Evidence of Mineral Control of Soil Aggregation

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INTRODUCTION

Soil minerals and organic particles interact resulting in aggregate formation. Those structural units are key actors for soil functioning. In particular, they protect soil organic matter (SOM) from degradation, regulate water and gas flows, reduce run-off and erosion (Six et al., 2004). Since clay minerals are the most active constituents of the soil matrix, due to their specific surface area and surface charge characteristics, they have been recognized to be very important for soil aggregation.

The relation of clay minerals to aggregate formation and stability has been documented in numerous studies. A review article comparing temperate and tropical soils showed that soils dominated by 1:1 clay minerals and oxides in tropical regions have higher aggregate stability than soils dominated by 2:1 clay minerals in temperate regions (Six et al., 2002). In a comparative study with two soils differing in texture and clay mineralogy, Denef & Six (2005) reported that clay mineralogy rather than soil texture plays a key role in aggregation. It is noteworthy that in all these studies, other aggregation factors also co-vary with mineralogy, i.e. texture, presence of oxi-hydroxides, SOM quality and/or climate. Hence, definitive conclusions on the role of different clay minerals on soil aggregation cannot be drawn from these studies.

The objective of this study was to determine the importance of different clay minerals on aggregation by comparing clay mineralogy from different aggregate size-classes recovered from the same soil. We hypothesized a selective accumulation of swelling clay minerals within aggregates compared to free clay fractions.

MATERIALS AND METHODS

Three surface soil samples (0-5 cm) were collected from tillage (TILL) and grassland (GRS) plots from a long-term (more than 25 years) agricultural research site in Versailles (France). The soil is a silt loam Luvisol with 17% clay (<2 µm fraction) in the surface horizon, and a mixed mineralogy, (Ill, Sm, mixed-layer Ill-Sm and Chl-Sm) and 1:1 (Kln) clay minerals (Hubert et al, 2009).

Soil samples were wet-sieved to 5 mm and air-dried. Samples were then submitted to a low intensity physical dispersion and subjected to aggregate-size fractionation (Fig 1). Afterwards, aggregates were completely dispersed by sonication to separate clay-size fractions within aggregates. Aggregate-size distribution and the proportion of the clay-size fractions within aggregates were finally calculated.

For X-ray diffraction (XRD) analyses, all clay fractions (Fig 1) were saturated with Ca^{2+} and filter deposits were then prepared by using the filter-transfer method (Hubert et al. 2009). Clay minerals were identified from peak positions in air-dried (AD) XRD patterns. After AD XRD pattern decomposition (Decomp program, Lanson, 1997), the gravity centre of AD X-ray patterns intensity in the 4-10° 2θ angular range was calculated from position and area parameters of elementary peaks (Barré et al., 2007). Gravity centre position is a proxy for relative swelling clay minerals content: the lower the value of the gravity centre (in °2θ), the higher of the content of swelling materials.

RESULTS AND DISCUSSION

Aggregate-Size Distribution

In GRS, aggregate-size distribution was dominated by large macroaggregates (500-5000 µm), which accounted for 45% of the dry soil weight (Fig 2). In contrast, aggregate-size distribution in TILL was dominated by microaggregates (50-250 µm) and silt-size aggregates (2-50 µm). Each accounted for 35% of dry weight (Fig 2). The lower amount of large macroaggregates in TILL than in GRS is most likely due to annual tillage and lower SOM content in TILL, 9.8 vs. 25.0 g C kg^{-1} soil (Six et al., 2004).

Clay Minerals Distribution in Aggregates

The proportion of the clay-size fraction was similar in aggregate-size classes in

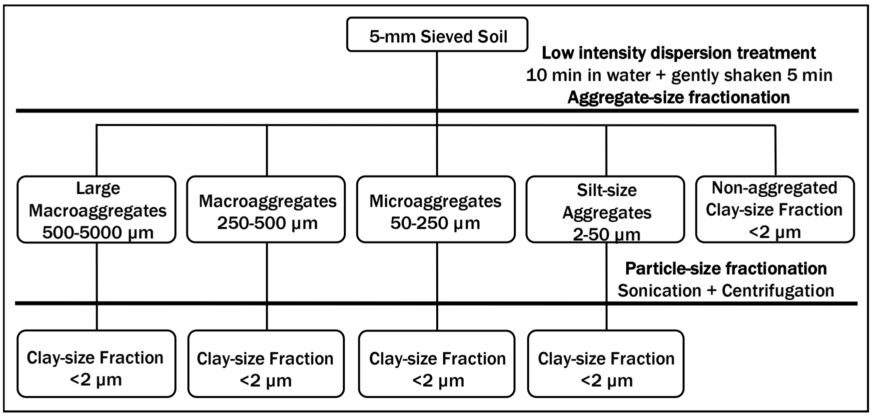

fig 1 *Schematic representation of dispersion and fractionation of soil samples.*

palabras clave: Minerales de la arcilla, Agregación, Suelo de clima templado

key words: Clay minerals, Aggregation, Temperate soil

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TILL and GRS, equivalent to 19% and 17%, respectively. Clay mineral distributions did not show significant differences between the two treatments. However, significant differences in clay mineral distribution among aggregate-size classes were observed. The AD XRD patterns of clay-size fractions within microaggregates in TILL and GRS showed higher content of swelling clay minerals. Conversely non-aggregated clay-size fractions were depleted in swelling minerals (Fig 3).

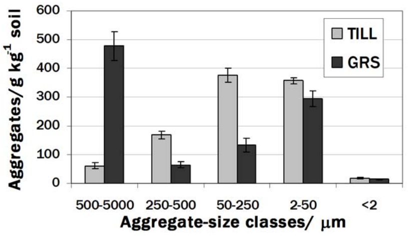

fig 2. Distribution of soil dry-weight across aggregate-size classes (corrected for sand) in the 0-5-cm layer of tillage (TILL) and grassland (GRS) plots. Large macroaggregates (500-5000 µm), macroaggregates (250-500 µm), microaggregates (50-250 µm), silt-size aggregates (2-50 µm), non-aggregated clay-size fraction (<2 µm). Bars are standard errors.

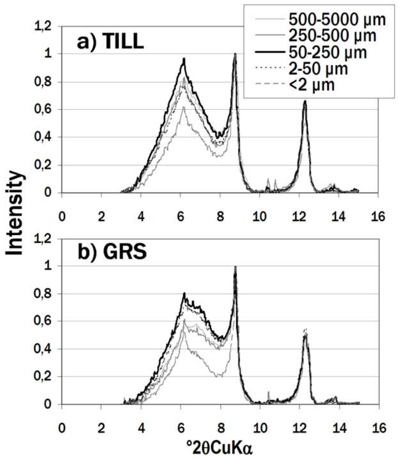

fig 3. Air-dried XRD patterns (normalized for illite) of aggregate-size classes in tillage (TILL, a) and grassland (GRS, b) plots. Large macroaggregates (500-5000 µm), macroaggregates (250-500 µm), microaggregates (50-250 µm), silt-size aggregates (2-50 µm), non-aggregated clay-size fraction (<2 µm).

These trends are clearly observed using the gravity centre position. In the two treatments, the gravity centre of 2:1 clay minerals in microaggregates was lower than in non-aggregated clay-size fraction. The gravity centre of 2:1 minerals also decreased from large macroaggregates to microaggregates (Fig 4). These results indicate a preferential accumulation of swelling clay minerals during microaggregates formation. The relative accumulation of swelling clay minerals in microaggregates supports the importance of mineral-mineral bonds and organo-mineral interactions by cation bridges in microaggregates formation, as suggested by several authors (e.g. Six et al., 2004).

The gravity centre of 2:1 minerals in clay-size fraction within silt-size aggregates was higher than in microaggregates, but lower than in non-aggregated clay-size fraction (Fig 4) in the two treatments. This indicates a preferential accumulation of swelling clay minerals during silt-size aggregates formation. Similarly, Virto et al. (2008) observed enrichment on 2:1 minerals in silt-size aggregates under an intensively tilled plot in the same soil. Thus clay mineralogy was also related to aggregation at this scale.

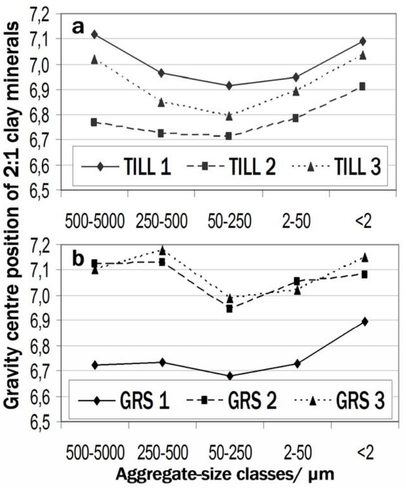

fig 4. Gravity centre of 2:1 mineral, of aggregate-size classes in tillage (TILL, a) and grassland (GRS, b) plots. Large macroaggregates (500-5000 µm), macroaggregates (250-500 µm), microaggregates (50-250 µm), silt-size aggregates (2-50 µm), non-aggregated clay-size fraction (<2 µm).

In aggregates >250 µm compared to microaggregates, the higher gravity centres of 2:1 minerals (Fig 4) suggested that other aggregation factor rather than clay mineralogy can play a major role in their formation and stabilization (i.e. SOM and fungal hyphae, Six et al., 2004). In TILL, the gravity centre gradually decreased from large macroaggregates to macroaggregates (250-500 µm) and microaggregates. In GRS, the gravity centre of aggregates >500 µm was similar and it decreased in microaggregates. It seems that the increasing role of mineralogy with decreasing aggregate-size scales is affected by the soil management system. Further research is needed to elucidate the contribution of different aggregation factors in the aggregate dynamics at different size scales.

CONCLUSIONS

Preferential accumulation of swelling clay minerals was systematically observed in microaggregates and partially in silt-size and macroaggregates, both in cultivated and non cultivated plots. In aggregates >500 µm, preferential accumulation of swelling clay minerals was very low compared to non-aggregated clay-size fraction, which may be due to the major role of other aggregation agents (i.e. SOM and/or fungal hyphae). Our results indicate that clay mineralogy plays a major role in aggregation processes and particularly at microaggregate scale.

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