Organic farming effects on clay dispersion in carbon-exhausted soils

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Figure 1. Clay particles dispersed in water (a), edge-to-edge flocculated in interaction with organic matter (b) or face-to-face cemented in lack of organic matter (c).

In this paper we show that clay particles in soils that are low in organic matter content are easily dispersed in the soil water. This has has important effects on soil ecosystem functions and services.

Many Danish soils are depleted in organic matter (OM) after decades of intensive cereal cultivation (ref. 7). This paper shows that clay particles (colloids) in soils that are low in OM content are easily dispersed in the soil water, which in turn has important effects on soil ecosystem functions and services.

Organic farming systems generally tend to increase soil OM contents and may thus mitigate the negative effects.

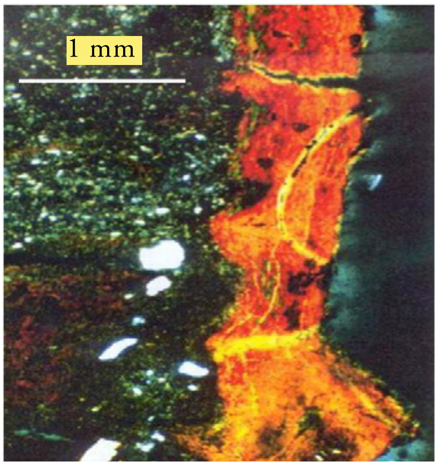

Figure 2. Micromorphology image of the wall of a macropore at 100-150 cm depth of a loamy soil on Sjælland. Deposits of laminated clay particles extend from the pore wall (reproduced from ref. 3).

Clay dispersion and potential consequences

Clay particles can be dispersed to soil water by the mechanical energy in traffic and tillage (Figure 1a). This is especially pronounced in soils with low OM content.

Dispersed clay particles may be leached to deeper soil horizons, where they can be deposited as clay skins in macropores (Figure 2).

Another potential fate of dispersed clay particles is transportation to the aquatic environment, potentially carrying strongly sorbing pollutants such as pesticides, PAHs or phosphorus. When dispersed clay particles re-assemble in the topsoil drying process, this may include flocculation with OM (first step in soil aggregation, Figure 1b).

Alternatively, for low-OM soils the drying process may induce cementation / internal crusting (Figure 1c), which may seriously reduce soil friability and hence the ease of soil fragmentation during seedbed preparation.

A vicious circle may hence be initiated because crusted, hard clods may then need an even higher energy input to fragment during tillage (potentially inducing more dispersion of clay particles).

In a previous ICROFS project, we collected soil from two neighbouring fields at Sjællands Odde that had the same geological origin and soil texture (refs. 2, 4, & 6).

One of the fields had grown forage crops in an organic cropping system for half a century (labelled High-C in Table 1). This included frequent application of animal manure in a crop rotation including grass leys.

In contrast, the other field had been used for continuous growing of small-grain cereal crops with only mineral fertilizers and with no return of organic residues to the soil for at least 25 years prior to the investigation (labelled Low-C in Table 1).

The contrasting management gave significant differences in soil OM content (Table 1). The dispersion of clay-sized colloids was higher for the Low-C soil than the High-C soil when field-moist soil was shaken in water for two minutes (Table 1).

Interestingly, however, when air-dried soil aggregates were treated similarly, the amount of dispersible clay was significantly lower for the Low-C than the High-C soil. This may be interpreted as a cementation of dispersed clay in the Low-C soil upon drying (ref. 2).

In accordance with this, the tensile strength of dry macro-aggregates (the energy needed to crush an aggregate) was highest for that soil. In essence, the high dispersion of clay in the soil with a low content of soil OM may cause the creation of inconveniently strong clods in dry conditions.

Threshold soil organic matter content?

Despite decades of research, it has not been possible to set a universal soil OM threshold for satisfactory tilth conditions for all soil types. As an example, we found a loamy sand soil at Askov with 2.2% OM to have an acceptable soil structure (ref. 5), while we observed severe soil degradation for the loamy Low-C soil at Sjælland with 2.5%

Soil characteristics	Management system	
	High-C	Low-C
Soil organic matter (g 100 /g soil)	3.4b	2.5a
Water-dispersible-colloids of wet soil (mg /g clay)	98a	134b
Water-dispersible-colloids of dry aggregates[1] (mg /g clay)	20.6b	18.0a
Tensile strength of dry aggregates[2] (kPa)	215a	267b

[1]Averaged across three aggregate sizes, 0.063-0.25, 0.5-1, 4-8 mm
[2]Averaged across four aggregate sizes, 1-2, 2-4, 4-8 and 8-16 mm

Table 1. Soil characteristics measured in two neighbouring soils with contrasting cropping and fertilization management. Figures labelled with different letters are significantly different (P=0.05). Please consult text for details. Data from refs 2, 4 & 6.

Crop rotation	Sampling year	
	2008	2009
Organic, including grass ley (O2)	0.95a	0.64a
Organic, annual crops (O4)	0.93a	0.61a
Conventional, annual crops (C4)	0.87a	0.57b

Table 2. Ratio between dispersed clay from dry & wet 1-2 mm aggregates when shaken in water for 2 minutes. Averages across fertilization and catch crop treatments for each crop rotation. Numbers of replicate plots for each rotation are 6, 6 and 4 for the O2, O4 and C4 rotations, respectively. Figures followed by the same letter within a specific year are not significantly different (P=0.05).

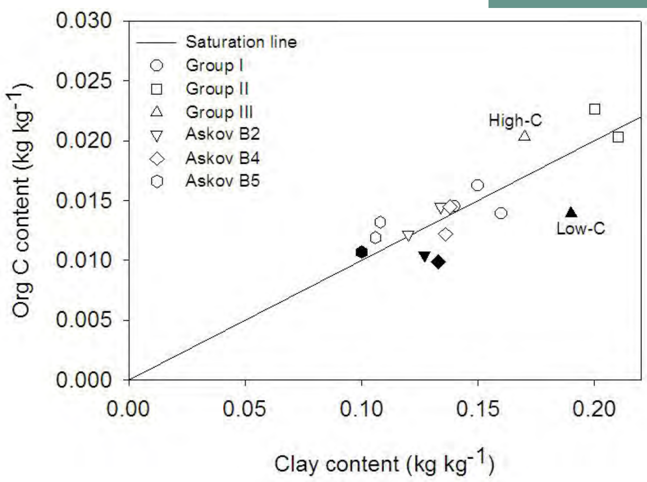

Figure 3. Relation between the content of clay and OC for a range of Danish soils with different soil management. Results on soil physical characteristics were reported for the Groups I-III soils by ref. 4 and 6, the Askov B2 and B4 fields were studied by ref. 5, and the Askov B5 soil by Per Schjønning in 1994. Soils with poor tilth are identified by closed symbols. The soils labelled "Low-C" and "High-C" are those discussed in relation to Table 1.

OM (Table 1).

However, recently Dexter et al. (2008) showed that many arable soils display a soil clay content and organic carbon (OC) ratio, n, of close to 10. Soils with higher ratios were 'unsaturated' with OM and were characterized by a high dispersibility of clay.

Clay definitions

Dexter et al. (2008) defined complexed clay (CC) as CC = (nOC) if (nOC < clay) else CC = clay, while non-complexed clay (NCC) in turn was defined as NCC = (clay - CC) if (clay - CC) > 0 else NCC = 0.

Figure 3 shows the relation between clay and organic C for a range of Danish soils studied in previous ICROFS projects. Soils shown as closed symbols were characterized by tilth problems, while soils with open symbols displayed a satisfactory soil structure.

The results in the Figure support the finding by Dexter et al. (2008) that soils below the 'saturation' line (clay/OC>10; NCC>0) have a critically low OM content.

Results from the CROPSYS project at Flakkebjerg

The ongoing CROPSYS project under ICROFS compares different arable crop rotations at three locations. The experiment was initiated in 1997, and the crop rotations differ in proportion of grass-clover in the rotation, use of catch crops and use of manure and fertilisers.

At Research Centre Flakkebjerg, the soil is generally severely depleted in OM. In a recent investigation of soil structural characteristics we found that all the 64 plots studied had soil OM contents below the Dexter 'saturation' line (Figure 4).

According to the Dexter terminology, points above the line are 'saturated' with OC and hence the soil in the CROPSYS plots at Research Centre Foulum is in good shape with respect to soil tilth.

This is in accordance with previous measurements at Foulum (ref. 8). Figure 4 also shows that the experimental field at Research Centre Flakkebjerg is very heterogeneous with clay content ranging from about 10 to 22%.

We also measured clay dispersibility of field-moist soil as well as of 1-2 mm aggregates either in air-dried conditions or at a water content corresponding to field capacity. Figure 5 shows results from the plots investigated in 2009.

We note that the amount of water-dispersible clay increases with the content of non-complexed clay (NCC). In this presentation the effect of the three cropping systems is embedded in the NCC-term that a management-induced increase in soil OM will decrease the amount of NCC. We have previously measured an additional increase in soil OC of the 'best' compared to the 'poorest' crop rotation in the Flakkebjerg CROPSYS site through 6 years of 0.0013 kg OC per kg soil.

This is equivalent to a decrease in NCC of 0.013 kg per kg soil, which should

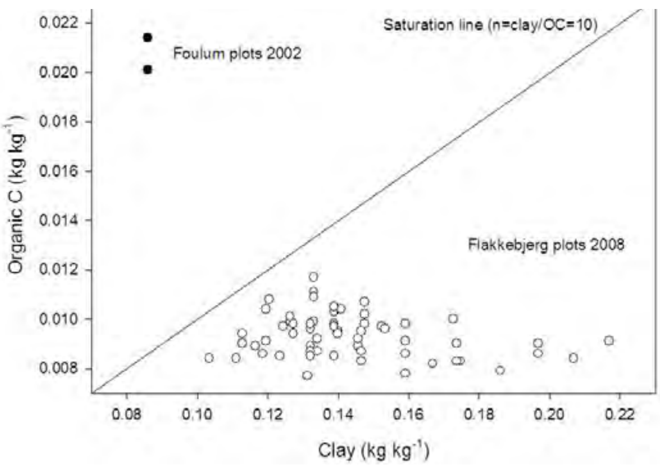

Figure 4. Relation between the content of clay and OC for the 64 experimental CROPSYS plots at Flakkebjerg and two selected plots at Foulum (the latter measured by ref. 8).

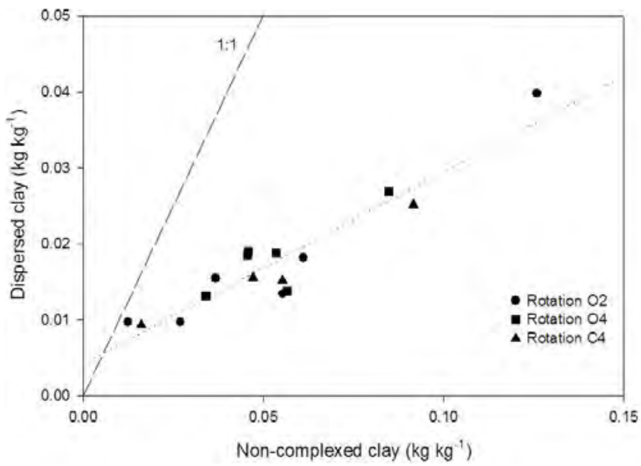

Figure 5. Relation between amount of soil non-complexed clay (NCC) and clay dispersed in soil samples taken from CROPSYS-Flakkebjerg plough layer (2009) and shaken in water for two minutes. Method according to ref. 1. Please consult text for details.

References

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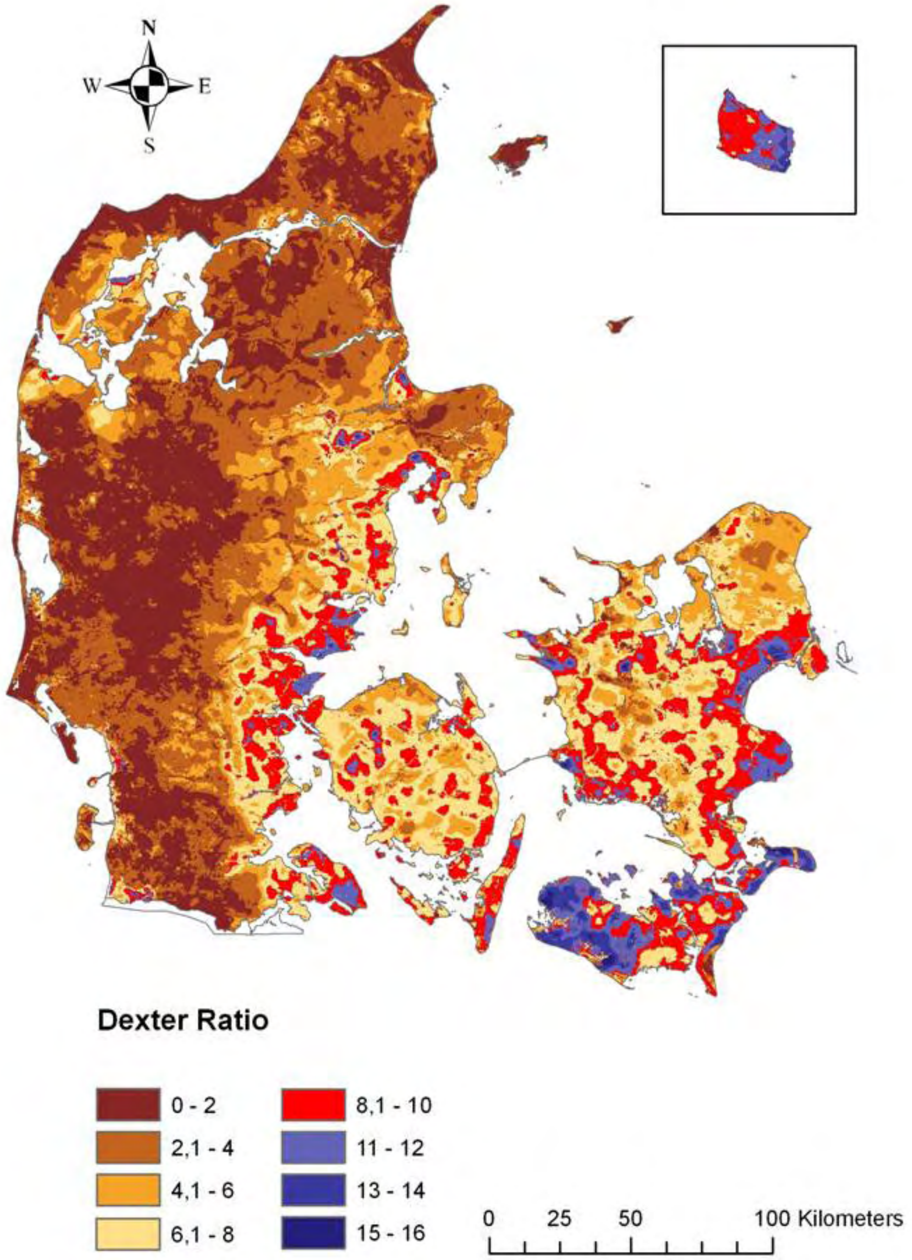

Figure 6. The 'Dexter-ratio' calculated as n=clay/OC, where OC is organic C for the plough layer of Danish soils. A value of n>10 indicates potential tilth problems due to critically low contents of OC. Created from the Danish Soil Database, www.djfgeodata.dk at Aarhus University.

be compared to measured values of 0.01-0.13 kg per kg soil. This indicates that (re-) saturation of the clay with OC at this Flakkebjerg field is a very slow process.

In Table 2 we have tabulated the ratio between the clay dispersed from the air-dried aggregates and field-moist aggregates, respectively. A low ratio indicates a high degree of cementation of clay particles at dry conditions. In both years, the highest ratio was observed for the organic O2 crop rotation with the highest input of OM to the soil, while the lowest was observed for the conventional C4 system.

This effect was significantly different for the 2009 plots. In accordance with the results shown in Table 1, the low ratios observed for the conventional plots indicate that more cementation and internal crusting is found here than for the organic crop rotations.

Figure 6 shows the 'Dexter-ratio' for Danish soils. It appears that for a range of the clay-holding soils in the eastern part of Denmark, the soil OM content is critically low. Following more studies, we anticipate the 'Dexter-ratio' to be a potential tool to identify soils that are critically low in soil OM.

Conclusions

Many Danish soils are exhausted in organic matter content, which affects key soil functions including their suitability for crop production.

The new Dexter-index is promising for identification of soils with critical low organic matter contents.

Organic crop rotations tend to increase soil organic matter and may mitigate the negative effects of low organic matter contents.

Our results show that it is a long-term task to re-establish satisfactory tilth conditions for carbon-exhausted soils.

Read more

You can find more information about the DARCOF III research project CROPSYS on the effect of cropping systems on production and environment on the following webpage: www.icrofs.org/Pages/Research/darcofIII_cropsys.html