Effects of dry soil aggregate size on organic carbon, total nitrogen, and soil texture under different land uses (Postprint)

Authors: HAO Mingyang, HE Jianuo, Weiyin Hu, ZHAO Zhou, LI Can, SONG Shikai, ZOU Xueyong, CHANG Chunping, GUO Zhongling

Date: 2025-10-22T00:00:00+00:00

Abstract

Soil organic carbon (SOC) and total nitrogen (TN) play an important role in the global carbon and nitrogen cycles. Soil aggregates are critical reservoir of SOC and TN. Therefore, in areas with severe wind erosion, the changes in the accumulation of SOC, TN, clay, silt, and sand contents within different dry aggregate size fractions can offer crucial insights into soil conservation by the control of wind erosion. In this study, surface soil samples (0–5 cm depth) were collected from farmland and grassland in the Bashang region of northern China in 2020. The bulk soil and aggregate size fractions were used to determine the concentrations of SOC, TN, clay, silt, and sand. The results showed that: (1) farmland had lower SOC and higher TN than grassland; (2) SOC in the aggregates of farmland decreased with increasing aggregate size ($P<0.010$), while SOC in the aggregates of grassland increased with increasing aggregate size ($P<0.010$), and nonsignificant variation of TN and clay was observed among different aggregate sizes; (3) the mean of aggregate silt significantly decreased with increasing aggregate size and the mean of aggregate sand increased with increasing aggregate size ($P<0.001$); (4) no correlations between sand or silt of aggregate and TN or texture of bulk soil was found; and (5) SOC in bulk soil was correlated with those in different aggregate sizes, and was also affected by the texture of bulk soil ($P<0.010$). This study highlights the role of dry soil aggregate size in the redistribution of SOC, TN, clay, silt, and sand contents under different land uses, thereby facilitating the understanding of the process of wind erosion induced SOC, TN, and mineral dust emission.

Full Text

Preamble

Journal of Arid Land (2025) 17(10): 1482–1495
doi: 10.1007/s40333-025-0030-x; CSTR: 32276.14.JAL.0250030x
Science Press & Springer-Verlag

Effects of Dry Soil Aggregate Size on Organic Carbon, Total Nitrogen, and Soil Texture Under Different Land Uses

HAO Mingyang[1], HE Jianuo[1], HU Weiyin[2], ZHAO Zhou[3], LI Can[1], SONG Shikai[1], ZOU Xueyong[4], CHANG Chunping[1], GUO Zhongling[1]*

[1] School of Geographical Sciences/Hebei Key Laboratory of Environmental Change and Ecological Construction/Hebei Technology Innovation Center for Remote Sensing Identification of Environmental Change, Hebei Normal University, Shijiazhuang 050024, China
[2] Soil and Water Conservation Station of Hebei Province, Shijiazhuang 050021, China
[3] Environmental Protection Technology Information Service Center at Jingxing of Shijiazhuang, Shijiazhuang 050399, China
[4] State Key Laboratory of Earth Surface Processes and Resource Ecology, Ministry of Education, Engineering Center of Desertification and Blown-sand Control, Faculty of Geographical Science, Beijing Normal University, Beijing 100875, China

Abstract

Soil organic carbon (SOC) and total nitrogen (TN) play crucial roles in global carbon and nitrogen cycles, with soil aggregates serving as critical reservoirs for both elements. In regions experiencing severe wind erosion, examining how SOC, TN, clay, silt, and sand contents accumulate within different dry aggregate size fractions can provide essential insights for soil conservation and wind erosion control.

This study collected surface soil samples (0–5 cm depth) from farmland and grassland in the Bashang region of northern China in 2020. Both bulk soil and aggregate size fractions were analyzed to determine SOC, TN, clay, silt, and sand concentrations. The results revealed that: (1) farmland exhibited lower SOC but higher TN concentrations compared to grassland; (2) SOC in farmland aggregates decreased with increasing aggregate size ($P<0.010$), whereas SOC in grassland aggregates increased with increasing aggregate size ($P<0.010$), while TN and clay showed no significant variation among aggregate sizes; (3) mean aggregate silt content significantly decreased with increasing aggregate size while mean aggregate sand content increased ($P<0.001$); (4) no correlations were found between aggregate sand or silt and bulk soil TN or texture; and (5) SOC in bulk soil correlated with SOC across different aggregate sizes and was also influenced by bulk soil texture (P<0.010). These findings highlight the role of dry soil aggregate size in redistributing SOC, TN, clay, silt, and sand contents under different land uses, thereby enhancing our understanding of wind erosion-induced SOC, TN, and mineral dust emission processes.

Keywords: wind erosion; soil properties; mineral dust; wind erodibility; climate change; land use

Citation: HAO Mingyang, HE Jianuo, HU Weiyin, ZHAO Zhou, LI Can, SONG Shikai, ZOU Xueyong, CHANG Chunping, GUO Zhongling. 2025. Effects of dry soil aggregate size on organic carbon, total nitrogen, and soil texture under different land uses. https://doi.org/10.1007/s40333-025-0030-x; https://cstr.cn/32276.14.JAL.0250030x

---

1 Introduction

Wind erosion represents an irreversible soil degradation factor in dryland ecosystems (Buschiazzo, 2015). The distribution of dry soil aggregates critically determines the extent of wind erosion (Zou et al., 2015). Soil aggregates are widely recognized as fundamental indicators of soil structure, and their formation is generally associated with soil organic carbon (SOC) content (Bronick and Lal, 2005; Reeves et al., 2019). Different-sized soil aggregates typically exhibit varying capacities for SOC retention (Zhang et al., 2022; Li et al., 2024), with finer, erodible dry aggregates in surface soils generally indicating more severe wind erosion hazards. Consequently, characterizing SOC variation within aggregates is essential for understanding wind erosion-induced SOC emissions to the atmosphere (Webb et al., 2012).

SOC content across various soil aggregate size fractions changes under different land use patterns. In humid regions, SOC typically saturates in fine soil aggregates (e.g., clay and silt), whereas in dryland ecosystems, SOC accumulation primarily occurs in coarser aggregates (Sokol and Bradford, 2019). Land use types directly or indirectly affect soil particle aggregation and SOC distribution through alterations in soil physical and chemical properties (Qiu et al., 2012; Udom and Ogunwole, 2015). Li and Pang (2010) observed significant variations in SOC and total nitrogen (TN) concentrations across different soil aggregate fractions under various land use types in China's southern Loess Plateau. Udom and Ogunwole (2015) found that forestland contained higher SOC and TN contents in each soil aggregate fraction compared to cultivated land. Several studies have demonstrated that SOC and soil aggregate stability decline with increasing cultivation duration (Mrabet et al., 2001; Udom and Ogunwole, 2015). These investigations have primarily focused on aggregate-protected SOC and TN contents under different land use types across various geographic environments.

Understanding how different soil aggregate sizes store and interact with SOC is crucial for developing sustainable management strategies to enhance carbon sequestration and stability (Six et al., 2002; Camenzind et al., 2016). SOC serves as an essential binding agent for aggregate formation, and through coating and isolation patterns that obstruct microbial decomposition, it forms the core mechanism of soil carbon sequestration (Xiao et al., 2021; Yang et al., 2022). Soil aggregates can be classified into macroaggregates (>0.25 mm) and microaggregates (<0.25 mm) using wet sieving techniques (Edwards and Bremner, 1967), with different-sized aggregates exhibiting varying SOC retention capacities (Zhang et al., 2022). Guo et al. (2017) suggested that soil aggregate structure is closely correlated with SOC, which is predominantly distributed in macroaggregates. Peng et al. (2024) found that SOC within macroaggregates was significantly and positively correlated with SOC in bulk soil.

Previous studies of aggregate stability and size distribution have predominantly employed wet sieving techniques (Gajic et al., 2006; Igwe and Nkemakosi, 2007; Gelaw et al., 2015; Su et al., 2023; Gentsch et al., 2024; Wu et al., 2024). In practice, dry soil aggregate size distribution relates directly to wind erosion, which induces SOC, TN, and mineral dust emissions. However, research utilizing dry sieving methods to investigate how dry soil aggregates affect soil physical-chemical properties (e.g., SOC, TN, clay, silt, and sand contents) remains scarce. Furthermore, no studies have explored how dry aggregate size influences the distribution of SOC, TN, clay, silt, and sand contents. Rotary and flat sieves are recognized as standard methods for evaluating soil dry aggregate properties related to wind erosion (Zobeck et al., 2003). In practical applications, various parameters related to dry aggregates can be determined through dry sieving, which is generally considered a standard approach for generating dry aggregates associated with wind erosion and can be used to assess the relative resistance of dry aggregates to wind erosion (Guo et al., 2017). Therefore, examining the distribution patterns of SOC, TN, clay, silt, and sand across different soil aggregate fractions is important for developing land management practices, controlling wind erosion and dust emission, and uncovering the mechanisms of SOC and TN sequestration in arid and semi-arid regions (Qiu et al., 2015; Duan et al., 2021). Accordingly, this research aims to: (1) determine the distribution patterns of SOC, TN, clay, silt, and sand contents across different dry aggregate sizes; and (2) investigate the potential factors influencing SOC, TN, clay, silt, and sand contents in different aggregate size fractions under varying land use patterns.

2.1 Study Area

Soil samples were collected in Kangbao County, Bashang region, located in the agricultural-pastoral ecotone of northern China (41°25 -42°08 N, 114°11 -114°56 E). The study area experiences a semi-arid temperate continental monsoon climate with dry, cold winters and warm, moderately humid summers. Mean annual precipitation is 350 mm, and the annual mean temperature is

1.2°C. Typical crops include summer wheat (*Triticum aestivum* L.) and oats (*Avena sativa* L.). The main soil types are Haplic Kastanozems (72.77%), Luvic Kastanozems (14.09%), and Calcic Kastanozems (11.57%) (Guo et al., 2017). The dominant land use types are farmland and grassland, occupying 69.00% and 21.00% of the area, respectively (Wang et al., 2015).

2.2 Soil Sampling

In this study, 24 soil sampling sites were selected in May 2020 (Table 1). At each site, soils were sampled for local land use types (farmland and grassland), yielding a total of 48 soil samples (Table 1). In the field, approximately 10 kg of soil was collected from the 0–5 cm depth using a flat-blade shovel. Soil samples were air-dried, and plant materials (e.g., roots, leaves, and shoots) and rocks were manually removed in the laboratory. Soil texture was predominantly sandy loam (18 sites) and silty loam (20 sites), with a few pockets of loamy textural class (10 sites) across the sampling locations (Table 1).

2.3 Dry Soil Aggregate Properties Related to Wind Erosion

Dry aggregate stability (DASt), soil erodibility fraction (EF), mean weight diameter (MWD), and geometric mean diameter (GMD) are the most widely used parameters for assessing dry aggregate properties (Zobeck et al., 2003; Ciric et al., 2012; Guo et al., 2017). Approximately 3000 g of soil from each site was sieved using a flat wire mesh screen with a diameter of 30 cm (Guo et al., 2017). To avoid overloading the flat sieve, we conducted a series of experimental tests for different sieving durations and shaker frequencies. The flat sieve with a horizontal motor shaker was set to oscillate horizontally at 120 times per minute. A nest of sieves with nominal openings of 5.000, 2.000, 0.850, 0.500, 0.250, and 0.106 mm was used to determine dry aggregate size distribution. Organic residues (roots, sticks, leaves, etc.) were carefully removed from the sieves after dry sieving. The wind-erodible fraction of dry aggregates (<0.850 mm), DASt, and GMD were calculated using the dry aggregate size distribution.

EF (%) was calculated as follows: <0 850 where W<0.850 is the weight of <0.850-mm aggregates from the first sieving (g), and T is the initial weight of the total sample (g).

DASt (%) was calculated as follows: where $(W>0.850)_1$ is the total mass of >0.850-mm aggregates retained by the 0.850-mm screen after the first sieving (g); and $(W<0.850)_2$ is the mass of >0.850-mm aggregates that passed through the 0.850-mm screen after the second sieving (g).

GMD (mm) was calculated as follows: where n is the number of aggregate size fractions; xi is the mean diameter of each size class (mm); and Wi is the proportion of the total aggregates in each size fraction (%).

GMD exp

2.4 SOC, TN, Clay, Silt, and Sand Contents

Particle size distribution of bulk soil and dry aggregates was measured using a Malvern Mastersizer 3000 Laser Diffractometer (Malvern Instruments Ltd., Worcestershire, UK). Clay, silt, and sand contents were determined according to the United States Department of Agriculture (USDA) soil texture taxonomy. Mean particle size (MPS) was determined using the method proposed by Okolo et al. (2020). SOC and TN contents were measured with an Elemental Analyzer 3000 (EuroVector, Pavia, Italy) (Eksperiandova et al., 2011). Calibration samples were run after every eight samples to verify instrument accuracy, and replicate analyses showed that variability between samples was generally less than 0.10% (Zhang et al., 2018). Results were analyzed using Callidus® software, which automatically provides a sample elemental composition report.

2.5 Data Analysis

To evaluate differences in mass fractions, SOC, and TN across different aggregate sizes, we used the least significant difference test from one-way analysis of variance (ANOVA). Analyses were conducted using SPSS v.26.0 software (IBM Ltd., Armonk, USA). Trends in SOC and TN contents across different aggregate sizes were determined using the Mann-Kendall method (Tosunoglu and Kisi, 2017) at the 95.00% confidence level with R v.4.2.1 software. Z-values indicated downward/upward trends, while P-values determined trend significance. Correlations between bulk soil properties and SOC and TN contents in dry aggregates were analyzed using Pearson' s correlation matrix in R v.4.2.1 software.

3.1 Dry Soil Aggregate Properties Linked with Wind Erosion

Figure 1 [Figure 1: see original paper] illustrates the properties of dry soil aggregates. Grassland exhibited a significantly higher proportion of <0.850 mm (erodible aggregate) fractions than farmland, while farmland showed a significantly higher proportion of >0.850 mm (non-erodible aggregate) fractions than grassland (Fig. 1a1 and b1). DASt ranged from 0.79% to 41.94%, with an average of 13.09% across all sampling sites (Fig. 1a2 and b2), while EF ranged from 30.95% to 96.80%, averaging 69.97% across all land use types (Fig. 1a3 and b3). DASt in farmland varied from 0.79% to 24.36% (average 10.82%) (Fig. 1a2), whereas DASt in grassland ranged from 2.20% to 41.94% (average 15.36%) (Fig. 1b2). EF in farmland ranged from 30.95% to 91.67% (average 59.00%) (Fig. 1a3), while EF in grassland ranged from 55.02% to 96.80% (average 80.95%) (Fig. 1b3). Grassland recorded significantly higher mean EF and higher average DASt compared to farmland. GMD ranged from 0.21 to 3.81 mm for farmland and from 0.14 to 0.61 mm for grassland (Fig. 1a4 and b4). These results indicated that aggregate size fractions varied significantly between the two land use types.

3.2 SOC, TN, Clay, Silt, and Sand Concentrations in Bulk Soil and Different Dry Soil Aggregate Fractions

Significant variation occurred in SOC concentration across different aggregate sizes and bulk soil between land use types (Fig. 2 [Figure 2: see original paper]). SOC concentrations in both aggregate size fractions and bulk soil were higher in grassland than in farmland (Fig. 2). In contrast, TN concentrations in different aggregate size fractions were lower in grassland than in farmland (Fig. 2). Compared to average SOC concentration in bulk soil (Fig. 2a2 and b2), average SOC concentration in different aggregate sizes was higher in both land use types (Fig. 2a1 and b1). Average TN concentrations in different aggregate sizes, except for the 2.000-5.000 mm fraction, were higher than those in bulk soil for farmland (Fig. 2a3), whereas average TN concentrations in different aggregate sizes, except for the 2.000-5.000 mm fraction, were lower than those in bulk soil for grassland (Fig. 2b3 and b4).

Significant differences in SOC concentration existed across aggregate sizes for all land use types ($P<0.001$). Average SOC concentration for aggregate size fractions showed an approximately linear decreasing trend with increasing aggregate size in farmland (Fig. 2a1). Notably, average SOC concentration significantly increased ($P<0.001$) with increasing aggregate size in grassland (Fig. 2b1). Average TN concentration showed a similar trend across aggregate sizes for all land use types, although differences were not significant ($P>0.050$).

Figures 3 [Figure 3: see original paper] and 4 [Figure 4: see original paper] show trends in clay, silt, sand concentration, and MPS. Interestingly, average clay concentration trends did not increase significantly ($P>0.050$) with aggregate size for either farmland or grassland (Fig. 3a1 and b1), although differences between the two land use types were significant ($P<0.001$). Average silt concentration decreased significantly ($P<0.001$) with increasing aggregate size (Fig. 3a3 and b3). In contrast, average sand concentration increased with increasing aggregate size (Fig. 4a1 and b1), and MPS showed a similar trend across aggregate sizes for all land use types (Fig. 4a3 and b3).

4.1 Factors Influencing Soil Properties

Grassland exhibited higher SOC and lower TN concentrations than farmland (Fig. 3). These results may be attributed to differences in biological activities, crop management practices, and soil texture (Gelaw et al., 2015; Nie et al., 2018; Khan et al., 2022; Wu et al., 2024). Compared to farmland, moderate anthropogenic disturbance and high inputs of root exudates and root debris that intensify biological activity increase SOC concentrations in both aggregates and bulk soil of grassland (Fu et al., 2004; Okolo et al., 2020). Local tillage practices, particularly conventional tillage, can accelerate SOC mineralization, reducing its concentration in surface soil (0–5 cm) through increased oxidation, release of soluble organic compounds, and enhanced microbial activity (McCarty et al., 1998; Mrabet et al., 2001). Furthermore, returning crop residues to the land and applying inorganic nitrogen and phosphorus fertilizers can increase TN concentrations in cultivated soil aggregates (Barber, 1995). Cropland soils contain more clay and silt but less sand than grassland soils, which may lead to higher water and nutrient utilization rates, rapid organic matter decomposition, and nitrogen accumulation (Schimel, 1986).

SOC concentration in different aggregate size fractions of farmland decreased with increasing aggregate size. Fang et al. (2015) found higher SOC concentrations in microaggregates, which can be attributed to microaggregates having larger surface areas that can absorb more SOC, while microbial and enzymatic decomposition efficiency may be lower in microaggregates (Fang et al., 2015). Therefore, SOC in macroaggregates, which originates from plant debris, might be reduced in farmland (Li et al., 2020). Moreover, conventional tillage practices can crush dry soil aggregates, leading to exposure and further decomposition of SOC within macroaggregates (Six et al., 2000a; Schmidt et al., 2018).

SOC concentration in grassland increased with increasing soil aggregate size. New organic matter from plant debris and fine roots was primarily distributed in macroaggregates in grassland (Huang et al., 2017). Consequently, SOC concentration in grassland aggregates showed an increasing trend with aggregate size, consistent with prior observations (Tisdall and Oades, 1982; Six et al., 2000a; Green et al., 2005; John et al., 2005; Yamashita et al., 2006; Gulde et al., 2008; Lugato et al., 2010; Webb et al., 2012; Du et al., 2021). Organic materials generated from plant debris and animal excrement serve as important sources for grassland dry soil aggregates. More organic debris exists in grassland surface soils, and these materials tend to become SOC through chemical and ecological processes. Accordingly, SOC primarily enriches in macroaggregates (Shrestha et al., 2007). Additionally, persistent and stable organic binding agents combine fine particles into microaggregates, which then form macroaggregates through cementitious substances such as polysaccharides, fine roots, fungal hyphae, and glomalin-related soil proteins (Tisdall and Oades, 1982).

SOC in different aggregate sizes correlated with bulk soil SOC for both farmland and grassland (Fig. 5 [Figure 5: see original paper]). This suggests that soils with higher SOC levels in macroaggregates also tend to exhibit higher SOC levels in microaggregates, due to the compositional nature of macroaggregates that consist of fine aggregates bound together by organic matter (Tisdall and Oades, 1982; Unger, 1997). Numerous studies have demonstrated positive correlations between SOC in bulk soils and clay or silt content (Zinn et al., 2005; Grueneberg et al., 2013), an effect attributed to SOC accumulation in clay and silt through chemical association with mineral surfaces (Lützow et al., 2006). The low correlation between clay and SOC in this study may be attributed to low clay content in local soils. We observed a positive correlation between SOC in dry aggregates and silt in bulk soil, primarily due to SOC accumulation in fine soil, as silt offers greater surface area for binding (Mayer, 1994; Ramaswamy et al., 2008). An alternative explanation could be that high aggregate fractions provide substantial physical protection for SOC against microbial decomposition (Six et al., 2000b; Carter, 2002; Barthes et al., 2008). Additionally, the observed increase in bulk soil sand content with decreasing SOC concentration in bulk soil or dry aggregates may result from the particle structure of sand limiting SOC retention and accumulation (Barthes et al., 2008). Sand presence increases soil porosity and permeability, leading to SOC leaching and migration (Dalal and Bridge, 1995).

Variation in TN with aggregate size was not statistically significant, and no correlations were found between TN in aggregates and TN or texture of bulk soil. Farmland management in this area is largely governed by smallholder farming systems, and management practices at each sampling site (such as tillage, fertilization, weeding, and irrigation) may have been inconsistent, complicating analysis of surface soil TN (Guo et al., 2017). Furthermore, while wet soil aggregates and soil texture (particle size distribution) are generally considered intrinsic soil properties, dry soil aggregates linked with wind erosion are essentially clods, suggesting that dry soil aggregates represent temporary soil properties (Zobeck, 1991; Guo et al., 2017). These intrinsic and temporary soil properties may complicate the physical, chemical, and ecological processes of dry soil aggregates of different sizes. Further studies are needed to investigate factors influencing TN variation with dry soil aggregate size.

No significant correlation was observed between clay in different aggregate sizes and that in bulk soil (Fig. 6a [Figure 6: see original paper] and b). However, silt and sand in different aggregate sizes correlated with those in bulk soil for both farmland and grassland (Fig. 6c and d; Fig. 6e and f). This suggests that soils with higher silt or sand levels in bulk soil can lead to higher silt or sand levels in dry aggregates. Larger dry soil aggregates indicate that more sand particles can be easily aggregated together under hydraulic cohesive stress, resulting in greater sand content in larger dry aggregates (Tatarko, 2001). Silt in dry soil aggregates could produce better aggregation (Tatarko, 2001); therefore, increasing dry aggregate size tended to decrease silt content.

4.2 Implications for Wind-Erosion Induced Dust and Soil Carbon Emission

Drylands with EF > 50.00% are generally classified as highly erodible by wind (Guo et al., 2017). Therefore, 66.67% of farmland soil samples and 100.00% of grassland soil samples were highly wind-erodible. Natural dust emission from wind erosion generally involves three distinct processes: direct aerodynamic lifting, discharge from dry soil aggregates through impacting saltating grains, and participation in saltation (Kok et al., 2013). Saltation bombardment associated with the latter two processes is generally considered the most important source of mineral dust compared to direct aerodynamic lifting (Shao, 2008). Accordingly, dry aggregates in the soil or in saltation play a critical role in the dust emission process. Our results indicated that smaller dry aggregates generally contained more <50 m suspended mineral soil particles (clay + silt), which may produce more dust aerosols during wind erosion. Different sizes of dry soil aggregates have different potentials for suspended mineral dust aerosol emission. Various mineral dust emission models exist across land use types; however, these empirical or mechanistic schemes generally assume uniform dust emission efficiency across different dry soil aggregate sizes. Consequently, more studies are required to explore how dry soil aggregate sizes impact dust emission efficiency.

It is generally recognized that lighter soil carbon matter associated with finer sediment can be more easily detached from surface soil, leading to SOC enrichment in aeolian eroded materials (Webb et al., 2012). The distribution of SOC across different dry soil aggregates facilitates understanding of how SOC enriches in aeolian sediment (Du et al., 2021). Dust emission with SOC represents an important carbon dioxide source to the atmosphere. An ongoing debate exists regarding the magnitude of SOC loss through mineral dust emission, since considerable spatial and temporal variation in SOC enrichment of aeolian sediment occurs widely across different soils and land use types (Du et al., 2021). Globally, soils with high dust potential occur across various soil textures and land use types, necessitating more investigations of SOC distribution in different dry soil aggregates for precise global carbon accounting of carbon-enriched dust.

5 Conclusions

This study investigated the effects of dry soil aggregate size on SOC, TN, clay, silt, and sand distributions under farmland and grassland in a typical wind erosion area of northern China. The results showed that farmland had lower SOC and higher TN concentrations than grassland, which could be ascribed to differences in biological activities, crop-management practices, and soil texture between the two land use types. The study further demonstrated that SOC in farmland aggregates decreased with increasing aggregate size, while SOC in grassland aggregates increased with increasing aggregate size. Mean aggregate silt content significantly decreased with increasing aggregate size, while mean aggregate sand content increased. SOC in different dry aggregate sizes correlated with bulk soil SOC for both farmland and grassland. Moreover, SOC in different dry aggregates and bulk soil was significantly affected by soil texture. These findings can facilitate understanding of wind erosion-induced SOC, TN, and mineral dust emission processes, which are crucial for the sustainable functioning of terrestrial ecosystems. Further studies are required to explore the relationships between SOC, TN, clay, silt, and sand concentrations in dry aggregates and soil properties related to wind erosion.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research was supported by the National Natural Science Foundation of China (42271002; 42201002), the Foundation of Central Guidance for Local Scientific and Technological Development (246Z3705G), the Water Conservancy Science and Technology Plan Project of Hebei Province (2023-64), and the Hebei Natural Science Foundation (D2021205013). The authors thank anonymous reviewers and the editors for their suggestions on improving the manuscript.

Author Contributions

Conceptualization: GUO Zhongling
Methodology: GUO Zhongling
Formal analysis: HAO Mingyang, HE Jianuo
Writing -original draft preparation: HAO Mingyang, HE Jianuo
Writing -review and editing: HU Weiyin, ZHAO Zhou, LI Can, SONG Shikai, ZOU Xueyong, CHANG Chunping, GUO Zhongling
Funding acquisition: CHANG Chunping, GUO Zhongling
Resources: CHANG Chunping, GUO Zhongling
Supervision: GUO Zhongling

All authors approved the manuscript.

References

Barber R G. 1995. Soil degradation in the tropical lowlands of Santa Cruz, Eastern Bolivia. *Land Degradation & Development*, 6(2): 95-107.

Barthes B G, Kouakoua E, Larre-Larrouy M C, et al. 2008. Texture and sesquioxide effects on water-stable aggregates and organic matter in some tropical soils. *Geoderma*, 143(1-2): 14-25.

Bronick C J, Lal R. 2005. Soil structure and management: A review. *Geoderma*, 124(1-2): 3-22.

Buschiazzo D E. 2015. Management systems in southern South America. In: Peterson G A, Unger P W, Payne W A. *Agronomy Monographs*. Madison: Soil Science Society of America, 395-425.

Camenzind T, Homeier J, Dietrich K, et al. 2016. Opposing effects of nitrogen versus phosphorus additions on mycorrhizal fungal abundance along an elevational gradient in tropical montane forests. *Soil Biology and Biochemistry*, 94: 37-47.

Carter M R. 2002. Soil quality for sustainable land management. *Agronomy Journal*, 94(1): 38-47.

Ciric V, Manojlovic M, Nesic L, et al. 2012. Soil dry aggregate size distribution: Effects of soil type and land use. *Journal of Soil Science and Plant Nutrition*, 12(4): 689-703.

Dalal R C, Bridge B J. 1995. Aggregation and organic matter storage in subhumid and semi-arid soils. In: Carter M R, Stewart B A. *Structure and Organic Matter Storage in Agricultural Soils*. Boston: CRC Press, 263-307.

Du H Q, Li S, Webb N P, et al. 2021. Soil organic carbon (SOC) enrichment in aeolian sediments and SOC loss by dust emission in the desert steppe, China. *Science of the Total Environment*, 798: 149189, doi: 10.1016/j.scitotenv.2021.149189.

Duan L X, Sheng H, Yuan H, et al. 2021. Land use conversion and lithology impacts soil aggregate stability in subtropical China. *Geoderma*, 389: 114953, doi: 10.1016/j.geoderma.2021.114953.

Edwards A P, Bremner J M. 1967. Microaggregates in soils. *Journal of Soil Science*, 18(1): 64-73.

Eksperiandova L P, Fedorov O I, Stepanenko N A. 2011. Estimation of metrological characteristics of the element analyzer EuroVector EA-3000 and its potential in the single-reactor CHNS mode. *Microchemical Journal*, 99(2): 235-238.

Fang X M, Chen F S, Wan S Z, et al. 2015. Topsoil and deep soil organic carbon concentration and stability vary with aggregate size and vegetation type in subtropical China. *PLoS ONE*, 10(9): e0139380, doi: 10.1371/journal.pone.0139380.

Fu B J, Liu S L, Chen L D, et al. 2004. Soil quality regime in relation to land cover and slope position across a highly modified slope landscape. *Ecological Research*, 19(1): 111-118.

Gajic B, Dugalic G, Djurovic N. 2006. Comparison of soil organic matter content, aggregate composition and water stability of gleyic fluvisol from adjacent forest and cultivated areas. *Agronomy Research*, 4(2): 499-508.

Gelaw A M, Singh B R, Lal R. 2015. Organic carbon and nitrogen associated with soil aggregates and particle sizes under different land uses in Tigray, northern Ethiopia. *Land Degradation & Development*, 26(7): 690-700.

Gentsch N, Riechers F L, Boy J, et al. 2024. Cover crops improve soil structure and change organic carbon distribution in macroaggregate fractions. *Soil*, 10(1): 139-150.

Green V S, Cavigelli M A, Dao T H, et al. 2005. Soil physical properties and aggregate-associated C, N, and P distributions in organic and conventional cropping systems. *Soil Science*, 170(10): 822-831.

Grueneberg E, Schoening I, Hessenmoeller D, et al. 2013. Organic layer and clay content control soil organic carbon stocks in density fractions of differently managed German beech forests. *Forest Ecology and Management*, 303: 1-10.

Gulde S, Chung H, Amelung W, et al. 2008. Soil carbon saturation controls labile and stable carbon pool dynamics. *Soil Science Society of America Journal*, 72(3): 605-612.

Guo Z L, Chang C P, Wang R D, et al. 2017. Comparison of different methods to determine wind-erodible fraction of soil with rock fragments under different tillage/management. *Soil and Tillage Research*, 168: 42-49.

Huang R, Lan M L, Liu J, et al. 2017. Soil aggregate and organic carbon distribution at dry land soil and paddy soil: The role of different straws returning. *Enviromental Science and Pollution Research*, 24(36): 27942-27952.

Igwe C A, Nkemakosi J T. 2007. Nutrient element contents and cation exchange capacity in fine fractions of southeastern Nigerian soils in relation to their stability. *Communications in Soil Science and Plant Analysis*, 38(9-10): 1221-1242.

John B, Yamashita T, Ludwig B, et al. 2005. Storage of organic carbon in aggregate and density fractions of silty soils under different types of land use. *Geoderma*, 128(1-2): 63-79.

Khan F U, Khan A A, Li K, et al. 2022. Influences of long-term crop cultivation and fertilizer management on soil aggregates stability and fertility in the Loess Plateau, northern China. *Journal of Soil Science and Plant Nutrition*, 22(2): 1446-1457.

Kok J F, Parteli E J R, Michaels T I, et al. 2013. The physics of wind-blown sand and dust. *Reports on Progress in Physics*, 75(10): 106901, doi: 10.1088/0034-4885/75/10/106901.

Li G L, Pang X M. 2010. Effect of land-use conversion on C and N distribution in aggregate fractions of soils in the southern Loess Plateau, China. *Land Use Policy*, 27(3): 706–712.

Li G R, Yu C Y, Shen P F, et al. 2024. Crop diversification promotes soil aggregation and carbon accumulation in global agroecosystems: A meta-analysis. *Journal of Environmental Management*, 350: 119661, doi: 10.1016/j.jenvman.2023.119661.

Li T T, Zhang Y L, Bei S K, et al. 2020. Contrasting impacts of manure and inorganic fertilizer applications for nine years on soil organic carbon and its labile fractions in bulk soil and soil aggregates. *CATENA*, 194: 104739, doi: 10.1016/j.catena.2020.104739.

Lugato E, Simonetti G, Morari F, et al. 2010. Distribution of organic and humic carbon in wet-sieved aggregates of different soils under long-term fertilization experiment. *Geoderma*, 157(3–4): 80–85.

Lützow M V, Kögel-Knabner I, Ekschmitt K, et al. 2006. Stabilization of organic matter in temperate soils: Mechanisms and their relevance under different soil conditions: A review. *European Journal of Soil Science*, 57(4): 426–445.

Mayer L M. 1994. Surface area control of organic carbon accumulation in continental shelf sediments. *Geochimica et Cosmochimica Acta*, 58(4): 1271–1284.

McCarty G W, Lyssenko N N, Starr J L. 1998. Short-term changes in soil carbon and nitrogen pools during tillage management transition. *Soil Science Society of America Journal*, 62(6): 1564–1571.

Mrabet R, Saber N, El-Brahli A, et al. 2001. Total, particulate organic matter and structural stability of a Calcixeroll soil under different wheat rotations and tillage systems in a semiarid area of Morocco. *Soil and Tillage Research*, 57(4): 225–235.

Nie X D, Li Z W, Huang J Q, et al. 2018. Thermal stability of organic carbon in soil aggregates as affected by soil erosion and deposition. *Soil and Tillage Reserch*, 175: 82–90.

Okolo C C, Gebresamuel G, Zenebe A, et al. 2020. Accumulation of organic carbon in various soil aggregate sizes under different land use systems in a semi-arid environment. *Agriculture, Ecosystems & Environment*, 297: 106924, doi: 10.1016/j.agee.2020.106924.

Peng J, Xiao L, Xu Z Y, et al. 2024. Effects of different land use change on soil aggregate and aggregate associated organic carbon: A meta-analysis. *Polish Journal of Environmental Studies*, 33(5): 5263–5274.

Qiu L P, Wei X R, Zhang X C, et al. 2012. Soil organic carbon losses due to land use change in a semiarid grassland. *Plant and Soil*, 355(1-2): 299-309.

Qiu L P, Wei X R, Gao J L, et al. 2015. Dynamics of soil aggregate-associated organic carbon along an afforestation chronosequence. *Plant and Soil*, 391: 237-251.

Ramaswamy V, Gaye B, Shirodkar P V, et al. 2008. Distribution and sources of organic carbon, nitrogen and their isotopic signatures in sediments from the Ayeyarwady (Irrawaddy) continental shelf, northern Andaman Sea. *Marine Chemistry*, 111(3-4): 137-150.

Reeves S H, Somasundaram J, Wang W J, et al. 2019. Effect of soil aggregate size and long-term contrasting tillage, stubble and nitrogen management regimes on CO_2 fluxes from a Vertisol. *Geoderma*, 337: 1086-1096.

Schimel D S. 1986. Carbon and nitrogen turnover in adjacent grassland and cropland ecosystems. *Biogeochemistry*, 2(4): 345-357.

Schmidt E S, Villamil M B, Arniotti N M. 2018. Soil quality under conservation practices on farm operations of the southern semiarid pampas region of Argentina. *Soil and Tillage Research*, 176: 85-94.

Shao Y. 2008. *Physics and Modelling of Wind Erosion*. Dordrecht: Springer.

Shrestha B M, Singh B R, Sitaula B K, et al. 2007. Soil aggregate- and particle-associated organic carbon under different land uses in Nepal. *Soil Science Society of America Journal*, 71(4): 1194-1203.

Six J, Elliott E T, Paustian K. 2000a. Soil macroaggregate turnover and microaggregate formation: A mechanism for C sequestration under no-tillage agriculture. *Soil Biology and Biochemistry*, 32(14): 2099-2103.

Six J, Paustian K, Elliott E T, et al. 2000b. Soil structure and organic matter distribution of aggregate-size classes and aggregate-associated carbon. *Soil Science Society of America Journal*, 64(2): 681-689.

Six J, Conant R T, Paul E A, et al. 2002. Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. *Plant and Soil*, 241(2): 155-176.

Sokol N W, Bradford M A. 2019. Microbial formation of stable soil carbon is more efficient from belowground than aboveground input. *Nature Geoscience*, 12(1): 46-53.

Su Y G, Huang G, Lin S N, et al. 2023. Patterns of organic carbon and nitrogen stocks in soil particle-size fractions along an aridity gradient in northern China' s deserts. *CATENA*, 221: 106785, doi: 10.1016/j.catena.2022.106785.

Tatarko J. 2001. Soil aggregation and wind erosion: Processes and measurements. *Annals of Arid Zone*, 40(3): 251-264.

Tisdall J M, Oades J. 1982. Organic matter and water-stable aggregates in soils. *Journal of Soil Science*, 33(2): 141-163.

Tosunoglu F, Kisi O. 2017. Trend analysis of maximum hydrologic drought variables using Mann-Kendall and Sen' s innovative trend method. *River Research and Applications*, 33(4): 597-610.

Udom B E, Ogunwole J O. 2015. Soil organic carbon, nitrogen, and phosphorus distribution in stable aggregates of an Ultisol under contrasting land use and management history. *Journal of Plant Nutrition and Soil Science*, 178(3): 460-467.

Unger P W. 1997. Aggregate and organic carbon concentration interrelationships of a Torrertic Paleustoll. *Soil and Tillage Research*, 42(1): 95-113.

Wang R D, Guo Z L, Chang C P, et al. 2015. Quantitative estimation of farmland soil loss by wind-erosion using improved particle-size distribution comparison method (IPSDC). *Aeolian Research*, 19: 163-170.

Webb N P, Chappell A, Strong C L, et al. 2012. The significance of carbon-enriched dust for global carbon accounting. *Global Change Biology*, 18(11): 3275-3278.

Wu X T, Wang S Y, Cheng H, et al. 2024. Variation of soil organic matter with particle size in the wind erosion region of northern China. *CATENA*, 241: 108025, doi: 10.1016/j.catena.2024.108025.

Xiao L M, Zhang W, Hu P L, et al. 2021. The formation of large macroaggregates induces soil organic carbon sequestration in short-term cropland restoration in a typical Karst area. *Science of the Total Environment*, 801: 149588, doi: 10.1016/j.scitotenv.2021.149588.

Yamashita T, Flessa H, John B, et al. 2006. Organic matter in density fractions of water-stable aggregates in silty soils: Effect of land use. *Soil Biology and Biochemistry*, 38(11): 3222-3234.

Yang X, Shao M A, Li T C, et al. 2022. Soil macroaggregates determine soil organic carbon in the natural grasslands of the Loess Plateau. *CATENA*, 218: 106533, doi: 10.1016/j.catena.2022.106533.

Zhang F J, Xue B, Yao S C, et al. 2018. Organic carbon burial from multi-core records in Hulun Lake, the largest lake in northern China. *Quaternary International*, 475: 80-90.

Zhang Z C, Bird A, Zhang C X, et al. 2022. Not all gravel deserts in northern China are sources of regionally deposited dust. *Atmospheric Environment*, 273: 118984, doi: 10.1016/j.atmosenv.2022.118984.

Zinn Y L, Lal R, Resck D V S. 2005. Texture and organic carbon relations described by a profile pedotransfer function for Brazilian Cerrado soils. *Geoderma*, 127(1-2): 168-173.

Zobeck T M. 1991. Soil properties affecting wind erosion. *Journal of Soil and Water Conservation*, 46(2): 112-118.

Zobeck T M, Sterk G, Funk R, et al. 2003. Measurement and data analysis methods for field-scale wind erosion studies and model validation. *Earth Surface Processes and Landforms*, 28(11): 1163-1188.

Zou X Y, Zhang C L, Cheng H, et al. 2015. Cogitation on developing a dynamic model of soil wind erosion. *Science China Earth Sciences*, 58(3): 462-473.

Note: Figure translations are in progress. See original paper for figures.