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Optimal organic carbon values for soil structure quality of arable soils. Does clay content matter?

Alice Johannes[a,b,*], Adrien Matter[a], Rainer Schulin[b], Peter Weisskopf[c], Philippe C. Baveye[d], Pascal Boivin[a]

[a] University of Applied Sciences of Western Switzerland hepia, Soils and Substrates group, Institute Land-Nature-Environment, route de Presinge 150, 1254 Jussy Geneva, Switzerland

[b] ETH Zürich, Institute of Terrestrial Ecosystems, Universitätstrasse 16, 8092 Zürich, Switzerland

[c] Swiss Federal Research Station Agroscope, Soil Fertility and Soil Protection group, Department of Natural Resources & Agriculture, Reckenholzstrasse 191, CH-8046 Zurich, Switzerland

[d] UMR ECOSYS, AgroParisTech-INRA, Université Paris-Saclay, Avenue Lucien Brétignières, Thiverval-Grignon 78850, France

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ABSTRACT

Most soil structure-related physical properties are correlated to soil organic carbon (SOC) content. Texture, mineralogy, and SOC:clay ratio are also acknowledged to affect physical properties, however there is no consensus or general conclusions in this respect. Against this background, the present study aims at determining objectives for the management of SOC in terms of structural quality of agricultural soils. The large area in which 161 free-to-swell undisturbed samples were obtained for this research represents a major part of the Swiss agricultural land and belongs to one broad soil group (Cambi-Luvisols). The structural quality was scored visually, and bulk volumes (inverse of bulk density) were measured at standard matric potentials. To define the effect of SOC without interference of soil mechanical degradation, soils with good structural quality scores were considered first in studying the relationship between SOC and soil pore volumes. Results suggest that the relationship is always linear, irrespective of the clay content of the soils. No optimum of SOC corresponding to a fraction of the clay content is found, contrary to the theory of "complexed organic carbon" (Dexter et al., 2008). However, the SOC:clay ratio decreases with decreasing soil structure quality. The SOC:clay ratio of 1:8 is the average for a very good structure quality. A SOC:clay ratio of 1:10 is the limit between good and medium structural quality, thus it constitutes a reasonable goal for soil management by farmers. A SOC:clay ratio of 1:8 or smaller leads to a high probability of poor structural state. These ratios can be used as criteria for soil structural quality and SOC management, and in that context, the concept of complexed organic carbon appears relevant.

1. Introduction

The content of soil organic matter (SOM) in a given soil results from the integrated effects of many factors like site conditions, biological activity, and soil management (Kay, 1998). SOM content is correlated to a number of soil physical properties, like soil bulk volume, moisture retention curve, fluid transfer properties, and mechanical resistance of the soil to stresses. This can be quantified via numerous parameters, most of which have been shown to be largely correlated to SOM. This is true for soil aggregate stability (e.g., Abiven et al., 2009; Six et al., 2004), mechanical properties (Keller and Dexter, 2012; Soane, 1990), or penetration resistance (e.g., Stock and Downes, 2008). The most documented is probably the relationship between SOM, or soil organic carbon (SOC), and soil bulk density (e.g., Saini, 1966). Continuous increase in soil porosity with SOC was reported in many cases. Studies that included a broad range of SOC values (from 0 to > 50%) usually found a semi-logarithmic relationship, thus decreasing effect of SOC on porosity or bulk density (BD) at large SOC content (e.g. Jeffrey, 1970). Studies based on a limited range of low SOC contents even found a linear relation, thus proportional increase, between porosity and SOC (e.g. Saini, 1966).

Because in many soils, a significant portion of the SOC is bound to clay minerals, several authors have considered clay or clay + fine silt content as covariables when analysing the effect of soil constituents on soil physical properties. Together with SOC, texture is generally assumed to influence the physical properties (Kay, 1998). Clay mineralogy was shown

* Corresponding author at: University of Applied Sciences of Western Switzerland hepia, Soils and Substrates group, Institute Land-Nature-Environment, route de Presinge 150, 1254 Jussy Geneva, Switzerland.
E-mail address: Alice.Johannes@hesge.ch (A. Johannes).

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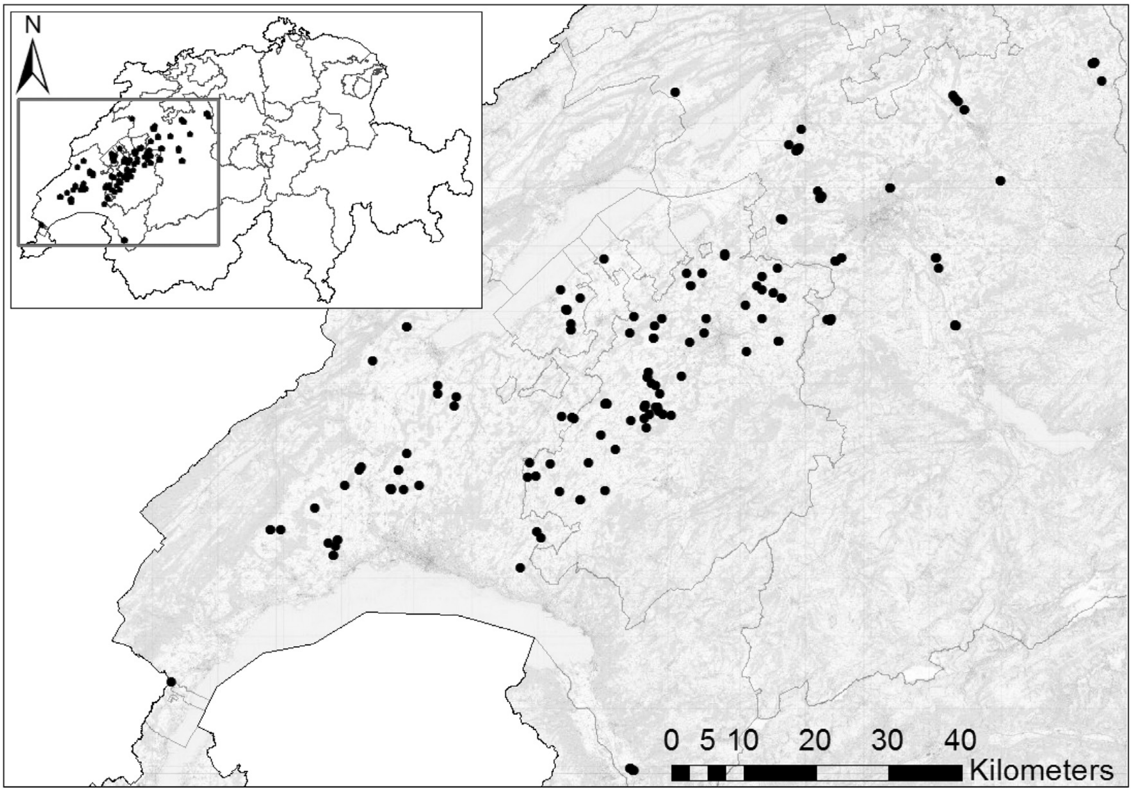

Fig. 1. Map of the soil sampling locations in Western Switzerland.

to influence the SOC content of soils with allophanic minerals, but not for those containing 1:1 and 2:1 phyllosilicates (Feller and Beare, 1997; Fernandez-Ugalde et al., 2016). The same linear relation between water content at pF2.5 and SOC, however, was found for the soils with all these mineral types according to Feller and Beare (1997). These authors pointed out that with increasing clay content, a larger SOC content was necessary to achieve the same level of aggregate stability.

Triggered by these observations, Dexter et al. (2008) analysed the role of the clay:SOC ratio in the relation between bulk density (BD) and SOC using soil databases from Poland and France that included soils of several taxonomic orders. They introduced the concept of "Complexed Organic Carbon" (COC) as the fraction of the SOC bound to clay, and found highest coefficient of determination of the linear relation between COC and soil volume (1/BD) for clay:COC = 10, thus interpreted as the saturation of the clay surface by SOC. They found the same optimum ratio for clay dispersibility and considered that the fraction of SOC corresponding to a tenth of the clay content was the maximum COC controlling the structure-related physical properties of soils. In particular, they concluded that structural porosity was no longer increasing with SOC above 10% of clay content, and that the optimum SOC content of a soil would thus be 10% of the clay content. They showed that the clay:SOC ratio 10 was separating the permanent pasture soils from the cropped soils in their database. Maximum correlation between 1/BD and SOC, however, does not mean optimum or desirable values of soil physical quality. In further tests of this approach, Schjonning et al. (2012) and Getahun et al. (2016) found that non-complexed clay (with a clay:SOC ratio of 10) was a better predictor of dispersible clay than total clay content, while aggregate strength was shown to be better explained by clay content alone.

These different analyses raise a number of issues. The main concern is that soil structural quality was not described in these various articles, which means that the used databases might include data of soils with different levels of structural degradation at the time of sampling, as is often the case in cropped soils. Other factors than SOC, e.g., mechanical stresses, influence the soil physical properties, which should not interfere with the assessment of the effect of SOC. Moreover, even when a specific sub order is considered, soil management, climate, and parent materials may have differed strongly in the different articles. Also, the techniques used to determine the physical properties were not described in detail. In particular for bulk density, a standardized matric potential should be applied prior to the volume measurement to eliminate the effect of the swelling state (Goutal et al., 2012).

This rapid overview of the literature on the connections between SOM or SOC and various physical characteristics of soils, taking into account or not the effect of the clay:SOC ratio, suggests that there might be an optimum or desirable range of SOM, but as pointed out by Loveland and Webb (2003), the evidence is "equivocal at best". SOM may be essential for a number of agricultural and environmental aspects, but in the field, it is managed by farmers. In this general context, the main objective of this research was to determine the SOC content that should be targeted in the management of an agricultural soil from a single soil group developed on the same parent materials, and to determine if clay content should be taken into account to identify this optimal SOC content. We focused on soil pore volumes and worked at large scale. We used the Visual Evaluation of Soil Structure (VESS, Ball et al., 2007) adapted to soil samples (Johannes et al., 2016) to make distinction between soils with degraded soil structure and soil with "good structure", thus possibly not impacted by mechanical stresses. On these later, the relationships between SOC or SOC:clay ratio and soil volume (1/BD), and the relevance of the concept of clay saturation by SOC proposed by Dexter et al. (2008) were analysed. The relationships between soil structure quality and the SOC:clay ratio were then discussed. Throughout this article, the description will be in terms of SOC only (not of SOM), to simplify the narrative.