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Distribution of soil water-stable aggregates and organic carbon content affected by tillage systems: a meta-analysis

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Abstract: A better understanding of soil carbon (C) distribution within aggregate fractions is essential to evaluating the potential of no-till for sustaining productivity and protecting the environment. A meta-analysis on 744 comparisons from 34 studies was conducted to determine the effects of three different tillage treatments (conventional mouldbould ploughing tillage (CT), reduced tillage (RT) and no tillage (NT)) on water-stable aggregate size distribution, soil C concentration in aggregate fractions. The meta-analysis indicates that compared with CT treatment, NT/RT significantly ($P<0.05$) increases macro-aggregate above 20 cm by 20.9%-82.2% (>2.00 mm) and 5.9%-19.1% (0.25-2.00 mm), whereas NT/RT significantly reduces micro-aggregate and silt clay fractions above 20 cm. NT/RT significantly ($P<0.05$) increases the SOC in macro-aggregate (>0.25 mm) and micro-aggregate (<0.25 mm) size classes above 20 cm soil depth compared with CT. The results suggest that soil sampling depth should be considered to evaluate the influence of tillage systems on the distribution of soil aggregate, and the content of aggregate-associated C content.

Key words: soil aggregation; soil organic carbon; reduced tillage; soil depth

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There has been an increased interest in the potentials of soil carbon (C) sequestration in agricultural fields with the the increased environmental changes. The quantity and stabilization mechanisms of soil organic carbon (SOC) related to soil aggregates are influenced by tillage practices[1]. Soil aggregate stability and SOC are key indicators for soil quality and environmental sustainability in agro-ecosystems. Firstly, aggregate formation influences the decomposition and turnover of SOC[2]. It has been reported that stable aggregates can physically protect SOC against rapid decomposition[3]. Secondly, SOC is considered to be the primary binding agent responsible for improving aggregate stability in micro-aggregates (<250 mm) and macro-aggregates (>250 mm)[4]. The SOC content in the macro-aggregates is an indicator of the stability of the aggregates and the retention or loss of C affected by different management practices[5]. Since physical protection of soil aggregate-associated OC is recognized to be one of the important SOC stabilization mechanisms[6],

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a better understanding of soil C distribution within aggregate fractions is essential to evaluating the potential of conservation tillage for sustaining productivity and protecting the environment. Averaged across all of the soil depth, NT/RT significantly increased SOC in macro-aggregates size by 11.5% (>2.00 mm size class) and 9.3% (0.25-2.00 mm size class) compared with CT. An 8.3% higher in SOC in micro-aggregates was also recorded in NT/RT than in CT treatment. No difference was recorded in SOC in silt clay fraction and bulk soil between CT and NT/RT treatment.

Previous studies on aggregates under conventional tillage compared with no-tillage treatment have been conducted[7]. For example, tillage has been reported to decrease soil aggregation and mean weight diameter due to the mechanical disruption of macro-aggregates from frequent tillage operations and reduce aggregate stability. Tillage management led to measurable changes in SOC contents of organic-mineral fractions[8]. Previous research documented that conservation tillage practice improved SOC and had a positive influence on increasing soil aggregation, aggregate stability, and soil C conservation compared with conventional tillage systems (CT). In addition, improving aggregate stability has the potential to increase resistance to erosion, especially in reference to wind erosion[9].

Although many researchers have studied the impacts of conservation tillage on soil aggregates and its associated C content, little is known about the effects of conservation tillage on soil aggregates and its associated C content at a broad scale. Meta-analysis is an effective method for integrating and comparing multiple individual studies to get general conclusions[10]. Thus, the purpose of this research is to (ⅰ) study soil aggregation and the soil C distribution within aggregate fractions under no-till (NT), reduced tillage (RT) and conventional tillage systems (CT); (ⅱ) determine how the impacts vary with soil sampling depth by applying meta-analysis method.

1 Materials and methods

1.1 Data collection

The ISI Web of Science and Google Scholar (Google Inc., Mountain View, CA, USA) are used to collect peer-reviewed articles published before 2015 in which CT was compared with conservational tillage including NT and RT. Key words applied for the search included "tillage" and "soil aggregat". As a result, a total of 34 studies containing 744 comparisons were collected.

Data shown in figure form were extracted using Data Thief software (Bas Tummer, Eindhoven, The Netherlands). The studies and number of comparisons within each study that were included in the analysis as well as associated information regarding location, crop, duration, and tillage treatment are listed. Aggregation size was grounded into the following classes: large macro-aggregate (>2 000 μm), small macro-aggregate (250-2 000 μm), micro-aggregate (53-250 μm) and silt clay fractions (<53 μm). Here RT mainly includes shallow chisel and rotary tillage. CT includes the deep mould board plowing tillage methods.

1.2 Data analysis

For each study, all comparisons between aggregate size distribution in CT and NT/RT systems were separately included in our meta-analysis. As such, multifactorial studies (i.e., those in which tillage treatments were combined with other treatments in a factorial design) and studies that reported results for multiple years contributed more than one comparison to our data set. For each comparison, the natural log response ratio ($\ln R$) was applied to show the effect size[11]

$$\ln R = \ln(V_{NT/RT}/V_{CT}), \quad (1)$$

where V is the mean value in the NT/RT treatments and R is the ratio of the mean percent of aggregate size, SOC in aggregate, C storage in aggregate, and mean weight diameter values under NT/RT and CT treatments.

In this study, a nonparametric weighting function was used because many data were provided without standard errors. To avoid bias toward studies reporting results for multiple years, the weight of each effect size was calculated as

$$W_i = (n_{CT} \times n_{NT/RT})/(n_{CT} + n_{NT/RT}), \quad (2)$$

where W_i is the weight for the i^{th} effect size, n is the number of field replicates[12].

Mean effect sizes were calculated as

$$\ln R = \sum (\ln R_i \times w_i) / \sum (w_i), \qquad (3)$$

where $\ln R_i$ is the effect size for percentage of aggregate size and content of aggregate-associated C content from the i^{th} comparison. Mean effect sizes and 95% bootstrapped CIs (4 999 iterations) were calculated using MetaWin 2 software[13]. To ease interpretation, the results for the analysis of $\ln R$ were back-transformed, and the percentage changes in percentage of aggregate size and content of aggregate-associated C content were reported as $(R-1) \times 100\%$. Treatment effects were considered significant if the 95% CIs did not overlap zero[14].

2 Results

2.1 Effect of tillage systems on soil aggregate distribution

NT/RT significantly increased soil macro-aggregates above 20 cm by 20.9%–82.2% (>2.00 mm) and by 5.9%–19.1% (0.25–2.00 mm) compared with CT (Figs. 1a and b), where S is effect size, d is depth. However, no difference was found below the 20 cm depth among tillage systems. When compared to CT, NT/RT significantly reduced micro-aggregate by 25.4% at 0–5 cm depth, by 16.3% at 0–10 cm soil layer, by 7.4% at 0–20 cm soil depth. However, no difference in percentage of micro-aggregate among tillage systems was found below 20 cm depth (Fig. 1c). When compared with CT, NT/RT reduced silt clay fraction by 23.0% at 0–5 cm soil depth, by 25.3% at 0–10 cm soil layer, by 14.4% at 0–20 cm soil depth (Fig. 1d). This difference was not recorded at 20–30 cm and 30–40 cm soil depths. Moreover, a significant 34.8% reduction of silt clay fraction in NT/RT treatment was also recorded at 40–60 cm depth.

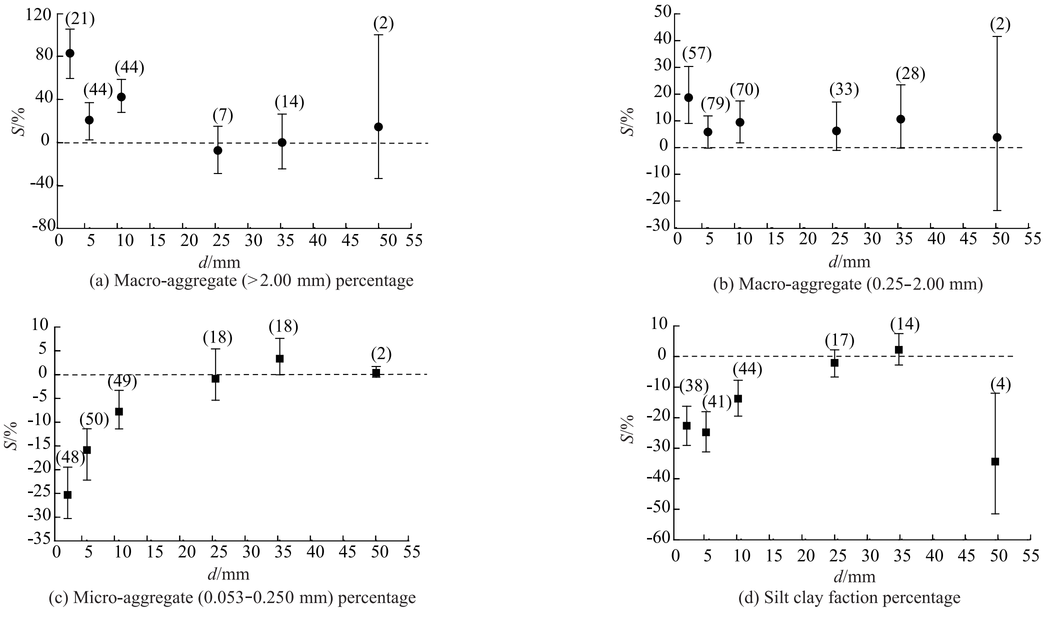
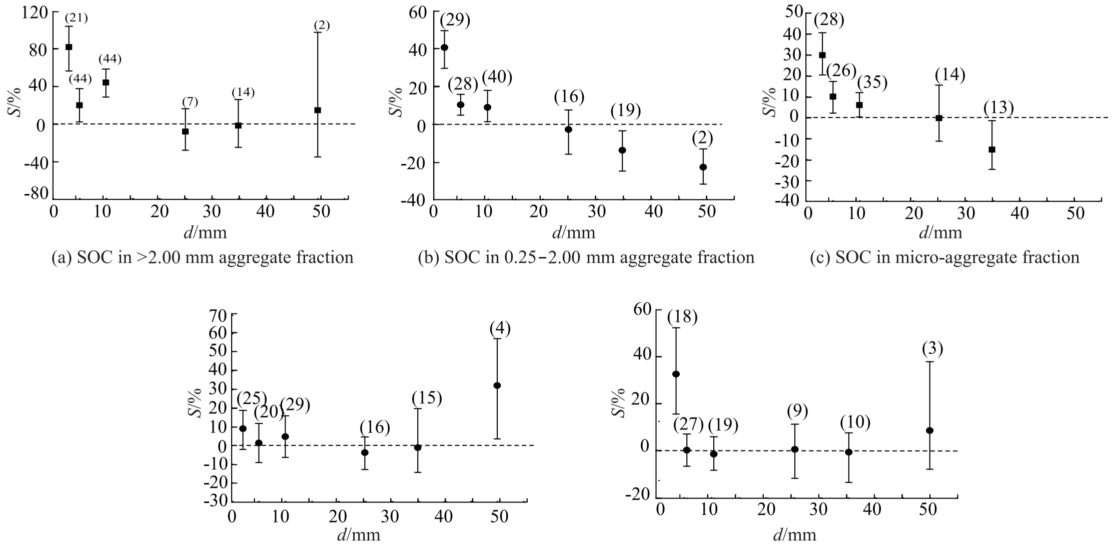


Fig.1 Percent change in soil aggregation distribution at different soil depths

2.2 Effect of tillage on SOC in aggregation

Compared with CT treatment, NT/RT significantly increased SOC at 0–5 cm, 0–10 cm, and 0–20 cm soil depths in the macro-aggregate fraction. In the micro-aggregate fraction only 0–5 cm and 0–10 cm SOC were higher in NT/RT than that in CT treatment (Figs. 2a and b). No difference in SOC in micro-aggregate fraction was found at the 0–20 cm and 20–30 cm soil depths, but at 30–40 cm soil layer, NT/RT significantly reduced SOC concentration 15.4% compared to CT treatment (Fig. 2c).

There was no difference in SOC in silt clay fraction except at 40–60 cm soil depth, where 33.6% higher was recorded in NT/RT compared with CT treatment (Fig. 2d). NT/RT significantly increased SOC concentration by 32.5% in bulk soil at 0–5 cm soil depth, however, no difference was found at >5 cm soil depth among tillage systems (Fig. 2e).



(a) SOC in >2.00 mm aggregate fraction (b) SOC in 0.25-2.00 mm aggregate fraction (c) SOC in micro-aggregate fraction

(d) SOC in silt clay fraction (<0.053 mm) (e) SOC in bulk soil

Fig.2 Percent change in SOC in different soil aggregate sizes

3 Discussion

3.1 Soil water-stable aggregate-size distribution

In the present study, NT/RT significantly increased the percentage of macro-aggregate compared with CT treatment, especially for above 20 cm soil depth. Similarly, GUO, et al.[1] showed that the proportions of 250-1 000 μm and >1 000 μm aggregates were higher in NT than that in CT due to the less soil disturbance and greater crop residue returning. The aggregate-size distribution and stability are key indexes of soil physical properties (e.g., soil structure, aggregation and degradation), CT could disrupt soil aggregates, exposing previously protected SOC against oxidation[15].

Below 20 cm depth, no difference was recorded in macro-aggregate between NT/RT and CT treatments. NT/RT significantly reduced the proportions of micro-aggregate compared to CT treatment. Moreover, NT/RT reduced the percentage of silt clay fraction compared with CT when the soil depth was 40-60 cm. Similarly, WANG, et al.[16] also reported that compared with CT, RT/NT could increase the percentage of macro-aggregate and reduce the proportion of silt clay fraction due to the disturbance of soil under CT treatment, which ultimately decreased the percentage of macro-aggregate.

3.2 Total C concentration within soil aggregate fractions

In the present study, NT/RT significantly increased SOC in the macro-aggregate fraction for 0-5 cm, 0-10 cm, and 0-20 cm soil depths. Similarly, other studies also showed that NT/RT increased the aggregate-associated C within all the aggregate sizes at the surface soil layer (0-20 cm) compared to CT treatment[17]. The higher macro-aggregate contents and SOC contents within macro-aggregates in the top 5 cm for RT and NT soils are in line with the findings of ANDRUSCHKEWITSCH, et al.[18]. However, this effect was just limited to the surface 5 cm of the soil. In addition, they suggested that it was not the slower macro-aggregate turnover at 0-5 cm soil depth of NT soils, but the higher bacterial and fungal activity was the reason for higher macro-aggregate contents. Our results also suggested the importance of water stable macro-aggregates in SOC storage. No difference in SOC in micro-aggregate fraction was found for 0-20 cm and 20-30 cm soil depths, but for 30-40 cm soil layer, NT/RT significantly reduced SOC in micro-aggregate fraction 15.4% compared to CT treatment. Similarly, other study also showed that CT had higher SOC in micro-aggregate fraction in related to NT/RT due to the reduction of fresh organic material input under NT/RT in greater soil depths (below 5 cm)[18]. However, this topic needed further studies. Therefore, our results indicated that the influence of tillage systems on aggregate-associated organic C was also affected by soil sampling depth.

4 Conclusions

1) The results of meta-analysis showed that NT/RT treatments provided more macro-aggregates (>0.25 mm) than CT at 0–5, 0–10 and 0–20 cm depths. Moreover, the magnitude of this increasing effect at different soil depths was in order of 0–5 cm> 0–20 cm>0–10 cm.

2) Compared to CT treatment, NT/RT significantly reduced micro-aggregate and silt clay fractions.

3) Compared to CT treatment, NT/RT significantly ($P<0.05$) increased the SOC in macro-aggregate (>0.25 mm) and micro-aggregate (<0.25 mm) size classes at top soil (<20 cm) layer.

参考文献(References)

[1] GUO Y F, FAN R Q, ZHANG X P, ZHANG Y, et al. Tillage-induced effects on SOC through changes in aggregate stability and soil pore structure [J]. Science of the total environment, 2020, 703: 134617.

[2] ZHANG Z, WEI C, XIE D, et al. Effects of land use patterns on soil aggregate stability in Sichuan Basin, China [J]. Particuology, 2008 (6): 157–166.

[3] BOSSUYT H, SIX J, HHENDRIX P F. Protection of soil carbon by microaggregates within earthworm casts [J]. Soil biology and biochemistry, 2005 (37): 251–258.

[4] ANGERS D A. Water-stable aggregation of Québec silty clay soils: some factors controlling its dynamics [J]. Soil & tillage research, 1998,47(1): 91–96.

[5] SHEEHY J, REGINA K, ALAKUKKU L, SIX J. Impact of no-till and reduced tillage on aggregation and aggregate-associated carbon in Northern European agroecosystems [J]. Soil & tillage research, 2015 (150): 107–113.

[6] LUTZOW M V, KOGEL–KNABNER I, EKSCHMITT K, et al. Stabilization of organic matter in temperate soils: mechanisms and their relevance under different soil conditions—a review [J]. European journal of soil science, 2006(57): 426–445.

[7] LU X L, LU X N, LIAO Y C. Effect of tillage treatment on the diversity of soil arbuscular mycorrhizal fungal and soil aggregate-associated carbon content [J]. Frontiers in microbiology, 2018 (9): 2986.

[8] SUN H Y, WANG C X, WANG X D, et al. Changes in soil organic carbon and its chemical fractions under different tillage practices on Loess soils of the Guanzhong Plain in north–west China [J]. Soil use and management, 2013 (29):344–353.

[9] BLANCO–MOURE N, MORET – FERNANDEZ D, LOPEZ M V. Dynamics of aggregate destabilization by water in soils under long-term conservation tillage in semiarid Spain [J]. Catena, 2012 (99): 34–41.

[10] WANG Y Q, ZHANG Y H, ZHOU S L, et al. Meta-analysis of no-tillage effect on wheat and maize water use efficiency in China [J]. Science of the total environment, 2018 (635): 1372–1382.

[11] MEI K, WANG Z F, HUANG H, et al. Stimulation of N_2O emission by conservation tillage management in agricultural lands: A meta-analysis [J]. Soil & tillage research, 2018 (182): 86–93.

[12] PITTELKOW C M, LIANG X, LINQUIST B A, et al. Productivity limits and potentials of the principles of conservation agriculture [J]. Nature, 2015, 517 (7534): 365–368.

[13] PINTOR L M, BYERS J E. Do native predators benefit from non-native prey? [J]. Ecology letters, 2015 (18): 1174–1180.

[14] SHAN J, YAN X. Effects of crop residue returning on nitrous oxide emissions in agricultural soils [J]. Atmospheric environment, 2013 (71): 170–175.

[15] SHRESTHA B, SINGH B, SITAULA B, et al. Soil aggregate-and particle-associated organic carbon under different land uses in Nepal [J]. Soil science society of America journal, 2007 (71): 1194–1203.

[16] WANG Y, JI Q, LIU S, et al. Effects of tillagepractices on water-stable aggregation and aggregate-associated organic C in soils [J]. Journal of agro-environment science, 2012 (31): 1365–1373. (in Chinese)

[17] SONG K, ZHENG X Q, LV W G, et al. Effects of tillage and straw return on water-stable aggregates, carbon stabilization and crop yield in an estuarine alluvial soil [J]. Scientific reports, 2019 (9): 4586.

[18] ANNDRUSCHKEWITSCH R, KOCH H J, LUDWIG B. Effect of long-term tillage treatments on the temporal dynamics of water-stable aggregates and on macro-aggregate turnover at three German sites [J]. Geoderma, 2014 (217):57–64.

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