, Fungal hyphae, mycorrhizal hyphae, bacterial cells, and algae develop simultaneously with the growth of plant roots and build up a visible organic skeleton to enmesh the mineral particles by adsorption to form young macro-aggregates, and they are greatly affected by tillage operations (Tisdall and Oades, 1982). Polysaccharides or mineral colloid form bonds of micro-aggregates through cementation of carboxylic or hydroxide groups with polyvalent bridges (Puget et al., 2000; Kemper and Rosenau, 1984; Caron et al., 1992; Cambardella and Elliott, 1992.).

Soil aggregate stability is the result of complex interactions among biological, chemical, and physical processes in the soil (Tisdall and Oades, 1982). A close relationship between SOC and aggregate stability has been established for temperate and tropical soil (Six et al., 1998; 2002a, 2002b). Water-stable breakdown mechanisms of soil aggregates involve the slaked and capillary-wetted pretreatments, and slowly wetting pretreatments. The slaked pretreatment causes considerable disruption. When air-dried soil is submerged in water, the air that is trapped inside the soil pores is rapidly displaced with water. Weak aggregates are disrupted as a consequence of the sudden release of this large buildup of internal air pressure. In contrast, the wetting pretreatment before wet sieving produces minimal disruption, because misted aggregates do not buildup air pressure in the pores and the air escapes with minimal aggregate disruption (Cambardella and Elliott 1993a; 1993a; Chen, 1998; Gale et al., 2000; Li et al., 2006). Subsequent slaking can differentiate stable and unstable macro-aggregates (Marquez et al., 2004; Beare and Bruce, 1993).

Chongqing is mountainous, where most of rice fields are located at the foot of mountains. About half of rice fields are flooded permanently (Xie, 2002). The crop system of permanently flooded rice fields is, commonly, a single middle rice crop and in fallow with floodwater layer after rice harvesting. Ridge culture is an innovative approach to present permanently flooded rice fields from over reduced in redox potential due to permanently flooded. Fixed ridges are constructed about 30 cm wide, and rice plants and winter wheat plants (or oil-seed rape) were cultivated on both sides of the ridge without tillage instead of a single rice crop a year (Xie, 2002). All the changes involved in the innovative approach, such as changes from plain to ridge, from single middle rice crop to single middle rice crop and winter upland crop, and from permanently flooded to drainage in the winter crop season would improve soil conditions that influenced soil aggregates formation and transformation. Literature is replete with information on the effects of maturing, nutrient management, vegetative restoration, and tillage practices on the soil aggregates stability, and the combined effects of conservation tillage on the formation and stabilization of aggregates in purple paddy soil in related to SOC reservoir are limited (Diego et al., 2006; Li et al., 2004; Peng et al., 2004; Grandy et al., 2002). Therefore, a long-term field experiment was conducted to understand the mechanisms of soil aggregate stability under conservation tillage in a permanently flooded rice field with various treatments.

2. Materials and methods

2.1. Site and soil

Soil aggregates-size stability distribution measurement was conducted in a field experiment site (30°26′N，106°26′E) set up in 1990 for comparison of nutrient cycling among convention (plain) culture and ridge culture with different crop systems of in the permanently flooded rice fields at the Experimental Farm of South-west China University, Chongqing (223 m elevation) (Gao et al., 2008). Annual average rainfall and temperature were 1105 mm with 70 % in May to September and 18.3 ℃, respectively. the annual sunshine time is 1,276 h; and the frost-free period is about 334 d. The soil is Hydragric Anthrosol developed from the parent material of Jurassic purple shale and sandstone weathering product. Soil particles and aggregates-size distribution were determined in the treatments with plain culture and ridge culture, which were described in detail as follows: (1) plain culture: one treatment of PUR-r was prepared. In PUR-r, the field was ploughed 3-5 days before rice transplanting and a floodwater layer was maintained during the rice crop season, but was drained in the winter crop season for winter crop growth. (2) Ridge culture: three treatments of NTR-f, NTR-r and NTRw-r were prepared. In NTR-f, a fixed ridge was conducted at about 30 cm wide, and rice plants were planted on both sides of the ridge with no tillage. Before rice transplanting, weeds grew in the winter crop season and rice stubbles remained from the previous rice plants were covered with mud in ditches nearby（table 1）. Through this practice, the ridges could be maintained for a long

Table 1. Annual amount of rice crop residues and weeds to field under different tillage system kg hm^{-2} y^{-1}

Treatment	Straw (kg ha^{-1} y^{-1})	Rape residues (kg ha^{-1} y^{-1})	Weed (kg ha^{-1} y^{-1})
PUP-r	3900	2880	1970
NTR-f	3250	-	2500
NTR-r	4775	1575	1725
NTRw-r	2750	2125	1900

time. Ditches between two ridges were filled with water to the level of 0-3 mm below the top of ridge during the rice-growing period. After rice harvesting, the field was in fallow and water level in ditches dropped to 5-10 cm below the ridge top in the winter crop season. In NTR-R, management for rice culture was the same as that for NTR-f. Winter crops were planted in both sides of ridge in the same way as for rice crop.

Water in ditches was drained in the winter crop season. In NTRw-r, management for rice culture and winter crop was the same as that of NTR-r. The width of ridge was three times more than that of NTR-r (figure 1). Winter crop planted in the treatments of PUR-r, NTR-r and NTRw-r was winter wheat from 1990 to 1997 and oil-seed rape from 1998 to 2000 (Cai et al., 2003).

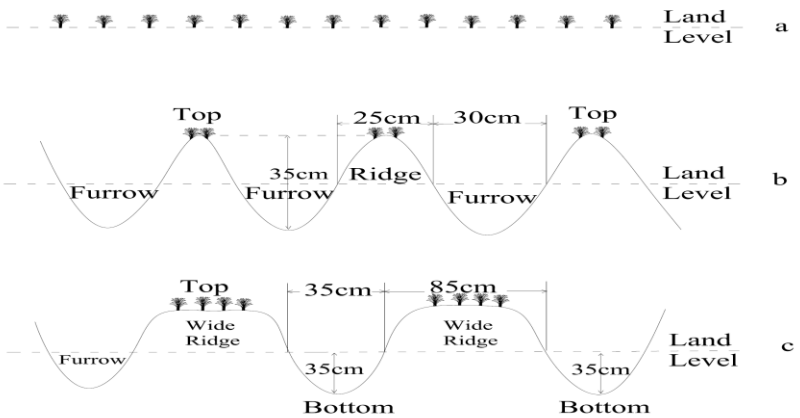

Fig. 1. The type of the bulletin for experimental culture (a: plain culture, b: ridge culture, c: wide ridge culture)

The paddy soil of the experiment field was Eutric Cambisol derived from purple rock. Before the experiment started in 1990, soil organic carbon content was 13.0 ± 1.2 g kg^{-1}, soil pH was 6.91 ± 0.24, and clay (0.001 mm) content was 144.2 g kg^{-1}. Chemical fertilizers were applied to all the plots at an equal rate in every rice-growing season, i.e. 273 kg urea ha-1, 500 kg superphosphate ha^{-1}, and 150 kg KCl ha^{-1}. Superphosphate was applied as basal fertilization, urea and KCl were applied as basal fertilization and topdressing. No exogenous organic manure was applied to each plot at a rate of about 20 t ha^{-1}, before rice transplanting. After rice harvesting, rice stubbles about 50~60 cm above ground stood in the field until incorporation into soil before the following period of rice transplanting. The treatment plots, with 4 m × 5 m each, were arranged in a complete randomized block experimental design with four replications. Under ridge culture**,** obvious changes of primary properties in paddy soil were found after 16 years (Table 2). Clay contents significantly increased by 34%, 79% and 51% under NTR-f, NTR-r and NTRw-r compared to that under PUR-r, respectively. SOC content decreased under NTR-f (10.11%), while increased under NTR-r and NTRw-r (18.00% and 9.66%, respectively). Changes of soil porosity indicated that soil structure had been improved under long-term conservation tillage.

Table 2. Primary properties of paddy soil under long-term conservation tillage systems

Treatment	Sand (%)	Silt (%)	Clay (%)	Organic C (g kg^{-1})	Porosity (%)

PUP-r	36.12	52.75	11.13	22.05	71
NTR-f	31.78	48.88	19.33	19.82	65
NTR-r	29.10	45.07	25.83	26.02	65
NTRw-r	31.72	46.55	21.73	24.18	59

2.2. Water-stable aggregates separation

Soil samples were collected to assess SOC and aggregates stability in October 2006 (one and a half months after rice harvesting). Soil was sampled at 0-20 cm for aggregates stability and SOC. Six samples were collected from each subplot and mixed to produce a composite sample from each treatment and replicate. In the laboratory, Subsamples for SOC determination were air-dried and sieved through a 0.25 mm mesh. Subsamples for aggregates-size separation were air-dried and sieved through a nest of two sieves to collect all the aggregates with a diameter between 2 and 6.72 mm mesh sizes.

Wet sieving using air-dried 2-6.72 mm sieved soil isolated aggregate-size fraction. Two 100-g subsamples of air-dried soil were used to analyze the aggregate stability distribution. Two pretreatments are applied before wet sieving: air drying followed by rapid immersion in deionized water (slaked) and air drying plus capillary rewetting to field capacity plus 5% (capillary-wetted) in two 250 ml beaker (Six et al., 1998). Both subsamples were stored overnight in a refrigerator at 4°C before wet sieving. Aggregates were physically separated in four aggregate-size fractions: (1) large macro-aggregates 2-6.72 mm in diameter, (2) small macro-aggregates between 0.25 and 2 mm in diameter, (3) micro-aggregates between 0.053 and 0.25 mm in diameter, and (4) the mineral fraction <0.053 mm in diameter. All the subsamples in 250 ml beakers were transferred on the top of a 3-nested sieve set (2 mm, 0.25 mm, and 0.053 mm) and submerged in deionized water for 5 minutes to allow slaking. A gentle vertical movement (strokes 2-3cm in amplitude and 5 min) within a column of water was done for 10 min using a wet sieving apparatus. After wet sieving, all the fractions were oven-dried at 70°C, except the large and small macro-aggregates obtained by the capillary-wetted pretreatment. These macro-aggregates were air dried and later used for the separation of larger and smaller stable macro-aggregates (Pojasok et al., 1990; Elliott and Cambardella, 1991; Six, 1998; Marquez et al., 2004).

2.3 Organic carbon concentration

SOC was determined from samples collected in aggregates separations using sulfuric acid oxidation with external heating (Anderson and Ingram, 1993).

2.4. Calculations and statistical analyses

2.4.1. Calculations

The mean size of aggregates is represented by the mean weight diameter (MWD) and natural mean weight diameter (NMWD). MWD and NMWD were obtained as indicated in Eqs. (1) and (2) (Six, 1998; Marquez et al., 2004; van Steenbergen, et al., 1991).

$$MWD = \sum_{1}^{n+1} \frac{r_{i-1} + r_i}{2} \times m_i \quad (1)$$

Where r_i is the mean equivalent diameter for each particle size interval (mm), $r_0 = r_1, r_n = r_{n+1}$, m_i is the weight of particles in the interval.

$$NMWD = \frac{MWD}{r_{\max} - r_{\min}} \quad (2)$$

Where $r_{\max}$ is the biggest initial diameter and $r_{\min}$ is the smallest initial diameter.

2.4.2. Statistical analysis

Statistical differences were determined with *t* Student test using statistica software (Statsoft, 2004).

3. Results

3.1. Soil aggregates composition

Distribution of soil aggregates under different breakdown mechanisms pretreatments was shown in table 3 and table 4. Although the multitude of disruption of aggregates was different, soil aggregates contents was mainly discovered in the fraction of 2~6.72 mm in particle size in each treatment under different pretreatments. After slaking treatments, the percentage of 2~6.72 mm size was lowest in PUR-r and highest in NTR-r, which suggested that multitude of disruption of aggregates in PUR-r was more severe than that in NTR-r. There were strongly differences between conservation tillage and CT of 2~6.72 mm size contents. 2~6.72 mm size aggregates in NTR-r and NTRw-r were significantly higher compared to its value in PUR-r, about 130.18% and 144.33%, respectively. And 2~6.72 mm class also increased in

NTR-f by 1.113 times over that in PUR-r. Significant differences between NTR-r and other treatments were discovered of the aggregates contents in the size of 0.25~2 mm, and its content under NTR-r was the lowest.

Table 3. Composition of aggregates in purple paddy soil under slaking pretreatment %

Treatment	＜0.053 mm	0.053～0.25 mm	0.25～2 mm	2～6.72 mm	Recovery
PUP-r	13.21±1.48a	10.20±0.81ab	20.60±3.05a	52.92±0.75c	96.93
NTR-f	9.40±0.53b	13.12±1.88a	16.61±4.62ab	58.90±5.44bc	98.02
NTR-r	5.27±0.42c	5.66±0.86c	11.50±3.25c	76.41±4.56a	98.83
NTRw-r	4.77±0.99c	7.88±3.76bc	15.11±4.13ab	68.89±8.65ab	96.65

Table 4. Composition of aggregates in purple paddy soil under slowly wetting pretreatment %

Treatment	＜0.053 mm	0.053～0.25 mm	0.25～2 mm	2～6.72 mm	Recovery
PUP-r	14.48±0.56a	13.23±0.71a	18.30±1.08a	51.84±2.53b	97.85
NTR-f	10.06±1.42b	11.11±0.53b	14.09±4.06a	63.26±5.90ab	98.52
NTR-r	2.65±0.49c	8.95±1.26c	15.61±8.48a	68.47±10.32a	95.68
NTRw-r	6.72±4.10bc	6.50±1.16d	14.74±0.59a	70.42±3.68a	98.38

Aggregates contents in all treatments under wetting treatment ranked in the order of PUR-r＜NTR-f＜NTR-r＜NTRw-r, which was different from that under slaking treatment. The amount of 2~6.72 mm in NTR-f, NTR-r and NTRw-r increased by 22.02%, 32.07% and 35.84% to comparison with the control, respectively. There were no significant differences of 0.25~2 mm aggregates-size contents between conservation and conventional tillage. The contents of 0.25~2 mm aggregates-size under slaking treatment were higher than that under wetting treatment in each treatment except that in NTR-r. Aggregates contents decreased with the decrease of aggregates-size, which indicated that conservation tillage might increase water-stable macro-aggregates proportion at cultivated layers in purple paddy soil.

3.3. Soil aggregates stability

According to wet sieving as above, the contents of 2~6.72 mm and 0.25~2 mm aggregates-size macro-aggregates under subsequent slaking treatment, which were collected from the fractions of 2~6.72 mm and 0.25~2 mm under wetting treatment and then air-dried, were determined (Table 5). 0.25~2 mm stable aggregates in all treatments were increased in the order of PUR-r (0), NTR-f (5.47%), NTRw-r (8.33%) and NTR-r (13.76%). The proportion of stable aggregates 2~6.72 mm in NTR-f, NTRw-r and NTR-r was increased by 10.51%, 9.27% and 6.74% compared to the control, respectively. The percentage of stable macro-aggregates contents in all treatments (PUR-r, NTR-f, NTRw-r and NTR-r) after subsequent slaking treatment was 64.26%, 74.09%, 93.31% and 94.31%, respectively. Consequently, conservation tillage could enhance the resistance of aggregates to slaking stresses in paddy soil, and reduce the multitude of the disruption of aggregates.

Table 5. Effects of subsequent slaking treatment on the percentage of macroaggregates in paddy soil

Treat-ments	0.25～2 mm			2～6.72 mm		
	Stable aggregate ($g\ kg^{-1}$)	Total aggregates ($g\ kg^{-1}$)	Stable Aggregate percentage %	Stable aggregate ($g\ kg^{-1}$)	Total aggregates ($g\ kg^{-1}$)	Stable aggregate percentage %
PUP-r	11.35	18.30	62.02	33.72	51.84	65.04
NTR-f	9.51	14.09	67.49	47.80	63.26	75.56
NTR-r	11.83	15.61	75.78	50.88	68.47	74.31
NTRw-r	10.37	14.74	70.35	50.55	70.42	71.78

The aggregate-size stability distribution is the quantity of stable and unstable soil aggregates categorized by their size and stability to disruption. Water-stable aggregates can improve soil stability, and enhance physical protective ability for soil organic carbon. The aim of agricultural management is to create the stable soil structure. The percentage of water-stable macro-aggregates decreased in the order of NTR-r, NTRw-r, NTR-f and PUR-r under fast slaking treatment and NTRw-r, NTR-r, NTR-f and PUR-r under wetting treatment, respectively. Similar distribution trends of water-stable macro-aggregates were observed under slaking treatment and wetting treatment when the stability of aggregates was represented as MWD and NMWD (table 6).

Table 6. Percentage and mean weight diameter of the water stable macroaggregates（＞0.25 mm）

Treatments	WSMA（%）	MWD（mm）	NMWD（mm）

	Slaking Pretreat-ment	Wetting Pretreat-ment	Slaking Pretreat-ment	Wetting Pretreat-ment	Slaking Pretreat-ment	Wetting Pretreatment
PUP-r	75.84	71.68	2.56	2.49	1.31	1.28
NTR-f	77.04	78.51	2.78	2.94	1.43	1.51
NTR-r	88.86	87.88	3.47	3.18	1.78	1.63
NTRw-r	86.91	88.11	3.19	3.25	1.64	1.67

3.4. Organic carbon in aggregates

Organic carbon (OC) contents were mainly found in the fraction of 0.25~2 mm and 2~6.72 mm, and then in <0.053 mm size aggregates and least in 0.053~0.25 mm under fast slaking treatment in all treatments (Figure 2). There was a pronounced difference of SOC contents in the fraction of 2-6.72 mm between conservation and conventional tillage. SOC contents under NTR-r, NTRw-r and NTR-f were 42.24%, 43.03% and 33.31% higher than that in PUR-r, respectively. Significant difference was observed among treatments of organic carbon in 0.25~2 mm size class, ranked in the order of NTRw-r > NTR-r> NTR-f> PUR-r. SOC contents in 0.053~0.25 mm under NTRw-r and NTR-r were significantly higher 1.11 and 0.59 times over that in the control, while in the fraction of <0.053 mm were higher about 16.43% and 58.98%, respectively.

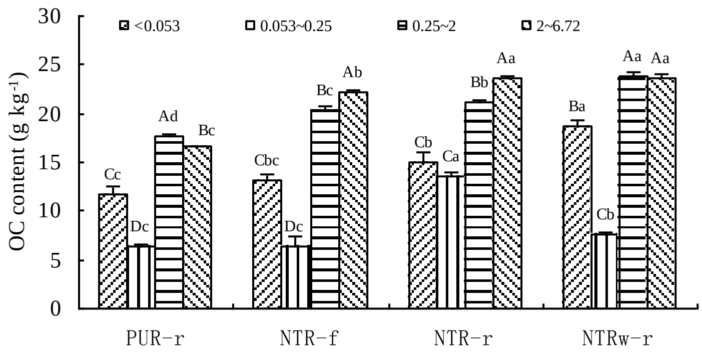

Fig. 2. Organic carbon contents in broken aggregates under slaking pretreatment

Distribution trends of SOC contents in aggregates under wetting pretreatment in all treatments were similarly to that under fast slaking pretreatment. Significant differences of SOC contents were found in aggregates of the tillage treatment and size fraction in each treatment and also found in micro-aggregates among treatments under wetting pretreatment. OC content in 0.053~0.25 mm after wetting treatments was higher than that under fast slaking pretreatment (Figure 3). Compared with the control, OC contents in the fraction of 2~6.72 mm and 0.25~2 mm under NTR-r were increased by 10.91% and 19.93%, while 0.7% and 28.47% under NTRw-r, respectively. It was worth paying attention to that OC content in each aggregates-size in the control under wetting pretreatment was higher than that under fast slaking pretreatment. There may be something wrong with the soil porosity when it was high in control, which could cause majority of particulate organic matter with internal or external aggregates to float upward during fast slaking pretreatment. Particle organic carbon was about more than 27% of total organic carbon in cultivated layer of purple paddy soil (Huang et al., 2005; Tufekcioglu et al., 1999) and was significant positive correlated with aggregates stability (Li et al., 2004).

OC contents in stable and unstable macro-aggregates under subsequent slaking pretreatment were measured (Figure 4). OC contents in stable aggregates were always higher than that in unstable aggregates, and the OC contents in 0.25~2 mm stable aggregates were higher than that in 2~6.72 mm stable aggregates. Under subsequent slaking pretreatment, significant differences were observed between conservation tillage and the control. OC contents in 0.25~2 mm stable aggregate under NTR-r, NTRw-r and NTR-f were significantly increased by 38.64%, 24.26% and 24.52% compared to the control, respectively. OC contents in 2~6.72 mm stable aggregates under NTR-r and NTRw-r were 9.94% and 20.57% higher than that in the control, respectively. It may be sure that most of OC contents were enriched in stable macroaggregates under long-term ridge or wide ridge culture integrated with no-tillage, crop rotation and rice stubble.

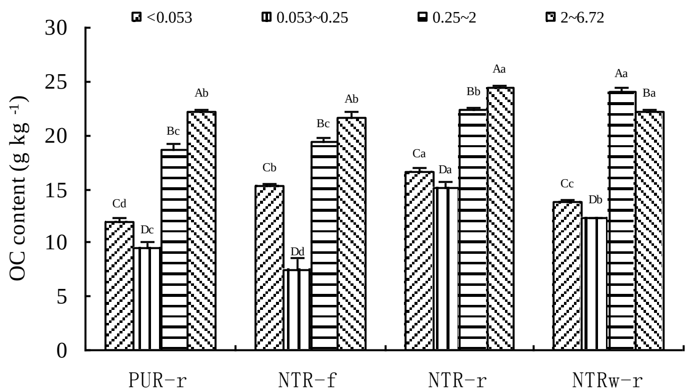

Fig. 3. Organic carbon contents in slaked aggregates under slowly wetting pretreatment

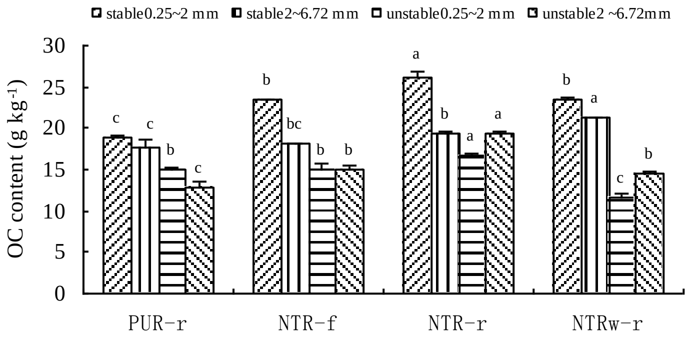

Fig. 4. Organic carbon contents in broken aggregates under subsequent slaking pretreatment

4. Discussion

4.1 Effects of ridge culture on the aggregates-size stability distribution

SOC contents increased under long-term ridge culture and aggregates stability was significantly enhanced. The disruption of aggregates during the slaking and wetting treatment produces smaller constituent aggregates. Aggregates contents decreased with the decrease in aggregates size, and the proportion of 2~6.72 mm aggregates-size was more than 50%. The magnitude of stable macro-aggregates under conservation tillage was also significantly higher than that under conventional tillage after subsequent slaking treatment. Excellent soil structure was determined not only by macro-aggregates but also by the quality and quantity of micro-aggregates, which may indicate the potential ability to format soil structure. Under wet-shaking treatment, bulk soil was mainly separated into the fraction of 0.02~0.25 mm aggregates-size (45~54%), and then 0.002~0.02 mm aggregates-size, macro-aggregates and its organic carbon increased at surface layers (0~10 cm) in paddy soil (Tang et al., 2007). In conclusion, fast slaking and wetting processes under natural condition may be the major breakdown mechanisms of macro-aggregates in purple paddy soil.

Aggregates stability is a quality indicator that directly related to soil organic matter, which can be redistributed within soil by tillage. Water stable aggregates in cultivated layers mainly caused by strike and extrusion of crop roots and cementation of secretion. The quantity of straw mulch returning into purple paddy soil ranked in the order of PUR-r > NTR-r > NTRw-r > NTR-f (Table 6). OC contents and aggregates stability in plain culture were lower than those in ridge culture. Macro-aggregates, which are C-rich substances under conventional tillage, were disrupted, and increased smaller aggregates contents, which are lack of organic carbon, resulting in low soil organic matter content. Moreover, long-term tillage practices diminish the quality and length of fine roots and microbial population in the upper horizons, and reduced the amount of macro-aggregates. Crop residues were enriched in soil surface layer by making ridge and plot in NTR-r and NTRw-r and increased unstable carbon inputs (soil biomass carbon and particulate organic matter), which are the main binding (cementing) agent to form macro-aggregates. From conversion, conventional submersion or drying to ridge/plot capillary-wetted cultivation, gravity water has been eliminated, and water erosion has been mitigated under conservation tillage (NTR-r and NTRw-r), thus soil maintains capillary wetting. Because water, gas, and heat regime exchanges frequently, these enable soil under ridge to contract itself and consequently form stable soil structure. Pore character of soil aggregates is the main factor influencing wetting speed, such as pore size and camber. Caron reported that pore camber indexes in NT is three times more compared to in CT, water immerse rate decreased by 70% and increased aggregates stability (Mazurak et al., 1950; Caron et al., 1996). It is suitable to form soil structure for soil pore type and quantity and soil density which was lower in NTR-r and NTRw-r compared to PUR-r that was caused by stable heat capability, relative stable electrical field, continuous immersing and strong water retention ability of labile organic matters which were rotted from root straw internal or external soil pore (Xie et al., 2002; Wei et al., 2006).

4.2 Relationship between soil organic carbon and aggregates-size stability

Organic matter is one of the key factors influencing soil stability. OC magnitude has close connection with aggregates stability, but the multitude of correlation was site-specific. There was low correlation between organic carbon and aggregates stability under fast slaking pretreatment, however, significant positive correlation was observed under wetting pretreatment (Li et al., 2006; Hernanz et al., 2002). Soils organic compounds not only buildup the cohesion and tensile strength among aggregates, and heighten soil aggregates stability, but also mitigate the wetting velocity because water capability of soil compounds was greatly higher than that in soil mineral. Moreover soil organic compounds hydrophobicity affects the wetting velocity. The addition of straw can promote microbe activity, and reinforce cohesion and hydrophobicity of aggregates. The impact of addition of straw multchon aggregates was greater than wet-dry cycles. Enhancement of soil hydrophobicity would hinder or delay infiltration velocity of soil water (Hallett et al., 1999), and make air in soil pore release slowly, thus reduce slaking resistance and enhance soil aggregates stability (Capriel et al., 1990). Soil hydrophobicity may illuminate the relationship between soil organic carbon and soil structure stability. Soil texture also has great impact on Soil hydrophobicity. When soil texture is different, Soil hydrophobicity has significant difference. Clay contents were 3.32 and 2.95 times in

NTR-r and NTRw-r over that in PUR-r, respectively. Ridge culture could protect soil from erosion because crop residues remain relatively undisturbed on the soil surface in contrast to plain culture, and the precipitation infiltrated soil in the form of capillary water. For the reduction of water erosion, the proportion of clay in soils under ridge culture increased. Hallett (1999) reported that when clay content was more than 25% or even more 40%, soil hydrophobicity was all the same great, and even the soil hydrophobicity in high soil clay content was greater than in low soil clay content. This may be because that hydorphobic organic particulate itself was rather small or organic matter content was greatly high, which can enwrap large and small particulate and lead to more greatness of specific surface of soil hydrophobic organic compounds.

5. Conclusion

Under slaking and wetting pretreatment, the amount of aggregates-size was mainly found in the diameter of 2~6.72 mm under ridge culture in paddy soil (more than 50%). The proportion of macro-aggregates under ridge culture treatment was greatly higher than that in conventional tillage soils under subsequent slaking pretreatment. The proportion of macro-aggregates and its OC content increased under long-term ridge culture in paddy field, which straightened soil aggregates stability. No significant difference of aggregates stability was found between slaking and wetting pretreatment. Organic carbon contents were obviously enriched in macro-aggregates, and SOC in aggregates were highly correlated with aggregates stability under wetting treatment. It is important to seek management practices that sustained soil resource. Keeping the soil in place is the best defense against soil degradation. Ridge culture without tillage could protect soil from erosion because crop residues remain undisturbed on the soil surface in contrast to plain culture where residue was incorporated. These evidences suggested that Long-term ridge culture may lead to changes of straw mulch inputs and soil microenvironment and enhancement of aggregates water stability.

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