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Organic matter and soil tilth in arable farming: Management makes a difference within 5–6 years

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Abstract

Management-induced depletion in soil organic carbon (SOC) may create critical tilth conditions for arable farming. We investigated the short-term effect of crop rotation and addition of animal manure on SOC fractions, the dispersibility of soil clay, the length of fungal hyphae, wet aggregate stability, tensile strength of dry aggregates, and the pore size distribution, gas diffusivity and permeability of undisturbed bulk soil. SOC fractions were measured in whole-soil samples and in 1–2 mm air-dried aggregates. Plough layer soil was sampled 5 and 6 years after the start of a field experiment with different cropping systems at two loamy sand soils (Foulum, ~9% clay and Flakkebjerg, ~14% clay). A soil drop test was performed in the field to evaluate *in situ* soil friability. A system dominated by small grain cereals not receiving animal manure served as a reference treatment (‘CEREAL’). This system was compared to the same crop sequence but with application of animal manure (‘CEREAL + MANURE’, only at one location), and to a diversified crop rotation including grass/clover but without addition of animal manure (‘CEREAL + GRASS’). A part of each field plot was compacted by a medium-sized tractor. The content of SOC was lowest for the CEREAL system at both locations. Hot-water extractable SOC displayed the same pattern. The carbon fractions in aggregates responded similarly to cropping systems as those in whole-soil samples. Clay dispersibility was highest in the CEREAL system. The length of fungal hyphae was enhanced by the versatile crop rotation. Soil compaction tended to increase clay dispersibility. Our results confirmed agronomic observations that the tilth in the Flakkebjerg soil was problematic and worse than in the Foulum soil, but generally only trends were found in amelioration of the poor mechanical tilth characteristics. In contrast, soil (macro)porosity was significantly higher for the CEREAL + GRASS system compared to the other two systems, and the CEREAL + MANURE and CEREAL + GRASS systems had more tortuous pore systems compared to the CEREAL system and better resisted compaction than the latter. We conclude that only 5–6 years of differentiated soil management significantly affected SOC fractions, the dispersibility of clay, and the growth of fungal hyphae. As only trends were found in the mechanical aspects of soil tilth, the tilth-forming agents may serve as early indicators of changes in soil tilth. Our results also indicate that soil pore characteristics are affected by short-term management and probably provide the basis for later significant changes also in mechanical tilth characteristics.

Keywords: Soil tilth; Soil organic carbon; Labile carbon; Fungal hyphae; Clay dispersibility; Aggregation; Soil pores; Cropping system; Manure; Compaction

1. Introduction

It is well known that plant and soil management have a huge impact on soil organic carbon (SOC) content, and that SOC influences soil functions (e.g. Carter, 2002). Many agricultural systems in industrialized countries induce low contents of SOC (Dick and Gregorich, 2004; Riley and Bakkegard, 2006). One key function of arable soil is its workability; the farmer needs to create seedbeds suitable for seed germination and crop growth. Watts and Dexter (1998) measured tensile strength of soil aggregates and estimated soil friability for a range of differently managed soils. Their results from the long-term Rothamsted field experiments

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showed convincingly that arable farming reduces SOC and friability compared to permanent pasture. For Danish conditions, we have previously shown that soils low in organic matter become mechanically hard when dry and unstable when wet (e.g. Munkholm et al., 2001, 2002; Schjønning et al., 2002a). Our attention on these problems was raised because of increased concern in the public on the sustainability of current production systems. It is frequently reported from agricultural advisers that soil workability is poor in many soils and that powered rotary tillage is needed to create proper seedbeds. The problem therefore includes the basic concern on continued use of SOC depleted soils in arable farming.

When evaluating farming systems with poor structural conditions it is important also to consider the mechanical impact to the soil. Studies have indicated that the energy input from tillage and traffic may induce high aggregate tensile strengths (Watts et al., 1996a,b,c; Watts and Dexter, 1997, 1998; Munkholm and Schjønning, 2004). Watts et al. (1996c) showed that an increase in aggregate tensile strength was associated with a marked increase in dispersible clay. As clay minerals interact with SOC in formation and stabilization of soil structure (e.g. Tisdall and Oades, 1982; Dexter, 1988), it is thus important also to consider tillage and traffic procedures in agricultural systems inducing low SOC contents.

We suggest the problems outlined above to be addressed in a conceptual framework bridging management and the dynamics in soil structure formation and degradation. Soil tilth is such a holistic concept. The term is used among farmers to describe soil workability, its suitability for sustaining plant growth, etc. Karlen et al. (1990) suggested a quantitative definition of the term that included physical characteristics of both bulk soil and individual aggregates. They further defined the tilth-forming processes as ‘‘The combined action of physical, chemical, and biological processes that bond primary soil particles into simple and complex aggregates and aggregate associations that create specific structural or tilth conditions’’. This definition was intended to provide a tool/framework for a better understanding of how soil management affects the soil tilth. The focus on tilth-forming processes certainly provides more holistic and less specific knowledge than the definition suggested for soil aggregation *per se* (e.g. Tisdall and Oades, 1982). However, the tilth-forming process approach acknowledges the binding mechanisms also involved in creation of the bulk, undisturbed soil (important for e.g. soil workability).

Our previous results suggested that the interactions between abiotic and biotic bonding and binding forces are complex and highly influenced by soil management (Munkholm et al., 2001, 2002; Schjønning et al., 2002a; Elmholt et al., 2005). These studies showed that high structural stabilities might be due to biotic bonding and binding mechanisms or to cementation of dispersed clay. For the soils low in extracellular polysaccharides (EPS) and fungal hyphae, the dispersibility of clay correlated to a high tensile strength of dry aggregates, which was also observed by other (Kay and Dexter, 1992; Watts and Dexter, 1997). Therefore, our previous results may be interpreted in terms of a high influence of the physicochemical process characterised by cementation of dispersed clay particles.

Thus, in agreement with the generally accepted description of aggregate formation (Tisdall and Oades, 1982), the formation and stabilization of soil structural units are determined by three bonding and binding mechanisms (Fig. 1). Mineral particles are glued to each other by (labile) fractions of organic matter, clay interacts with the organic matter in this process, and biotic structures like fungal hyphae and fine roots help binding structural elements to aggregates. We hypothesize that soil management will affect the interaction between these mechanisms, and determine which mechanism(s) will dominate in a given system. Fig. 1 focuses on crop rotation, traffic and tillage, and animal manure because these management options have been addressed in this study. However, every management tool would be expected to affect the tilth-forming processes.

The purpose of this study was to quantify early effects of crop rotation and addition of animal manure upon SOC content in particular but also on the tilth-forming processes discussed above. Another purpose was to evaluate, whether labile carbon (C) fractions were more sensitive to management than total SOC. We also wanted to investigate if isolated macro-aggregates could better reveal management effects than whole-soil samples. Finally we wanted to test, whether 5–6 years of different crop rotations and the

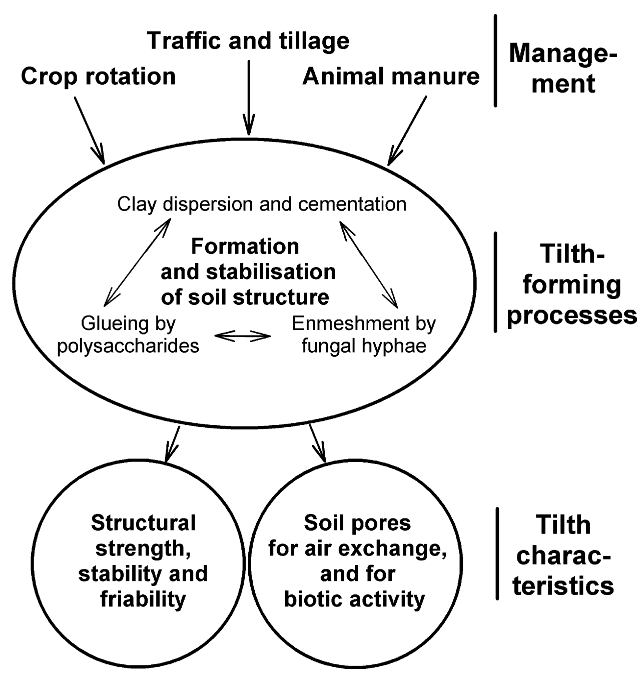

Fig. 1. A conceptual framework for use in the present study, relating management, tilth-forming processes, and the resulting tilth characteristics. Tilth-forming factors like the drying–wetting process not directly controlled by management were not addressed in this study.