Multi-level assessment of soil quality – linking reductionistic and holistic methodologies

Per Schjønning, Lars J. Munkholm, Kasia Debosz and Susanne Elmholt
Danish Institute of Agricultural Sciences, Department of Crop Physiology and Soil Science, Research Centre Foulum, P.O. Box 50, DK-8830 Tjele, DENMARK.
E-mail: per.schjonning@agrsci.dk

Summary

Soil quality is often used as a qualitative, general term. However, quantification is an important feature of the scientific approach to nature. On the other hand, addressing specific soil parameters as indicators of soil quality includes a reduction of the whole soil system. Therefore, results obtained by specialized methodologies ought to be evaluated by methods integrating the soil characteristics *in situ*. In this presentation, results are given from an investigation of the tilth of two differently managed loamy soils. One of the soils had been managed for decades with a forage crop system (labeled FCS), which included fertilization with farmyard manure, while the other had been grown with a continuous cereal system (labeled CCS), receiving no input of organic matter. In the field, the structure of the top 30-cm soil layer was described visually (spade analysis) and by studying the fragmentation behavior (soil drop test). Further, the field measurements included determination of soil strength by a torsional shear box method. In the laboratory, shear strength was determined on bulk soil sampled in metal cylinders, and tensile strength was estimated from crushing tests of individual, differently sized aggregates. The FCS soil appeared porous, with crumbs as structural units, while the CCS soil was compact with blocks as structural units. The soil drop test yielded the highest degree of fragmentation for the FCS soil. The torsional shear box method showed the CCS soil to have the highest bulk soil strength. This was confirmed by the laboratory shear annulus method. Finally, the tensile strength measurements revealed a much higher strength of 8-16, 4-8 and 2-4 mm dry aggregates from the CCS soil as compared to the FCS soil, while 1-2 mm aggregates were strongest in the FCS soil. This indicates a higher friability for the FCS soil, which is in accordance with the soil behavior in the field tests. In conclusion, the quality of the FCS soil – as evaluated by its mechanical behavior – was found to be higher than that of the CCS soil. An important result is the good correlation between the integrating field methods and the differentiating laboratory methods. This means that the quantifying, reductionistic scientific approach is not conflicting with the 'holistic' descriptions in the field.

Keywords: farming systems, soil structure, soil strength, soil fragmentation, ease of tillage, field methods, laboratory methods, methodologies

Introduction

In a review of the development of research in organic agriculture, Niggli & Lockeretz (1996) mention the contrasting opinions concerning the most relevant scientific approach when addressing alternative farming systems. They highlight the need for *'short-term, user-oriented, highly applied research'* as well as *'the long, slow search for a better understanding of the fundamental natural processes on which any agricultural system rests'*. In this context, it is of great importance to secure a good communication between scientists and the non-scientific approach of the NGO's. The scientists normally use methodologies which demand a 'reduction' of the soil system before the specific analysis can take place (reductionism) while the NGO's involved in the promotion of the alternative systems are focussing on evaluation of the whole system (holism). Research in organic farming systems should therefore preferably include the linking of quantitative, scientific measures of system characteristics and the farmers qualitative impression and judgement of the same characteristics (Harris & Bezdicek, 1994; Romig et al., 1995).

This paper reports some of the results obtained in a case study investigation of soil strength and fragmentation characteristics at two long-term differently managed soils in Denmark. An organically managed field was referenced by a conventionally managed counterpart of similar pedological origin. The two soils are identical to those labeled as *Soil Pair II* by Elmholt et al. (2000) [this issue]. Quantitative scientific laboratory methods were supplemented with descriptive methods in the field in order to evaluate the conclusions drawn from the classical methods. A full description of the investigation is given by Schjønning et al. (*submitted*) and Munkholm & Schjønning (*submitted*).

Materials and Methods

Soils studied

The full investigation (Schjønning et al., *submitted*; Munkholm & Schjønning, *submitted*) included three groups of soils, each group with two or three differently managed fields. In this paper, only one of these groups will be considered (labeled *group III* in Schjønning et al. (*submitted*), *group 2* in Munkholm & Schjønning (*submitted*) and *Soil pair II* in Elmholt et al. (2000) [this issue], respectively). Both soils within this group were sandy loams developed on till plains from the Weichselian glacial stage and may be classified as Oxyaquic Agriudolls / Glossic Phaeozems according to the USDA / FAO classification systems, respectively (Krogh & Greve, 1999). Consult Table 1 in Elmholt et al. (2000) [this issue] for information on basic soil characteristics.

The management characteristics of the soils in investigation are described in detail by Schjønning *et al.* (*submitted*). One of the soils belonged to a dairy farm with a five-year crop rotation including a two-year grass ley (labeled FCS [forage crop system]) and received farmyard manure. It was compared to a neighboring soil managed for at least twenty years with no animal manure application and grown continuously with small grain cereals or rape (*Brassica napus* L.) (labeled CCS [continuous cereal system]). Both soils had been managed according to conventional tillage practices including mouldboard ploughing.

Hierarchical strategy for analyses

As mentioned by Elmholt et al. (2000) [this issue], the full investigation was a multidisciplinary approach, including physical as well as microbiological characterization of the soils. This may be designated as *horizontal interdisciplinarity*, Figure 1. At the same time, especially the soil physical characteristics were assessed by several methodologies, ranging from visual evaluations in the field to measurements on single, dry aggregates in the laboratory. We suggest to label this approach *vertical interdisciplinarity*, Figure 1.

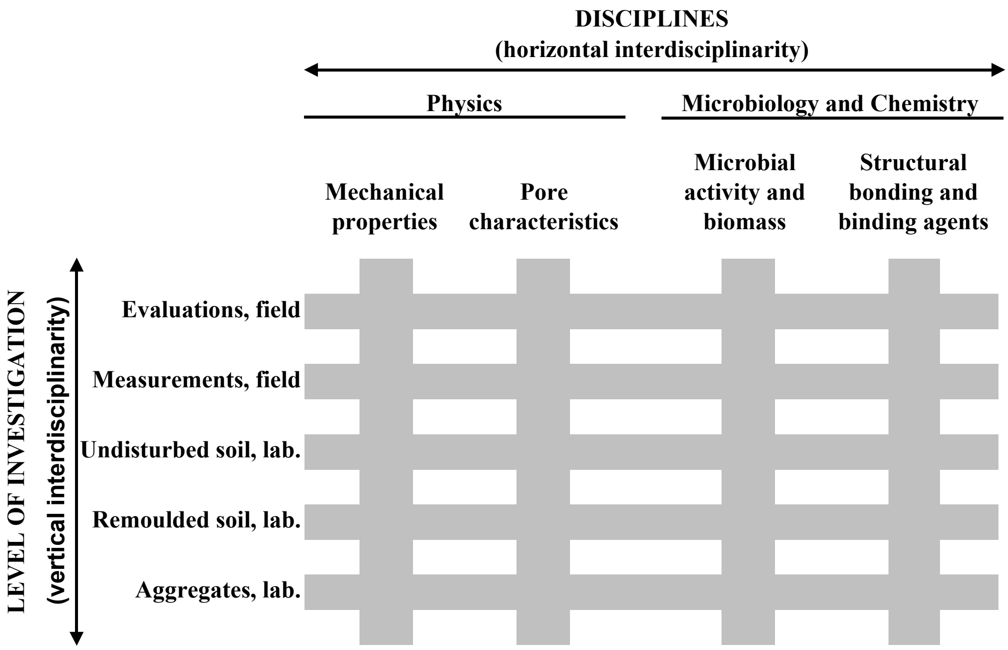

Figure 1. The analytical strategy included combinations of research disciplines (horisontal interdisciplinarity) as well as analyses of soil characteristics at different levels of 'reduction' of the research object (vertical interdisciplinarity).

Measurements

Sampling and field measurements took place in the spring in an autumn-sown winter wheat or spelt (*Triticum aestivum* L.) as detailed by Elmholt et al. (2000) [this issue]. Only short descriptions of specific methodologies will be given in this paper and these will be found within the 'Results and Discussion' section. Consult Schjønning et al. (*submitted*) and Munkholm & Schjønning (*submitted*) for a detailed description of methodology.

Results and Discussion

Visual soil evaluation

The visual evaluation of soil in the field was performed as described by Munkholm (2000) (Figure 2, left). It revealed, that the soil in the CCS field was compact with a blocky structure and of a firm consistency even when moist (Figure 2, right). The FCS soil was on the other hand porous with a crumbly structure, when both wet and dry. The ease/difficulty of digging and sampling in the two differently managed fields further confirmed these observations.

Figure 2. The visual soil evaluation involves studies of the top 30 cm soil (left). The CCS soil appeared dense, with a blocky soil structure (right). Notice the compact plough pan below 20 cm depth.

The soil drop test

Science is all about the quantification of the observations, as opposed to general empiricism. The question is therefore whether the visual soil evaluation could be quantified in some way by scientific tests. The soil drop test in a reproducible way can quantify how the soil fractionates at a certain energy input. The test is described by Schjønning et al. (*submitted*) and consists of letting an undisturbed soil sample (a cube measuring *c.* 7 x 8 x 11 cm) drop to the ground from a height of exactly 75 cm (Figure 3, left) thereby in principle simulating a soil tillage process. The soil fractions are then transferred to a nest of sieves from which the aggregate size distribution can be determined (Figure 3, right). The figure shows that the CCS soil fragmented only poorly (many large, intact aggregates) while the FCS soil was more friable which indicates that this soil would be a more easily tilled soil, for example for a seedbed.

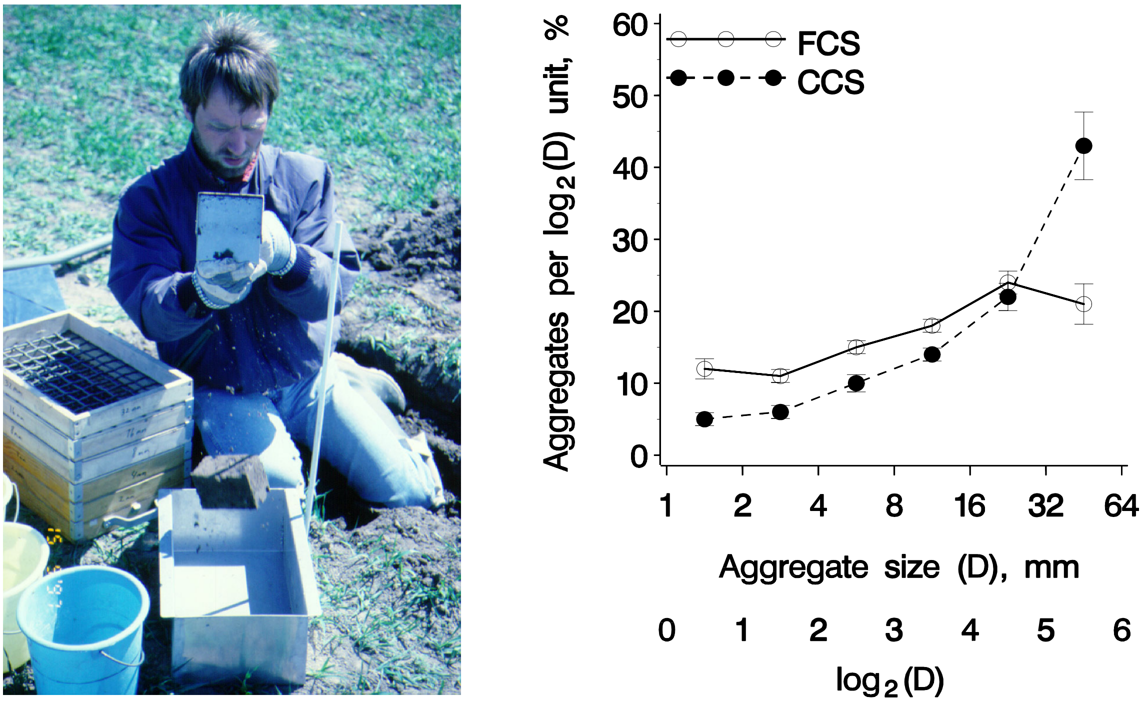

Figure 3. Performing the soil drop test (right) provides information of the soil fragmentation behaviour in the field (right).

Shear strength – field measurements

The aggregate size distribution is a *relative* number. In order to understand and describe a system, a quantification of scientifically well-defined parameters in *absolute* numbers is required. We therefore decided to try and measure the forces that determine soil fractionation. To do so we used the torsional shear box method in the field (Payne & Fountaine, 1952). This enables the determination of the forces, per unit area, that bind soil particles together. A cylindrical box is forced into the ground, a specific load is applied (there are measurements at several different loads) and the box is turned around. The peak strength when soil fails is measured (Figure 4, left). Figure 4, right, reveals that the highest shear strength was measured in the CCS soil which is in accordance with the results from the previously mentioned level of analysis (the soil drop test).

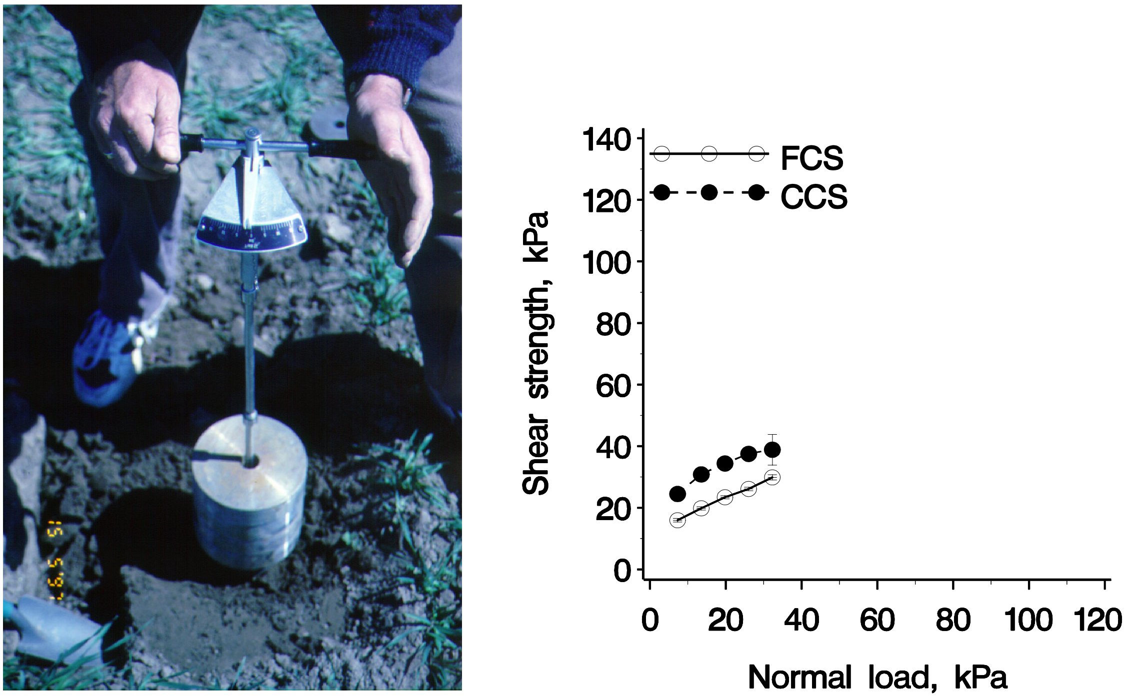

Figure 4. The torsional shear box method (left) gives information about soil strength in absolute terms (right).

Shear strength – laboratory measurements

Laboratory measurements provide control of the test conditions better than in the field. Undisturbed soil core samples of 100 cm^3 were therefore taken in the field and drained to –300 hPa matric potential. Using methodology in principle equivalent to that of the field tests, the forces counteracting shearing were measured at loads ranging to above 100 kPa (Schjønning, 1986) (Figure 5, left). Figure 5, right, shows that it was possible to reproduce the soil properties measured in the field. The laboratory tests also showed the CCS soil to have the highest shear strength. There is, however, a difference in the level of shear strength between the two methods. This may be due to the fact that the laboratory measurements were applied to samples taken after harvest; despite the fact that the soil cores had approximately the same water content as in the spring, they were sampled 4-5 months after the field measurements. Another important potential cause is the different character of the soil failure generated by the two methods. With the field method the failure is along natural planes of least resistance in the soil whereas with the laboratory method the soil is forced to fragment along predefined soil horizons. This means that forces between as well as within aggregates will contribute to shear strength.

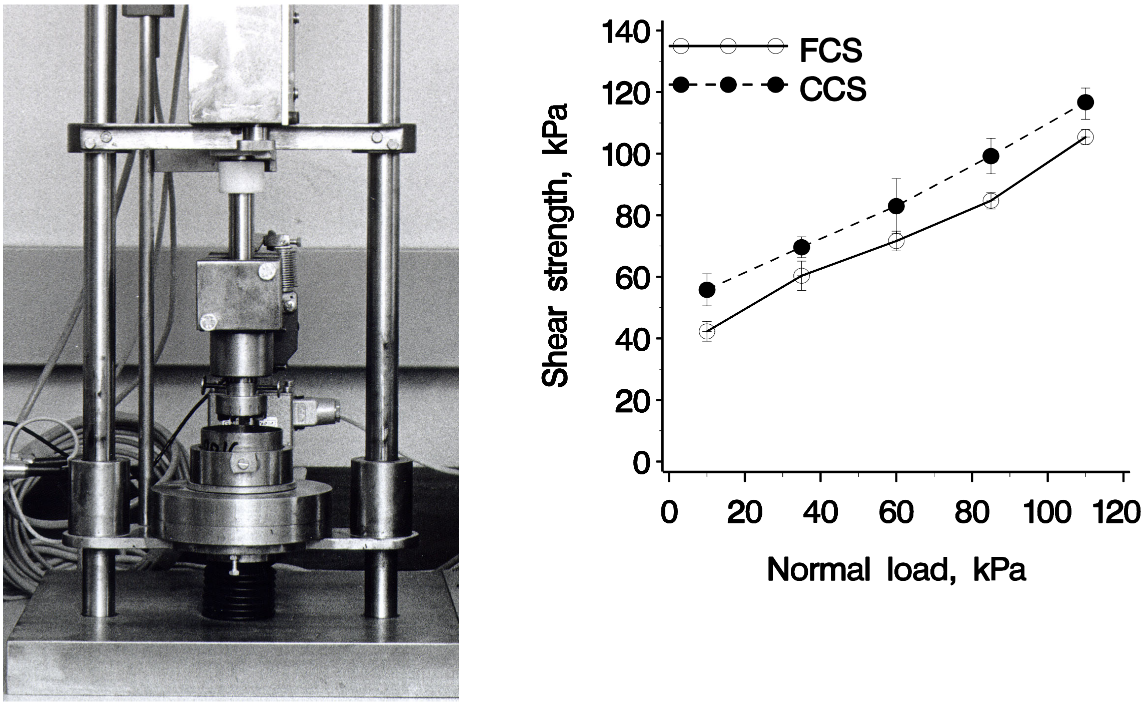

Figure 5. The determination of bulk soil strength in the laboratory (left) allows a good control of measuring conditions and provides information (right) analogous to that obtained by the torsioinal shear box method.

Tensile strength and soil friability

The shear strength measurements indicated that the bulk soil strength was in agreement with the fractionation pattern obtained with the drop test, i.e. the FCS soil fragmented into smaller aggregates, corresponding to a lower cohesive force in the soil. However, the drop test also showed that only the large clods fragmented. In this well-structured FCS soil, the smallest aggregates had such a large cohesive strength that the result of the test was a broad distribution of aggregate sizes and not only a collection of smaller particles. In order to understand the results of the drop test (and similar results from the visual evaluation concerning the friable consistency of crumbs) further differentiation (further reduction of the research objective) is required. In the project this was achieved by measuring tensile strength on individual air-dried aggregates. The hypothesis is that the measurement of the strength of several sizes of aggregates enables a quantification of the friability perceived with the visual evaluation and the drop test in the field. A friable soil is defined as a soil where large aggregates have a low tensile strength and small aggregates a relatively large strength (Utomo & Dexter, 1981). The analysis consists of measuring the tensile strength of air-dried individual aggregates in a compression test, using a mechanical press in the laboratory (Dexter & Kroesbergen, 1985; Figure 6, left). Figure 6, right, shows that the large aggregates (right-hand side of the x-axis) in the CCS soil had a larger tensile strength than those of the FCS soil. This is in line with the indications from the drop test (see Figure 3, right). Figure 6 also shows that the opposite is true for small aggregates (1-2 mm); small aggregates in the

FCS soil had a larger strength than in the CCS soil. The friability of the soil is subsequently quantified as the coefficient of the slope in the double logarithmic depiction of aggregate size and tensile strength (Figure 6, right). A numerically large slope (high strength of small and low strength of large aggregates) is therefore an expression of a highly friable soil, which was the case for the FCS soil.

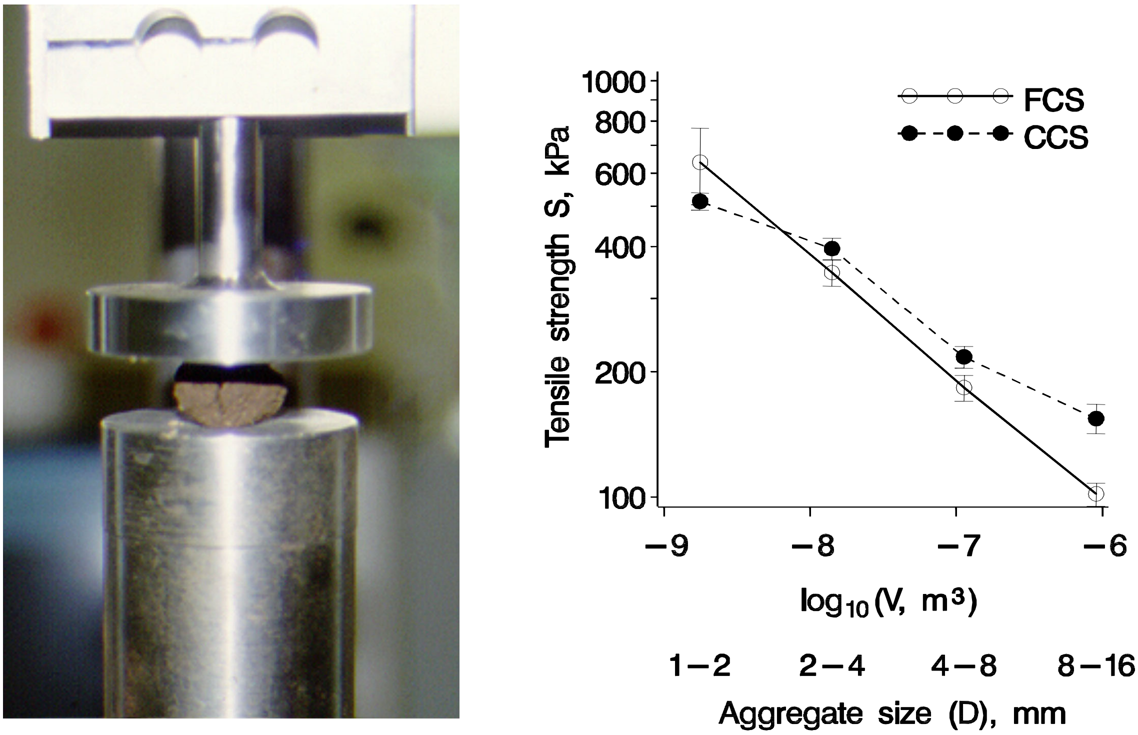

Figure 6. Determination of tensile strength of individual air-dried aggregates (right) means a rather extreme reduction of the soil system. However, a high friability (a steep slope) was found for the FCS soil, which also appeared friable in the field (right).

Conclusions and perspectives

In combination, the results presented here revealed a high ease of tillage in the FCS soil; when mechanically disturbed, the bulk soil fragmented into smaller sizes ideal for a good seedbed. In contrast, the CCS soil required a larger energy input to fractionate and there was a tendency for the soil to be pulverized into inconveniently small particles.

There is not necessarily a conflict between a holistic and a reductionistic methodology, and our results showed a good correlation between the integrating field methods and the differentiating laboratory methods. The results further indicated that sophisticated analytical methodologies (reductionistic research) are essential for quantification and understanding of soil behavior. The reductionistic methods, however, should always be used and interpreted in the larger (holistic) context.

More research is needed in the further uncovering of the mechanisms responsible for a 'good' soil structure considering the crucial effects for optimal soil functioning. We need a better understanding of how the soil ecosystem in a diversified farm management system develops to give the most optimal conditions for the soil processes of importance for sustainable farming. Such work may well follow the above design and include the application of integrating, holistic methods as well as differentiating, reductionistic investigations of causal relations in the ecosystem.

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