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Investigations on carbon–structure-relations in aggregated soils subjected to different tillage intensity

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Abstract

Aim of this work was to prove changes in carbon-structure-relations by investigating the impact of disruptive forces of tillage activities and mechanical loading on the spatial distribution of soil organic carbon (SOC) inside large macroaggregates (5 – 20 mm across) and CO_2-release of intact soil cores (236–471 cm³). Undisturbed samples were taken from the topsoil of loamy sand field plots under no-tillage (NT), reduced tillage (CONS) and conventionally ploughed (CT). Air-dried aggregates were peeled from the outside (exterior region) to the inside (interior region) using the SAE method from Park and Smucker (2005).

The effect of tillage intensity on the spatial distribution and stabilization of SOC was confirmed within macroaggregates irrespective of aggregate size class. With increasing tillage intensity (NT < CONS < CT) aggregates were less stable and their SOC content was found to be depleted in aggregate exterior compared to interior layers. This led averagely to a 2/3 higher SOC stock (0–20 cm soil depth) in macroaggregates under NT compared to CT. At the bulk soil scale a high susceptibility against SOC losses due to mechanical loading was observed, that varied with soil strength and as consequence on soil management indicated by a higher CO_2-release under CT.

Keywords: Soil organic carbon, tillage systems, CO_2-release, mechanical loading, soil strength, aggregate peeling, conservation tillage, large macroaggregates

Introduction, scope and main objectives

Combating climate change needs abilities of mitigating anthropogenic CO_2-emissions from arable soils. Implementation of alternative management strategies with lower disturbance intensity compared to conventional ploughing (CT) is stated to increase the soil organic carbon pool (SOC) of arable topsoils by 0.2 ± 0.13 t/ha/year (Arrouays et al., 2002, Mordhorst, 2013). Inside of intact aggregates organic substrates are physically protected against microbial attack since microorganisms as potential decomposers can´t access these pores or they are inactive under limited environmental conditions such as oxygen, water and energy supply. Physical inaccessibility of SOC is known to be an effective mechanism to sequester carbon at different size and time scales (Balesdent et al., 2000, Six et al., 1998, Young and Ritz, 2000). Soil management influences structure formation processes and the associated physical carbon protection in aggregates. Hence, the susceptibility against SOC losses is related to stress-induced changes in aggregation and internal pore structures, and depends therefore on the mechanical strength properties (Horn and Smucker, 2005).

Aim of this work was to prove related changes in carbon-structure-relations by investigating the impact of disruptive forces of tillage activities or mechanical loading on the SOC distribution inside aggregates and CO_2-release at different scale sizes: the *bulk soil scale* using intact soil cores as well as the *aggregate scale* using intact macroaggregates (5 – 20 mm across). It was hypothesized, that the spatial SOC distribution and stabilization potential within these macroaggregates is controlled by soil management, for example by soil tillage intensity (conventional ploughing and conservational/no-tillage systems). Secondly, it was expected that the SOC loss potential (CO_2-release) is dominated by the soil strength (stability of aggregates) depending on soil tillage frequency.

Methodology

Undisturbed soil cores (236 and 471 cm³) and soil blocks (1000 cm³) were collected from a topsoil of field plots of a loamy sand texture (59% sand, 28% silt, 13% clay) at a Danish Research Station (mean annual temperature of 7.7 °C, annual rainfall of 560 mm). Field plots have been subjected to different tillage treatments for 9 years before sampling. A no-tilled (NT), reduced tilled (harrowed down to depth of 8–10 cm: CONS) and conventionally ploughed (CT) Stagnic Luvisol (FAO, 2006) from glacial till was sampled in inter-traffic line zones.

For investigations on the aggregate scale, field moist soil blocks taken from 0–10 and 10–20 cm depths were gently fractionated into the aggregate-size classes (AS class) 5–8, 8–12, 12–20 mm by manually breaking larger fragments along their weakest rupture planes. After air-drying, single aggregates from each AS class (n = 10) were separated into three concentric layers of equal solid mass ratio representing the exterior, transitional and interior aggregate region using the SAE method developed by Park and Smucker (2005b). In addition, aggregate volume was measured for whole aggregates and after removing the exterior and transitional concentric layer using a Pyknometer (Geopyc 1360, Micromeritics). Soil organic carbon (SOC) was measured for each concentric layer by dry combustion at 1200°C (Coulomat 702, Fa Ströhlein instruments) as well as total Kjeldahl N using a Flow-Injection Analyzer.

The mechanical stability of these aggregates was derived from (a) their Erosive strength (E_s) calculated from abrasive forces, which were required for peeling the aggregates from the outside to the inside, and (b) their tensile strength (Y) using the Crushing Test according to Dexter and Kroesbergen (1985).

CO_2-release was determined at the bulk soil scale for undisturbed soil cores taken from 10 – 15 cm depth (n = 6), which were pre-drained to field capacity (-6 kPa) prior laboratory measurements. CO_2-changes due to soil structure deformation by mechanical load application (max. 400 kPa) were measured dynamically using the Gas Flow Compaction Device as well as statically in terms of basal respiration rates using an alkali CO_2 trap inside of respiration chambers.

Results

At the *aggregate scale*, the effect of tillage intensity on the spatial distribution and stabilization of SOC was confirmed within macroaggregates of almost all tested AS classes: With increasing tillage intensity (NT < CONS < CT) aggregates were less stable (lower E_s and Y) and their SOC content was found to be depleted in aggregate exterior compared to interior layers in both depths. Fig. 1 shows a lower amount of SOC of exterior regions for 2/3 of CT aggregates compared to their interior layers. In contrast, SOC was relatively enriched in aggregate exterior regions for >80 % of aggregates from all AS classes under NT. Additionally, significantly higher C/N ratios in exterior layers compared to interior were observed for NT aggregates in both depths, opposite results were found for CT and CONS treatments. Although accumulation of SOC under NT was limited to 0–10 cm soil depth, the SOC stock within these macroaggregates was almost 2/3 as large increasing averagely from 15 t/ha (CT) to 26 t/ha (NT) summed up for 0 – 20 cm depth.

At the *bulk soil scale*, we could confirm the strong impact of structural deterioration by exceeding internal soil strength on changes in CO_2-release. In fact, primary reduction in CO_2-release by soil compaction was not persistent over time, because increasing carbon losses (CT > CONS > NT) compared to the initial state (without compaction) were found when the soil was re-equilibrated to field capacity (-6 kPa) again. This demonstrates a varying high susceptibility against SOC losses due to externally mechanical impacts depending on soil strength and as a consequence on soil management.

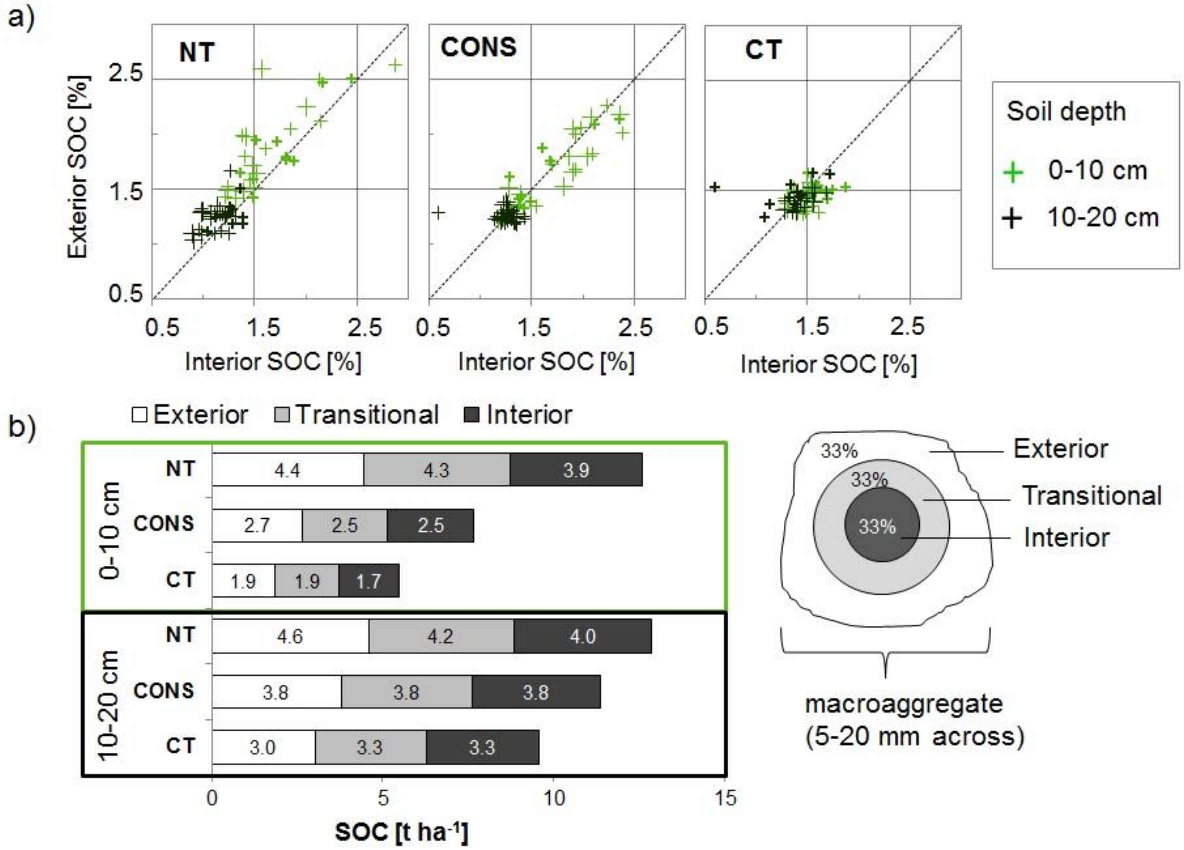

Fig. 1: Relation between exterior and interior SOC within macroaggregates (5–20 mm across) from 0–10 and 10–20 cm sampling depth of a sandy-loam Stagnic Luvisol (published in Mordhorst, 2013) (a) and calculated mean SOC stocks of concentric aggregate layers (b) depending on tillage intensity (CT = conventional ploughing, CONS = Reduced tillage (harrowing 8-10 cm), NT = No-tillage).

Discussion

Higher depletion of SOC at exterior regions with increasing tillage intensity (NT < CONS < CT) suggests higher microbial decomposition rates through the enhanced aeration of interaggregate pores. Accumulation of SOC in the outer skin of aggregates has repeatedly been observed for aggregates of equal size order (e.g. Park and Smucker, 2005a; Urbanek et al., 2011). Such gradients may be promoted by carbon depositions onto aggregate surfaces derived from roots or fungal hyphae which are likely dominated between aggregates (Kavdir and Smucker, 2005). Higher N content and lower C/N ratio of exterior regions under CT suggest higher microbial biomass and higher microbial activity (Park and Smucker 2005a).

The establishment of SOC gradients within aggregates possesses a great potential for SOC sequestration, but requires that aggregate turnover-rate is low and the internal aggregate porosities increase over time in order to expand the SOC storage towards interior regions (Park and Smucker, 2005). In this way, Park et al (2007) demonstrated the formation of preferential diffusion path ways in microfissures for transporting DOC from exterior to interior regions, which are yet free of potential decomposers. As the aggregate turnover rate is lowest under NT and aggregates were stable, it is conceivable that such diffusion processes were responsible for the absolutely higher SOC contents in interior regions of NT compared to CT aggregates (Fig. 1a). In contrast, tillage-induced loss of aggregate stability, indicated by lower erosive and tensile strengths, likely prevents the establishment of concentric gradients from outer to inner regions.

Results indicated the importance of minimizing aggregate turnover rates for improving carbon sequestration.
Otherwise, when aggregates were destroyed by mechanical loading (according to agricultural field traffic), the SOC sequestration potential was diminished again. The increase in CO_2-release after re-equilibrating a compacted soil to field capacity (-6 kPa) was presumably related to changes in microbial activity, originating from enhanced energy supply following structural rearrangement by mechanical and hydraulic stresses. Since ploughing promotes the incorporation of freshly organic residues to deeper soil regions compared to CONS and NT, highest CO_2 losses were found for CT soil cores from 15 cm depth.

Conclusions

The strong response of tillage practices on aggregate strength and SOC distribution inside aggregates affecting the SOC sequestration potential in soils was confirmed. Results underpin the importance of minimizing macroaggregate turnover being essential for the formation of stable macroaggregates and the establishment of SOC gradients from the exterior to interior aggregate regions. Investigation of carbon-structure relations on that scale size (mm to cm) has proven to be valuable for evaluating the effect of management (e.g. soil tillage systems) on the susceptibility against mechanical load applications and accompanied CO_2-release that diminishes the carbon sequestration potential again.

References

Arrouays, D., Balesdent, J., Germon, J.C, Jayet, P.A., Soussana, J.F., Stengel, P., 2002. Increasing carbon stocks in French agricultural soils? Synthesis of an assessment report, INRA Paris, 33 pp.

Balesdent, J., Chenu, C., Balabane, M., 2000. Relationship of soil organic matter dynamics to physical protection and tillage. Soil and Tillage Research 53, 215-230.

Dexter, A.R., Kroesbergen, B., 1985. Methodology for determination of tensile strength of soil aggregates. Journal of Agricultural Engineering Research 31(2), 139–147.

FAO, 2006. World reference base for soil resources 2006: a framework for international classification, correlation and communication. World soil resources reports, 103.Rome

Horn, R., Smucker, A., 2005. Structure formation and its consequences for gas and water transport in unsaturated arable and forest soils. Soil and Tillage Research 82, 5-14.

Kavdir, Y., Smucker, A.J., 2005a. Soil aggregate sequestration of cover crop root and shoot-derived nitrogen. Plant and soil 272, 263-276.

Mordhorst, A. 2013. Soil Structure-Carbon Relations of Differently Textured and Managed Arable Soils Subjected to Mechanical Loading. Schriftenreihe Institut für Pflanzenernährung and Bodenkunde, CAU Kiel, Vol. 99.ISSN: 0933-680X

Park, E.-J., Smucker, A.J.M, 2005a. Dynamics of carbon sequestered in concentric layers of soil macroaggregates. Korean J. Ecol. 28, 181-188.

Park, E.-J., Smucker, A.J.M., 2005b. Erosive Strengths of Concentric Regions within Soil Macroaggregates. Soil Science Society of America Journal 69, 1912

Park, E.J., Sul, W.J., Smucker, A.J., 2007. Glucose additions to aggregates subjected to drying/wetting cycles promote carbon sequestration and aggregate stability. Soil Biology and Biochemistry 39, 2758-2768.

Six, J., Elliott, E.T., Paustian, K., Doran, J.W., 1998. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Sci. Soc. Am. J. 62, 1367-1377.

Urbanek, E., Smucker, A., Horn, R., 2011. Total and fresh organic carbon distribution in aggregate size classes and single aggregate regions using natural 13 C/12 C tracer. Geoderma 164, 164-171.

Young, I.M., Ritz, K., 2000. Tillage, habitat space and function of soil microbes. Soil and Tillage Research 53, 201–213.