Medium-term Effects of Mineral Fertilizer and Organic Amendments on Aggregate and Soil Organic Carbon and Nitrogen Dynamics in Rhizosphere and Bulk Soil

Wenhai Mi (wenhaimi@126.com)
Yangzhou University
Taotao Zha
Yangzhou University
Qiang Gao
Yangzhou University
Haitao Zhao
Yangzhou University

Research Article

Keywords: aggregate stability，mean weight diameter，cattle manure，rice straw

Posted Date: June 1st, 2021

DOI: https://doi.org/10.21203/rs.3.rs-500528/v1

Abstract

Soil aggregate stability is one of the important physical properties affecting rice (*Oryza sativa* L.) production and soil sustainability. This study was undertaken to evaluate the influence of different medium-term fertilization regimes on soil aggregate stability and aggregate associated carbon and nitrogen in rhizosphere and bulk soil. This experiment consisted of three treatments including mineral fertilizer alone (NPK), mineral fertilizer plus rice straw (NPK + RS), and controlled-release blended fertilizer plus cattle manure (CRF + CM). The results showed that bulk soil contained higher mean weight diameter (MWD) than in rhizosphere soil at the rice jointing and maturity stages. Compared to the NPK alone, combined application of NPK with organic amendments improved the proportion of > 0.25 mm macroaggregate, soil organic carbon (SOC), total nitrogen (TN) concentrations, and MWD in both rhizosphere and bulk soil. In rhizosphere, the proportion of macroaggregate was significantly positively ($p < 0.01$) correlated with root biomass while had no significant correlations with SOC in all sizes aggregates. By contrast, bulk soil had a significantly ($p < 0.01$) positive relationship between the proportion of > 2 mm class and organic C associated with smaller particle-size aggregates (0.25–2 mm and < 0.25 mm). During the rice-growing season, the highest MWD value was observed at the jointing stage except for the NPK + RS treatment in bulk soil. Overall, the results suggested that the medium-term application of mineral fertilizer with organic amendments is beneficial to improve soil aggregate stability and C and N accumulation.

Introduction

Soil aggregate stability is an important indicator of soil quality since it influences soil water-holding capacity, biological activity, root penetration and plant growth (Six et al. 2000; Wu et al. 2018). Various mechanisms have been proposed to account for soil aggregation process. Tisdall et al. (1982) suggested that primary particles are bound into microaggregates (20–250 μm diameter), which, in turn, are bound into larger aggregates (> 250 μm diameter). Organic matter is the major binding agent which affects aggregate stabilization at different level. The organic binding agent can be classified into three main groups on the basis of age and degradation of the organic matter: (1) transient (mainly polysaccharides); (2) temporary (roots and hyphae); (3) persistent (humic materials associated with aluminium and amorphous iron) (Tisdall et al. 1982; Jastrow et al. 1998). The persistent organic binding agents play a key role in the forming of < 0.25 mm microaggregate while physical enmeshment by roots is regard as a major mechanism involved in the binding of microaggregates into > 0.25 mm macroaggregates (Miller et al. 1990). Therefore, soil adjacent to roots might have different physical properties with those of bulk soil (Chen et al. 2006). Whalley et al. (2005) used image analysis and found that bulk soil contained larger numbers of small and medium-sized pores than the rhizosphere for wheat and maize.

Fertilization not only affects plant growth but also changes the soil organic matter (SOM) content, thereby influencing the formation and stability of soil aggregates. Tripathi et al. (2014) observed that farmyard manure application for 41 years had higher mean weight diameter (MWD) than mineral fertilizer alone in tropical rice-rice system. However, Barbosa et al. (2015) showed that application of swine manure immediately increased the dispersible clay content and reduced soil aggregation for corn production due to the increased concentrations of carboxylic groups. Soon et al. (2012) found that straw retained on surface had no effect on soil aggregation in a cold semi-arid region in a barley (*Hordeum vulgare* L.), field pea (*Pisum sativa* L.), wheat (*Triticum aestivum* L.), canola (*Brassica napus* L.) crop rotation. The inconsistent research reports showed that effects of organic manure application on soil aggregate stability are still inconclusive. Moreover, most researches only compared the aggregate stability under different fertilization managements at a certain time (Zhang et al. 2014; Xin et al. 2016). Few studies quantitatively considered the effects of different fertilization regimes and rice growth stages on soil aggregates and its C dynamics in rhizosphere and bulk soil.

The objectives of this study were to determine the influence of three different fertilization regimes on soil aggregate and SOC and total nitrogen (TN) dynamics of rice rhizosphere and bulk soil within one rice-growing season. We hypothesized combined application of mineral fertilizer and organic amendments increased the MWD in both rhizosphere and bulk soil as well as the aggregate associated C and TN content.

Materials And Methods

Field site description

The medium-term experiment was located at the Xinzhu country (29 °C 01′10″N, 119 °C 28′10″E and 80 m above mean sea level), Jinhua city, Zhejiang province, China. The prevailing climate of the experimental is a subtropical monsoon climate with four distinct seasons. Mean annual temperature is 17.5 °C, and mean annual rainfall is 1424 mm. The soil at the experimental site belongs to yellow clayey paddy soil. Mean aggregate size distribution (per 100 g) was 37 g sand, 35 g silt, and 28 g clay.

Experimental layout and sampling

The experiment was initiated in 2011 and included three treatments with three replicates. Each plot size was 5 m width and 6 m length. Treatments were: (1) inorganic N-P-K fertilizers application alone (NPK); (2) the NPK fertilizers plus rice straw at 3 Mg ha^{-1} per rice-growing season (NPK + RS); (3) controlled-release blended fertilizer plus cattle manure at 4.7 Mg ha^{-1} per rice-growing season (CRF + CM). Before imposing experimental treatments, the soil contained 28.1 g kg^{-1} soil organic matter, 1.75 g kg^{-1} total N, 117 mg kg^{-1} alkali-hydrolyzable N, 11.6 mg kg^{-1} available P, 78 mg kg^{-1} available K, and pH was 5.24.

Common urea, superphosphate, and potassium chloride were the sources of N, P and K, respectively. Controlled-release blended fertilizer (CRF, N-P-K, 24-12-12) was provided by Kingenta Ecological Engineering Group Co., Ltd., Shandong, China. All three treatments received the same rates of inorganic nutrients (180 kg N, 90 kg P_2O_5, and 120 kg K_2O per hectare) in each rice-growing season. For the NPK alone and NPK + RS treatments, the complete doses of P and K chemical fertilizers were applied as a basal dressing. Nitrogen fertilizer was applied as split applications at ratios of 40%: 30%: 30% (basal: tillering: booting) for the early rice, and at ratio of 40%: 60% (basal: tillering) for the late rice. For the CRF

+ CM treatment, CRF was applied as a single basal application. Rice straw and cattle manure were applied on the soil surface once before rice transplanting. On average, rice straw contained 44% C, 0.9% N, 0.1% P, and 2% K on a dry weight basis. Cattle manure contained 29% C, 2% N, 1% P, and 1.2% K on a dry weight basis.

Tillage operations for each plot include deep plough at the depth of 22–25 cm in April and shallow plough at the depth of 10–15 cm in late–July before transplanting every year. Early rice was transplanted in late-April and harvested in late-July. Late rice was transplanted at the end of July and harvest in early-November. The fields remained fallow between harvest and transplanting (from November to next year April). Seedlings were transplanted at four plants per hill in a planting pattern of 16.5 cm × 19.8 cm for early rice, and two plants per hill in a planting pattern of 19.8 cm × 19.8 cm for late rice each year. Early rice variety was “Jinzao 09” and late rice variety was “Yueyou 9113”.

Soil samples from each plot were taken at three stages: tillering stage (May 19th, 2018), jointing stage (June 10th, 2018), and after rice harvest (July 25th, 2018). Specific soil sampling methods are as follows: Ten whole plants with their roots were randomly selected and extracted from soil in each plot. Then, after gentle shaking off the loosely adherent soil, the tightly adherent soil was carefully collected regarded here as rhizosphere soil. The unvegetated soil (0–20 cm) adjacent to the rice plants was sampled as bulk soil (Ai et al. 2013). Ten soil cores (diameter 5 cm) from each plot were mixed to form a composite soil sample. Thus, total 54 composite soil samples were collected (3 treatments × 2 soil fractions × 3 replicates × 3 rice growth stages). The samples were placed in hard plastic boxes (180 mm × 120 mm ×70 mm) and immediately transported to the laboratory. After removing residual roots, soil samples were passed through 8.0 mm sieve and stored at 4 °C before analysis.

Soil aggregate fractionation and chemical analysis

Soil samples were physically fractionated into different classes of aggregates by wet sieving (Kemper et al. 1986) following the method described by Wang et al. (2015). In wet sieving, 100 g of < 8 mm soil sample was immersed in water on top of a stack of sieves (5–, 2– and 0.25 mm). The stack was moved up and down by 3 cm, 30 times per minute for 30 min. Soil aggregate fractions remaining on the sieves were oven-dried at 50 °C, weighed and stored at room temperature for C and N analyses. The ratio of aggregate mass on each sieve to the total soil mass was calculated.

The mean weight diameter (MWD) was calculated by the following equations (Pinheiro et al. 2004):

$$MWD = \sum_{i=1}^{n} \mathrm{XiWi} \qquad (1)$$

where *Xi* is mean diameter of each size fraction and *Wi* is the weight of aggregate in that size range as a fraction of the total analyzed sample weight, and n is the number of the sieves.

Total soil organic carbon (TOC) and total N concentrations were analyzed by dry combustion method using a Vario MACRO C/N elemental analyzer (Elementar Corp, Germany) (Tian et al. 2012).

Statistical analysis

Data were subjected to analysis of variance (ANOVA). The significant differences were compared using the Duncan multiple range test at the 0.05 level of probability. Pearson's correlations were used to evaluate the relationships between the soil aggregate composition and SOC concentration.

Results

Size distribution of soil aggregates

The largest proportion of soil aggregates was the 0.25–2 mm class, followed by < 0.25 mm and > 2 mm classes for all fertilization treatments and rice growth stages in both rhizosphere and bulk soil (Table 1). Compared to the NPK alone, NPK + RS and CRF + CM treatments significantly increased the proportion of > 2 mm class while decreased the proportion of aggregates < 0.25 mm during the whole rice growth season regardless of rhizosphere and bulk soil ($p < 0.05$, Table 1).

Table 1
Soil aggregate size distribution among different fertilization regimes at three rice growth stages.

Sampling Time	Treatment	Rhizosphere soil			Bulk soil		
		> 2 mm	0.25-2 mm	< 0.25 mm	> 2 mm	0.25-2 mm	< 0.25 mm
Tillering	NPK	15.6 ± 0.5b	52.2 ± 1.3c	32.2 ± 1.7a	14.8 ± 0.4c	50.3 ± 2.0a	34.9 ± 2.0a
	NPK + RS	17.8 ± 0.4a	56.3 ± 1.4b	26.0 ± 1.7b	23.4 ± 1.0b	48.3 ± 1.7a	28.3 ± 1.0b
	CRF + CM	17.9 ± 0.2a	59.3 ± 0.9a	22.8 ± 1.1c	26.9 ± 0.8a	47.0 ± 2.1a	26.0 ± 1.4b
Jointing	NPK	25.1 ± 1.4b	41.1 ± 0.9b	33.8 ± 0.5a	29.0 ± 0.9b	38.2 ± 1.1a	32.8 ± 1.1a
	NPK + RS	31.1 ± 0.4a	37.6 ± 0.4c	31.3 ± 0.7b	36.1 ± 1.2a	39.3 ± 0.5a	24.6 ± 1.1b
	CRF + CM	28.3 ± 2.1a	44.5 ± 2.1a	27.2 ± 1.1c	37.5 ± 2.2a	39.2 ± 1.4a	23.3 ± 0.8b
Maturity	NPK	16.6 ± 1.6c	47.8 ± 1.1b	36.2 ± 0.6a	21.7 ± 1.1b	47.3 ± 1.4 a	31.0 ± 1.3a
	NPK + RS	19.8 ± 1.6b	56.4 ± 2.0a	23.8 ± 0.8c	34.6 ± 0.8a	47.7 ± 0.5a	17.6 ± 0.5c
	CRF + CM	23.9 ± 0.9a	49.9 ± 1.9b	26.2 ± 1.2b	32.4 ± 2.2a	44.1 ± 2.0b	23.5 ± 2.5b

Note: NPK = mineral fertilizers alone; NPK + RS = mineral fertilizers plus rice straw; CRF + CM = controlled release blended fertilizer plus cattle manure. Values in a column at the same rice growth stage followed by the same small letter are not significantly different at the 5% level of probability.

Mean weight diameter (MWD)

Bulk soil had significantly higher MWD values than in the rhizosphere soil for three fertilization treatments at the rice jointing and maturity stages ($p < 0.05$, Table 2). At the rice tillering stage, only significantly greater MWD value in bulk soil than in rhizosphere soil was observed in the CRF + CM treatment ($p < 0.05$, Table 2). Among the three fertilization treatments, the NPK + RS and CRF + CM treatments showed significantly higher MWD values than in the NPK alone treatment during the whole rice growing season regardless of rhizosphere and bulk soil ($p < 0.05$, Fig. 1). In addition, the CRF + CM treatment showed the most profound positive effect on the MWD value (1.08 mm in rhizosphere soil and 1.13 mm in bulk soil) in the early rice growing stage (Fig. 1). On the other hand, soil MWD value was also significantly affected by rice growth stages. Among the three rice growth stages, the highest MWD value was observed at the rice jointing stage except for the NPK + RS treatment in bulk soil (Fig. 2).

Table 2
Mean weight diameter (MWD) between rhizosphere soil and bulk soil under three fertilization regimes and rice growth stages.

		Tillering	Jointing	Maturity
NPK	Rhizosphere soil	0.98 ± 0.02a	1.05 ± 0.02b	0.96 ± 0.02b
	Bulk soil	0.95 ± 0.02a	1.09 ± 0.01a	1.04 ± 0.02a
NPK + RS	Rhizosphere soil	1.05 ± 0.02a	1.12 ± 0.01b	1.09 ± 0.01b
	Bulk soil	1.08 ± 0.01a	1.23 ± 0.02a	1.27 ± 0.01a
CRF + CM	Rhizosphere soil	1.08 ± 0.01b	1.14 ± 0.02b	1.1 ± 0.01b
	Bulk soil	1.13 ± 0.01a	1.25 ± 0.03a	1.2 ± 0.04a

Note: NPK = mineral fertilizers alone; NPK + RS = mineral fertilizers plus rice straw; CRF + CM = controlled release blended fertilizer plus cattle manure. Values in a column at the same fertilization treatment followed by the same small letter are not significantly different at the 5% level of probability.

Soil organic carbon (SOC) and total nitrogen (TN) concentrations in aggregates

Compared to the NPK alone treatment, the CRF + CM treatment significantly increased the SOC concentrations except for the < 0.25 mm aggregate at maturity (Figs. 3 and 4). Similar result was also observed for TN. However, there were no obvious differences in C: N value between CRF + CM and NPK alone treatments in most of aggregate sizes at three rice growth stages (Figs. 3 and 4).

The organic C associated with 0.25–2 mm showed the largest contribution of the total SOC content, indicating the majority of SOC was present in the 0.25–2 mm class (Table 3). Furthermore, fertilization altered the aggregate-assoicated C mass distribution. The organic C associated with macroaggregate (> 2 mm and 0.25–2 mm) ranged between 73.6% and 83.9% for NPK plus organic amendments, which was greater than in NPK alone treatment (67.8–71%). Correspondingly, the percentage of organic C associated with < 0.25 mm was significantly higher in NPK alone than that in the other combination of NPK and manure treatments (Table 3).

Table 3
Contribution (%) of C of each aggregate size fraction under different fertilization managements at three rice growth stages in rhizosphere and bulk soil.

Sampling Time	Treatment	Rhizosphere soil			Bulk soil		
		> 2 mm	0.25-2 mm	< 0.25 mm	> 2 mm	0.25-2 mm	< 0.25 mm
Tillering	NPK	16.9 ± 0.8c	54.1 ± 1.4b	29.0 ± 2.0a	14.7 ± 1.2c	54.0 ± 0.4a	31.3 ± 1.3a
	NPK + RS	19.3 ± 0.5b	59.2 ± 0.9a	21.5 ± 0.5b	25.9 ± 0.9b	50.3 ± 2.1b	23.8 ± 1.2b
	CRF + CM	20.9 ± 0.5a	60.1 ± 1.6a	19.0 ± 1.4b	31.1 ± 1.8a	47.6 ± 1.5b	21.4 ± 1.9b
Jointing	NPK	25.0 ± 0.3b	44.5 ± 0.9a	30.5 ± 1.2a	29.2 ± 0.3b	38.6 ± 1.4a	32.2 ± 1.2a
	NPK + RS	34.4 ± 0.1a	39.2 ± 1.1b	26.4 ± 1.3b	36.2 ± 2.5a	39.4 ± 2.5a	24.4 ± 1.6b
	CRF + CM	32.7 ± 4.6a	45.0 ± 3.6a	22.3 ± 1.7c	38.2 ± 1.7a	38.9 ± 2.1a	22.9 ± 0.9b
Maturity	NPK	18.5 ± 1.4b	51.1 ± 2.1b	30.3 ± 0.7a	22.2 ± 1.7b	48.0 ± 0.7a	29.8 ± 2.3a
	NPK + RS	21.0 ± 0.8b	59.4 ± 2.2a	19.7 ± 2.0b	35.2 ± 2.6a	48.7 ± 1.5a	16.1 ± 1.1b
	CRF + CM	28.5 ± 1.6a	54.7 ± 2.1b	16.8 ± 0.6c	34.4 ± 3.7a	46.5 ± 2.3a	19.0 ± 1.5b

Note: Values in a column at the same rice growth stage followed by the same letter are not significantly different at the 5% level of probability. All abbreviations are as in Table 1.

Relationship between aggregate size fractions, aggregate stability and soil properties

The relationships between aggregate size fractions and aggregate associated C concentrations were the main differences in rhizosphere and bulk soil (Table 4). For instance, bulk soil had a significantly ($p <$ 0.01) positive relationship between the proportion of > 2 mm class and organic C associated with smaller particle-size aggregates (0.25–2 mm and < 0.25 mm) while rhizosphere had not (Table 4). By contrast, positive correlations between MWD and aggregate associated C concentrations were found in both rhizosphere and bulk soil (Table 4).

Table 4
Correlations between soil aggregate size fractions, MWD and soil properties in rhizosphere (n = 27).

			Aggregate size			MWD
			> 2 mm	0.25-2 mm	< 0.25 mm	
Rhizosphere soil						
	SOC	> 2 mm	0.238	0.274	-0.731***	0.662***
		0.25-2 mm	0.320	0.290	-0.865***	0.808***
		< 0.25 mm	0.135	0.189	-0.478*	0.409*
	Root biomass		0.889***	-0.7***	0.043	0.668***
Bulk soil						
	SOC	> 2 mm	0.368	0.084	-0.576**	0.482*
		0.25-2 mm	0.499**	0.071	-0.746***	0.638***
		< 0.25 mm	0.720***	-0.473*	-0.582**	0.700***

* means $p < 0.05$, ** means $p < 0.01$, *** means $p < 0.001$.

Discussion

Our results showed that significantly lower MWD value in rhizosphere than in bulk soil at rice jointing and maturity stage. The possible explanations were: (1) the volume expansion exerted by growing roots caused a decrease porosity of soil aggregates (Bruand et al. 1996); (2) water uptake by roots and wetting the aggregates during watering were the main physical forces that promote rhizosphere aggregate disruption (Whalley et al. 2005); (3) root-induced priming effect might increase decomposition of SOM (Bird et al. 2011), which in turn increased aggregate dispersion. By contrast, no differences in MWD value between rhizosphere and bulk soil under NPK and NPK + RS at rice tillering stage, which was possibly attributed to the fact that rice root system was underdeveloped and had little effect on soil aggregates. Contrary to our result, Caravaca et al. (2002) found that higher proportion of stable aggregates was recorded in rhizosphere of *Rhamnus lycioides* L. The inconsistent observation was possibly due to differences in plant species and soil types.

Our studies also showed that long-term application of mineral fertilizer combined with organic manures increased proportion of macroaggregate (> 0.25 mm) in both rhizosphere and bulk soil. However, the mechanism of macroaggregate forming in rhizosphere and bulk soil might be different. In bulk soil, the proportion of > 2 mm aggregates had significantly positive correlations with SOC in smaller size aggregates (Table 4), which was similar with the result of Regelink et al. (2015), who reported that SOC content was correlated positively with water-stable aggregates (> 0.25 mm). Calabi-Floody et al. (2011) suggested that organic matter is a complex mixture of many organic substances, including polysaccharides, lignin, proteins, humic substances, and poorly soluble aliphatic compounds. Numerous properties of organic substances enabled organic matter to influence soil aggregation through different mechanisms. Hence, larger proportions of macroaggregate in combined mineral fertilizer with organic amendments treatments were possibly attributed to the addition of organics promoted formation of macroaggregates through binding of smaller aggregates.

By contrast, there were no correlations between the proportion of > 2 mm aggregate and organic C contents in all size aggregates in rhizosphere (Table 4). Our observation was similar with Haynes et al. (1991), who exhibited that changes in stability of soil aggregate occurred rapidly under different management practices before any changes in total SOC content were detected. Jastrow et al. (1996) also suggested that SOC seems to be more of a response rather than a mechanism that drives aggregation. Hence, another possible explanation is that the rhizosphere soil aggregate size distribution is more influenced by the rice root system. Jastrow et al. (1998) suggested that roots served as a framework for the formation of macroaggregate. In this study, higher root biomass was observed in mineral fertilizer with organic amendments treatments (Fig. S1), which may have a stronger physical entanglement of soil particles. Moreover, larger rice root biomass produced more secretions that contribute to soil aggregation process in rhizosphere.

In general, 8 years of rice growth and tillage operation lead to many factors of aggregation and disaggregation of the aggregates. Bulk soil and rhizosphere soil aggregates are being evaluated in a rice-growing season, so dynamism in aggregate formation caused by organic inputs and roots at that moment. Abiven et al. (2009) suggested that the short-term effects of organic inputs on aggregate stability were due to microbial activity and organic matter fractions, such as water-soluble carbohydrates, particulate organic matter, and polysaccharides. We speculated that the highest microbial activity at rice jointing stage accelerated the decomposition of organic manures and root residues, and the production of small molecular organic substances promoted macroaggregate forming.

Conclusions

Higher MWD determined in bulk soil than in rhizosphere under all fertilization treatments at rice jointing and maturity stages. Combined application of mineral fertilizer with cattle manure or rice straw increased MWD, the proportion of macroaggregate, and its organic C concentrations compared to the application of mineral fertilizer alone regardless of rhizosphere and bulk soil.

Abbreviations

NPK, nitrogen (N), inorganic phosphorus (P) fertilizer, and potash (K) fertilizer; NPK+RS, mineral fertilizer plus rice straw; CRF+CM, controlled-release blended fertilizer plus cattle manure; SOC, soil organic carbon; TN, total nitrogen; MWD, mean weight diameter.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for Publication

Not applicable.

Funding

This work was funded by the Jiangsu Natural Science Funding for Youth Scholars (BK20180905).

Competing Interests

The authors declare that they have no competing interests.

Availability of data and materials

All data generated or analyzed during this study are included in this published article and its supplementary information files.

Authors’ contributions

H.T. Zhao designed the study. W.H. Mi wrote the paper. Q. Gao, and T.T. Zha provided performed soil physical and chemical analysis.

References

1. Abiven S, Menasseri S, Chenu C (2009) The effects of organic inputs over time on soil aggregate stability-A literature analysis. Soil Biology and Biochemistry 41(1):1–12. https://doi.org/10.1016/j.soilbio.2008.09.015
2. Ai C, Liang GQ, Sun JW, Wang XB, He P, Zhou W (2013) Different roles of rhizosphere effect and long-term fertilization in the activity and community structure of ammonia oxidizers in a calcareous fluvo-aquic soil. Soil Biology and Biochemistry 57:30–42. https://doi.org/10.1016/j.soilbio.2012.08.003
3. Barbosa GMC, Oliveira JF, Miyazawa M, Ruiz DB, Filho, JT (2015) Aggregation and clay dispersion of an oxisol treated with swine and poultry manures. Soil and Tillage Research 146:279–285.https://doi.org/10.1016/j.still.2014.09.022

4. Bird JA, Herman DJ, Firestone MK (2011) Rhizosphere priming of soil organic matter by bacterial groups in a grassland soil. Soil Biology and Biochemistry 43(4):718–725. https://doi.org/10.1016/j.soilbio.2010.08.010
5. Bruand A, Cousin I, Nicoullaud B, Duval O, Begon JC (1996) Backscattered electron scanning images of soil porosity for analyzing soil compaction around roots. Soil ScienceSociety of America Journal 60(3) : 895–901. https://doi.org/10.2136/sssaj1996.03615995006000030031x
6. Calabi-Floody M, Bendall JS, Jara AA, Welland ME, Theng BKG, Rumpel C, Mora MdeL (2011) Nanoclays from an Andisol: extraction, properties and carbon stabilization. Geoderma 161(3-4) : 159–167. https://doi.org/10.1016/j.geoderma.2010.12.013
7. Caravaca F, Herna´ndez T, Garcı´a C, Rolda´n A (2002) Improvement of rhizosphere aggregate stability of afforested semiarid plant species subjected to mycorrhizal inoculation and compost addition. Geoderma 108(1):133–144. https://doi.org/10.1016/S0016-7061(02)00130-1
8. Chen YM, Wang M, Zhuang SY, Chiang PN (2006) Chemical and physical properties of rhizosphere and bulk soils of three tea plants cultivated in Ultisols. Geoderma 136(1-2):378–387.https://doi.org/10.1016/j.geoderma.2006.04.003
9. Haynes RJ, Swift RS, Stephen RC (1991) Influence of mixed cropping rotations (*pasture-arable*) on organic matter content, water stable aggregation and clod porosity in a group of soils. Soil & Tillage Research 19(1):77–87. https://doi.org/10.1016/0167-1987(91)90111-A
10. Jastrow JD (1996) Soil aggregate formation and the accural of particulate and mineral-associated organic matter. Soil Biology and Biochemistry 28(4-5):665–676. https://doi.org/10.1016/0038-0717(95)00159-X
11. Jastrow JD, Miller RM, Lussenhop J (1998) Contributions of interacting biological mechanisms to soil aggregate stabilization in restored prairie. Soil Biology and Biochemistry 30(7):905–916. https://doi.org/10.1016/S0038-0717(97)00207-1
12. Kemper WD, Rosenau RC (1986) Aggregate stability and size distribution. In: Methods of soil analysis, Part1. Physical and Mineralogical Methods (2nd Edition). Agron. Mono, pp. 425–442. https://doi.org/10.2136/sssabookser5.1.2ed.c17
13. Miller RM, Jastrow, JD (1990) Hierarchy of root and mycorrhizal fungal interactions with soil aggregation. Soil Biology and Biochemistry 22(5):579–584. https://doi.org/10.1016/0038-0717(90)90001-G
14. Pinheiro EFM, Pereira MG, Anjos LHC (2004) Aggregate distribution and soil organic matter under different tillage systems for vegetable crops in a Red Latosol from Brazil. Soil and Tillage Research 77:79–84. https://doi.org/10.1016/j.still.2003.11.005
15. Regelink IC, Stoof CR, Rousseva S, Weng LP, Lair GJ, Kram P, Nikolaidis NP, Kercheva M, Banwart S , Comans RNJ (2015) Linkages between aggregate formation, porosity and soil chemical properties. Geoderma 247–248:24–37.https://doi.org/10.1016/j.geoderma.2015.01.022
16. Six J, Elliott ET, Paustian K (2000) Soil structure and soil organic matter. II. A normalized stability index and the effect of mineralogy. Soil Science Society of America Journal 64(3):1042–

1049.https://doi.org/10.2136/sssaj2000.6431042x

17. Soon YK, Lupwayi NZ (2012) Straw management in a cold semi-arid region: Impact on soil quality and crop productivity. Field Crops Research 139:39–46. https://doi.org/10.1016/j.fcr.2012.10.010
18. Tian J, Fan MS, Guo JH, Marschner P, Li XL, Kuzyakov Y (2012) Effects of land use intensity on dissolved organic carbon properties and microbial community structure. European Journal of Soil Biology 52:67–72. https://doi.org/10.1016/j.ejsobi.2012.07.002
19. Tisdall JM, Oades JM (1982) Organic matter and water-stable aggregates in soils. European Journal of Soil Biology 33:141–163. https://doi.org/10.1111/j.1365-2389.1982.tb01755.x
20. Tripathi R, Nayak AK, Bhattacharyya P, Shukla AK, Shahid M, Raja R, Panda BB, Mohanty S, Kumar A, Thilagam VK (2014) Soil aggregation and distribution of carbon and nitrogen in different fractions after 41 years long-term fertilizer experiment in tropical rice-rice system. Geoderma 213:280–286. https://doi.org/10.1016/j.geoderma.2013.08.031
21. Wang XJ, Jia ZK, Liang LY, Yang BP, Ding RX, Nie JF, Wang JP (2015) Maize straw effects on soil aggregation and other properties in arid land. Soil and Tillage Research 153:131–136. https://doi.org/10.1016/j.still.2015.05.001
22. Whalley WR, Riseley B, Harrison PBL, Bird NRA, Leech P K, Adderley WP (2005) Structural differences between bulk and rhizosphere soil. European Journal of Soil Science 56 (3):353–360. https://doi.org/10.1111/j.1365-2389.2004.00670.x
23. Wu QC, Zhang CZ, Yu ZH, Zhang JB, Zhu CW, Zhao ZH, Xiong J, Chen JL (2018) Effects of elevated CO_2 and nitrogen addition on organic carbon and aggregates in soil planted with different rice cultivars. Plant and Soil 432:245–258. https://doi.org/10.1007/s11104-018-3801-8
24. Xin XL, Zhang JB, Zhu AN, Zhang CZ (2016) Effects of long-term (23 years) mineral fertilizer and compost application on physical properties of fluvo-aquic soil in the North China Plain. Soil and Tillage Research 156:166–172. https://doi.org/10.1016/j.still.2015.10.012
25. Zhang P, Wei T, Jia ZK, Han QF, Ren XL (2014) Soil aggregate and crop yield changes with different rates of straw incorporation in semiarid areas of northwest China.Geoderma 30–231:41–49. https://doi.org/10.1016/j.geoderma.2014.04.007

Figures

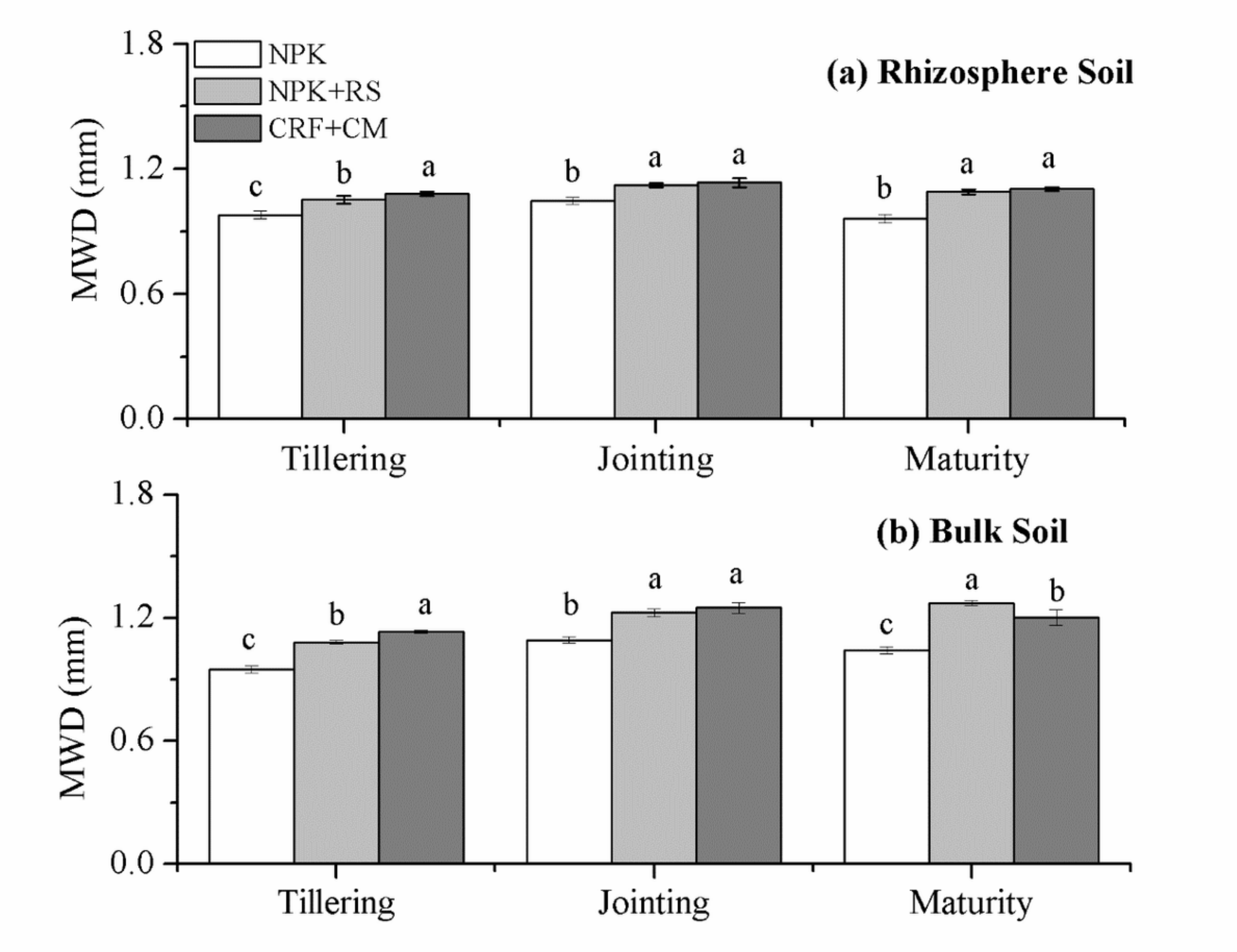

Figure 1

Mean weight diameter (MWD) among different fertilization regimes at three rice growth stages. Values with same letters in the same rice growth stage are not significantly different at the 5% level of probability. Error bars represent standard deviations. All abbreviations are as in Table 1.

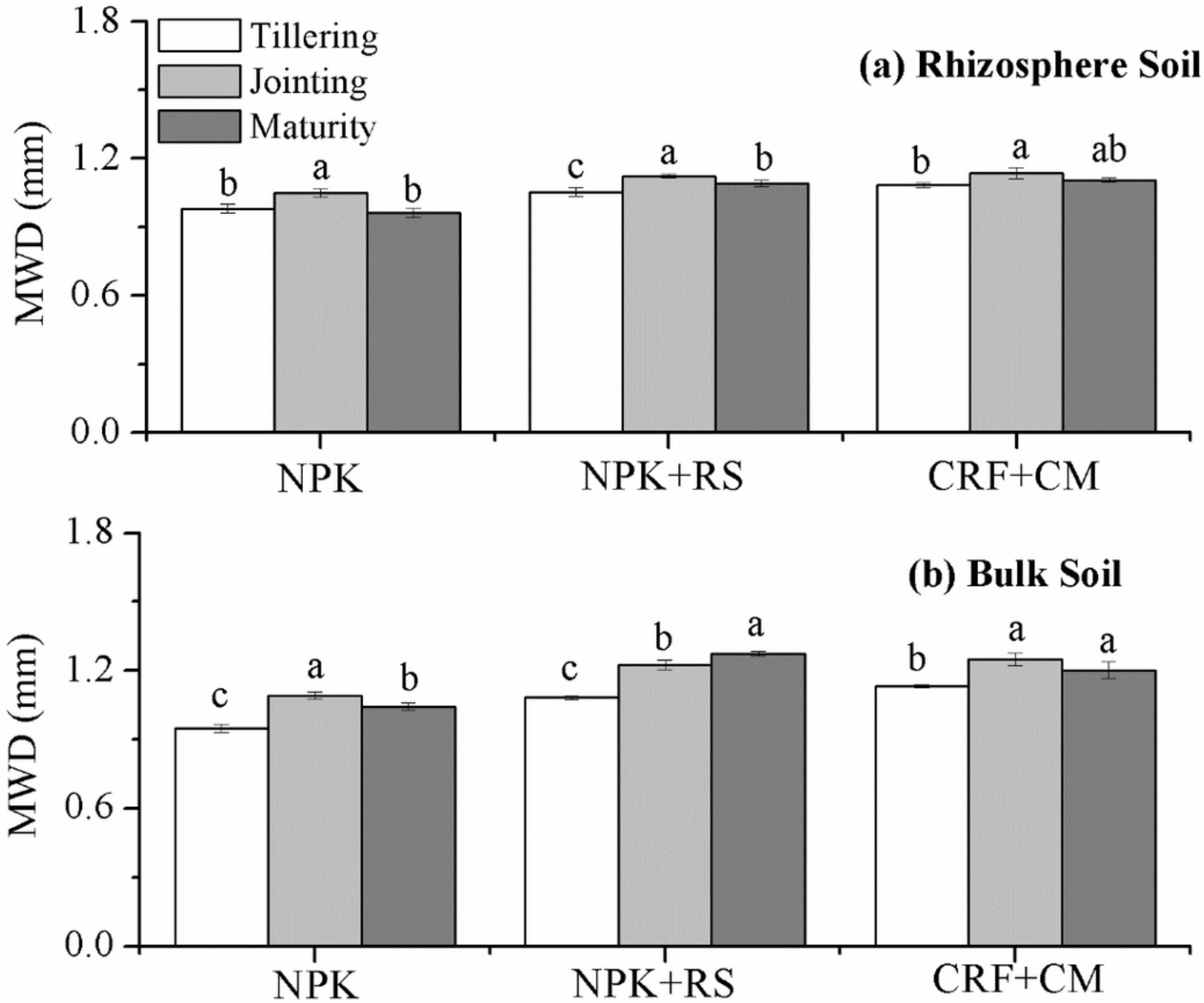

Figure 2

Mean weight diameter (MWD) among three rice growth stages under different fertilization regimes. Values with same letters in the same fertilization treatment are not significantly different at the 5% level of probability. Error bars represent standard deviations. All abbreviations are as in Table 1.

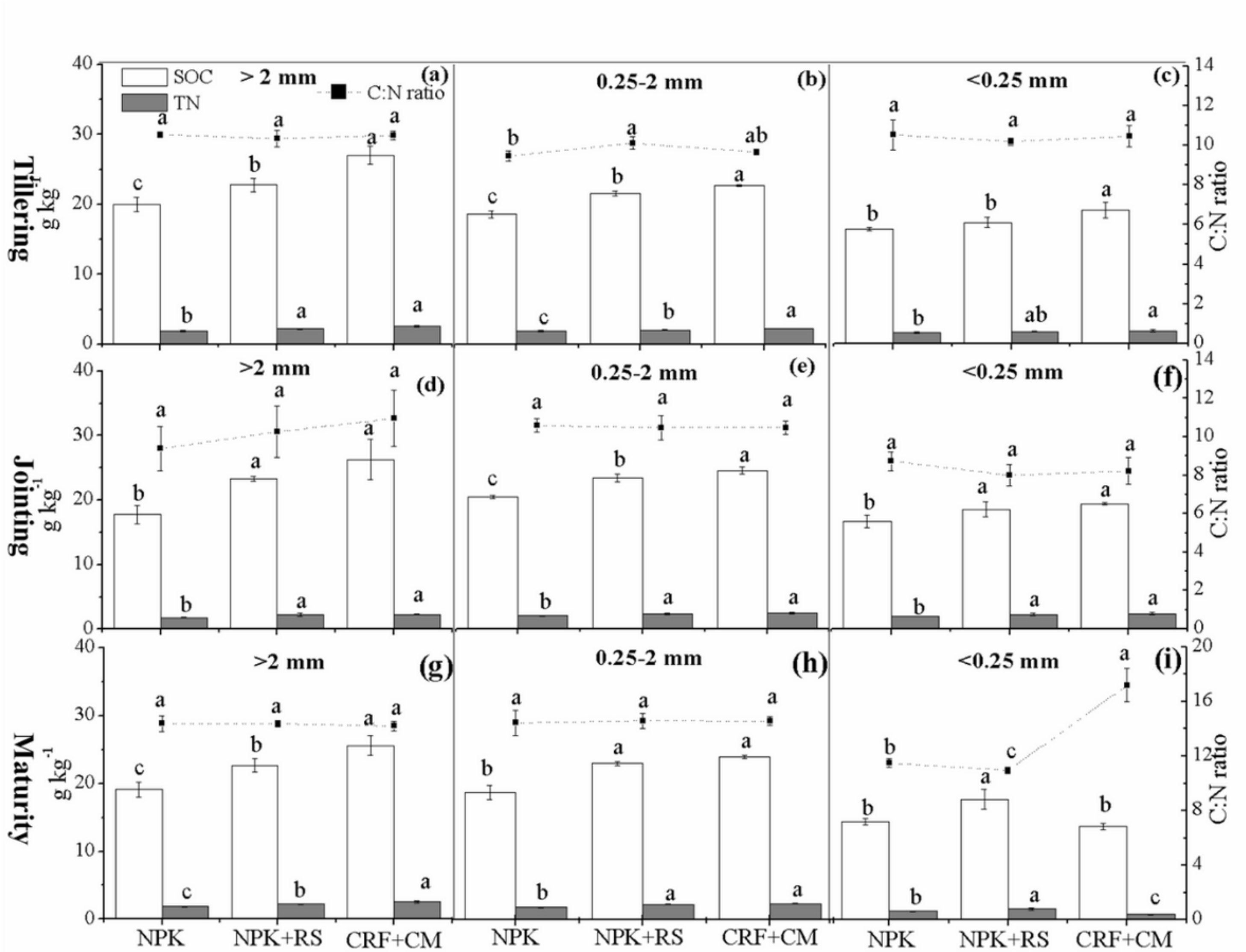

Figure 3

Concentrations of SOC, TN and C:N ratio in aggregate size fractions under different fertilization treatments at three rice growth stages in rhizosphere. Values with same letters are not significantly different at the 5% level of probability within each fraction. Error bars represent standard deviations. All abbreviations are as in Table 1.

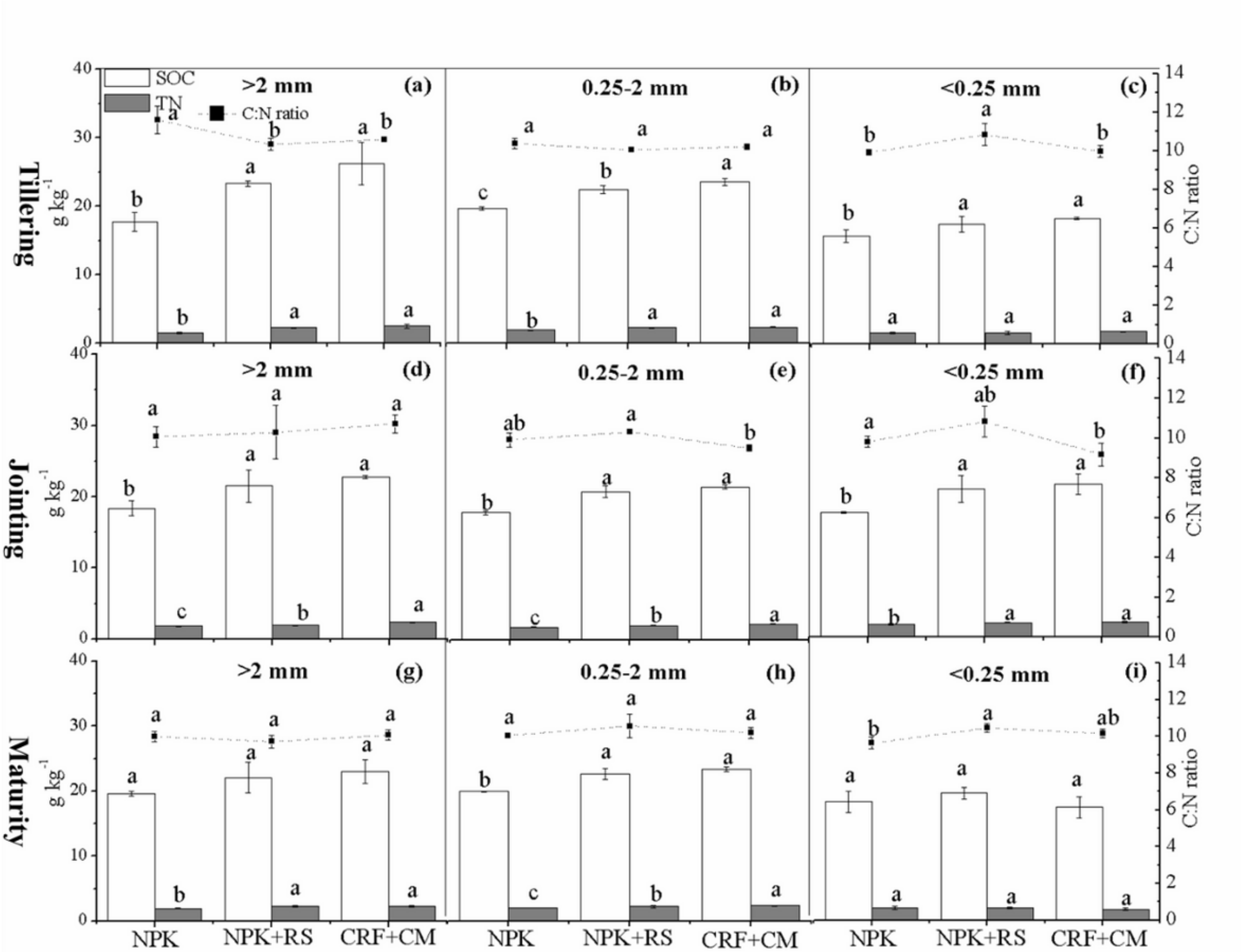

Figure 4

Concentrations of SOC, TN and C:N ratio in aggregate size fractions under different fertilization treatments at three rice growth stages in bulk soil. Values with same letters are not significantly different at the 5% level of probability within each fraction. Error bars represent standard deviations. All abbreviations are as in Table 1.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- TableS1.docx