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# The effects of organic farming on the soil physical environment

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## Summary

The aim of this research was to investigate the effects of organic farming practices on the development of soil physical properties, and in particular, soil structure in comparison with conventional agricultural management. The soil structure of organically and conventionally managed soils at one site was compared in a quantitative manner at different scales of observations using image analysis. Key soil physical and chemical properties were measured as well as the pore fractal geometry to characterise pore roughness. Organically managed soils had higher organic matter content and provided a more stable soil structure than conventionally managed soils. The higher porosity (%) at the macroscale in soil under conventional management was due to fewer larger pores while meso- and microscale porosity was found to be greater under organic management. Organically managed soils typically provided spatially well distributed pores of all sizes and of greater roughness compared to those under conventional management. These variations in the soil physical environment are likely to impact significantly on the performance of these soils for a number of key processes such as crop establishment and water availability.

**Key Words:** Soil structure, Image analysis, Organic management, Multiscale approach

## Introduction

Soil structure is one of the most important properties influencing physical, chemical and biological processes within soils because it determines the accessibility of air, water and nutrients as well as drainage of the soil and its resistance to erosion, seedling emergence and root penetration (Gerhardt, 1997). Furthermore, soil structure is a property which can be greatly affected, and hence also manipulated, by agricultural management practices. The threat of soil deterioration is of particular concern since if structure is lost it is not easily repaired. The literature suggests that organic management contributes to the creation of an ¨enhanced¨ soil structure for crop production (Reganold, 1995; Papadopoulos *et al*., 2006). Organic farming practices have been associated with improved soil properties through a number of considerations including the addition of soil organic matter, increased earthworm population, biodiversity, soil fertility etc. This supports the view that there is greater potential for soil structural improvement in organically managed soils than conventionally managed (Shepherd *et al*., 2002, Pulleman *et al*., 2004).

Most previous work has made direct comparisons between organic/biodynamic and non-organically managed soils in a descriptive, qualitative manner, but a dynamic, quantitative approach should result in more useful data. The present study aims to quantify differences in soil structure between organic and conventional soil management and extend the understanding of the influences of these farming systems in the development of soil structure at different scales of observation. In order to achieve this, soils were studied at different spatial resolutions using digital processing techniques on images obtained from X-ray Computed Tomography (CT), impregnated and polished soil blocks and soil thin sections. An understanding of how soil structure is affected by the various farming practices and which processes relate specifically to structural development is likely to promote a more sustainable land management.

## Materials and Methods

Two organic (organically managed for three years) and two conventional fields from the same soil type (silt clay loam) were selected from ADAS High Mowthorpe, Pickering, North Yorkshire in order to quantitatively describe soil structure. The organic rotation consisted of wheat, barley and grass with clover while the conventional consisted of wheat, barley and beans. For each field, three undisturbed (384 $cm^3$) and three disturbed soil samples were collected from 0–15 cm and 15–30 cm soil depths. The saturated hydraulic conductivity (Ksat), soil aggregate stability and soil organic matter (SOM) content were measured as described in detail by Rowell (1994), Le Bissonnais (1996) and the British Standard Methods (1990) respectively. The soil sampling period was selected very carefully in order to make the comparison between the two farming systems feasible and avoiding possible influences of the results by the existence of live crop roots. As such, sampling took place four weeks after sowing.

X-ray CT was used for the detection of pores at the macroscale (pores $\geq$ 750 μm) using a medical scanner (Phillips MX8000 IDT). The time of scanning was 5 minutes for every16 samples at 140 kV and 201 mAs with 0.8 mm distance between each incision. 41 images of size 60 × 60 pixels were acquired from each soil sample and analysed using image analysis.

Crystic resin was used for the impregnation of the undisturbed soil samples. When the resin was cured, soil samples were then cut using a diamond saw and each surface was polished. Images of 760 × 970 pixels from the surface of the polished soil blocks were taken using a digital camera (Olympus C3030) and analysed using image analysis for the observation of pores $\geq$ 70 μm.

Soil thin sections were prepared for the detection of pores $\geq$ 7 μm following the method described by Fitzpatrick (1980). A cross polarising microscope was used for the acquisition of digital images. Eight images of size 1280 × 1024 pixels were obtained from each soil depth for image analysis.

Image analysis was applied to images obtained from all scales of observation using the program AnalySIS® (v. 3.0, Soft Imaging Systems (SIS) Germany). Measurements included pore sizes, perimeter and circularity. Fractal geometry has been considered an appropriate tool to characterise the rough and irregular pore boundaries typically observed in soil thins sections (e.g. Kampichler and Hauser, 1993). The analysis is based on the scaling relationship between perimeter (P) and area (A) that arises when a family of similarly shapes objects with fractal perimeters occurs. For conventional objects with smooth perimeters the following relation holds

$$P \propto A^{1/2} \qquad (1)$$

but for fractal perimeters this is replaced by

$$P \propto A^{D/2} \qquad (2)$$

where $D$ is the perimeter fractal dimension and satisfies $1 < D < 2$. As D increases the perimeter becomes rougher and more complex. The fractal dimension is extracted from a linear regression on a log-log plot of $P$ against A. The slope is equal to $D/2$.

## Results

The results of the soil physical quality measurements (Table 1) illustrate that there was no difference in total porosity (derived by bulk density) (%) between the two managements while the organically managed soils had higher saturated hydraulic conductivity and organic matter (%) and produced more stable soil aggregates with significantly higher organic matter (%) than that under conventional management ($P < 0.05$).

Table 1. *Soil physical quality and image analysis results for all scales of observation of organic and conventional management at different soil depths (± standard error of means)*

| | Organic | | Conventional | |
|---|---|---|---|---|
| Total porosity (%)[1] | 66.9 ±3.2 | | 70.5 ±8 | |
| Sat. Hydraulic Conductivity (cm $s^{-1}$) | 0.12 ±0.02 | | 0.08 ±0.01 | |
| Soil Organic Matter (%) | 9.3 ±0.4 | | 4.4 ±1.7 | |
| Soil Aggregate Stability | Stable | | Unstable | |
| Soil Depth (cm) | 0 – 15 | 15 – 30 | 0 – 15 | 15 – 30 |
| Macro-scale (750 µm) | | | | |
| Macroporosity (%) | 37.3 ±2.5 | 28.0 ±5.1 | 43.4 ±12.2 | 31.3 ±5.0 |
| Average Pore Size ($mm^2$) | 3.92 ±1.2 | 2.58 ±0.6 | 4.88 ±0.9 | 4.37 ±0.2 |
| Pore Roughness | 1.52 ±0.05 | 1.57 ±0.01 | 1.47 ±0.03 | 1.48 ±0.01 |
| Meso-scale (70 µm) | | | | |
| Mesoporosity (%) | 23.02 ±1.9 | 16.43 ±3.0 | 15.45 ±2.4 | 13.14 ±2.6 |
| Average Pore Size ($mm^2$) | 0.21 ±0.08 | 0.14 ±0.05 | 0.22 ±0.03 | 0.14 ±0.02 |
| Pore Roughness | 1.46 ±0.05 | 1.40 ±0.02 | 1.34 ±0.02 | 1.35 ±0.01 |
| Micro-scale (7 µm) | | | | |
| Microporosity (%) | 21.73 ±2.4 | 16.63 ±2.1 | 15.91 ±3.5 | 13.64 ±1.3 |
| Average Pore Size ($mm^2$) | 0.004 ±$7x10^{-4}$ | 0.003 ±$6x10^{-4}$ | 0.003 ±$4x10^{-4}$ | 0.002 ±$2x10^{-4}$ |
| Pore Roughness | 1.37 ±0.03 | 1.34 ±0.01 | 1.27 ±0.02 | 1.25 ±0.02 |

[1] Derived from soil Bulk Density

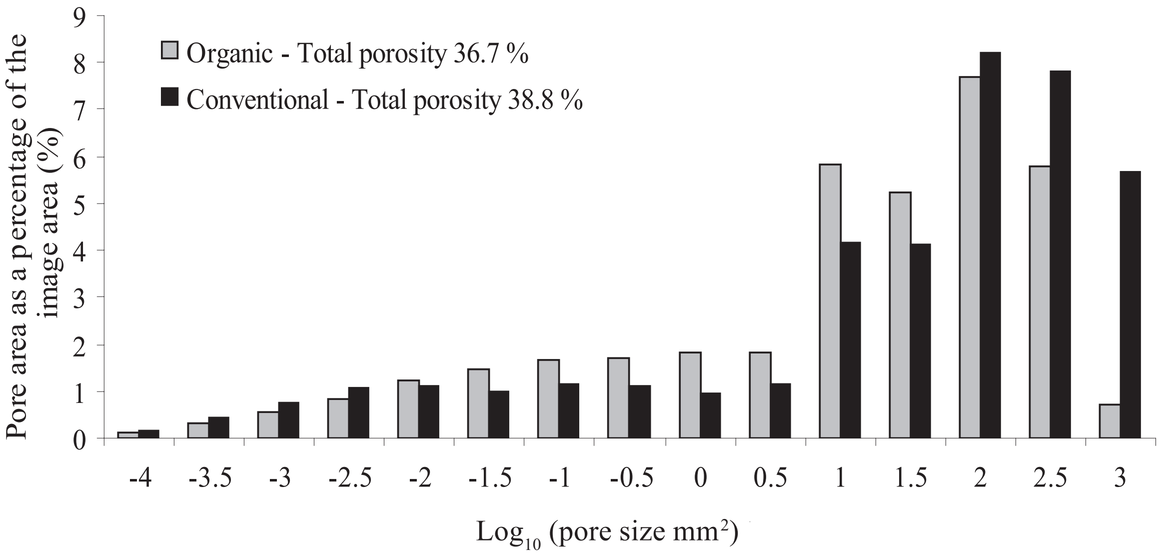


Fig. 1. Pore size distribution of organic and conventional soils from all scales of observation averaged for both soil depths derived from image analysis.

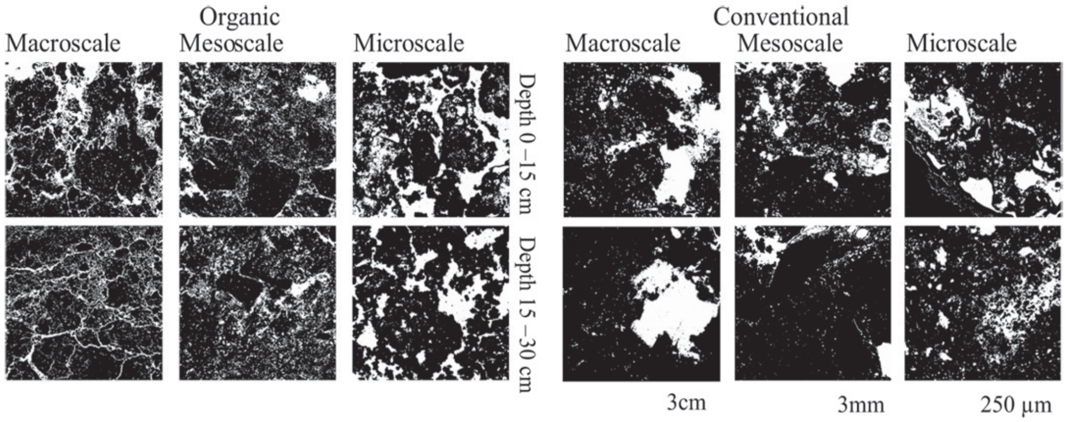


Fig. 2. Images representing soil structure of organically and conventionally managed soils for the different scales at both soil depths

Image analysis measurements at the macroscale demonstrated that conventionally managed soils had higher macroporosity (%) than that of the organic at both soil depths although the porosity of the latter consisted of smaller pores as indicated from the average pore size ($mm^2$) (Table 1) and the pore size distribution (PSD) (Fig. 1). At the mesoscale, the porosity was greater under organic management at both soil depths with no differences in average pore size ($mm^2$). The soils under organic management also had greater porosity at the microscale at both soil depths which consisted of larger pores than those under conventional management as suggested by the average pore size ($mm^2$) and PSD. Rougher pores were developed under organic management at all scales of observation and at both soil depths. Fig. 2 illustrates visual differences for representative images of soil structure of organically and conventionally managed soils at both soil depths.

## Discussion

Soils under organic management had higher SOM content and provided more stable soil aggregates than those of the conventionally managed soils. Comparison in terms of porosity revealed that organic soils had greater porosity at the meso- and microscale comprised of smaller pores than at the conventional and less porosity at the macroscale due to few large pores observed under conventional management. The more even distribution of pore sizes and spatial arrangement from visual observations under organic management suggests that a more developed pore network exists under organic management which is supported by the greater value of Ksat. The soil aggregate stability measured by slaking also suggests that the pore networks under organic management provide a more stable soil structure. Rougher pores observed under organic management should impact beneficially on soil physical properties such as water flow and water holding capacity. Rougher pore surfaces also provide habitat space for soil micro-organisms. A comprehensive understanding of the effects of the two management systems on soil structure is vital for sustainable land management.

## References

**British Standard Methods of test for Soil for civil engineering purposes Part 3.** *Chemical and Electro-chemical Tests BS 1377*.Part3:1990.

**Fitzpatrick E A. 1980.** *The micromorphology of soils. A manual for the preparation and description of thin sections of soils.* Department of Soil Science, University of Aberdeen, UK.

**Gerhardt R A. 1997.** A comparative analysis of the effects of organic and conventional farming systems on soil structure. *Biological Agriculture and Horticulture* **14**:139–157.

**Kampichler C, Hauser M. 1993.** Roughness of soil pore surface and its effects on available habitat space of microarthropods. *Geoderma* **56**:223–232.

**Le Bissonnais Y. 1996.** Aggregate stability and assessment of soil crustability and erodibility: I. Theory and methodology. *European Journal of Soil Science* **47**:425–437.

**Papadopoulos A, Mooney S J, Bird N R A. 2006.** Quantification of the effects of contrasting crops in the development of soil structure: an organic conversion. *Soil Use and Management* **22**:172-179.

**Pulleman M M, Six J, Breemen N, Jongmans A G. 2004.** Soil organic matter distribution and microaggregate characteristics as affected by agricultural management and earthworm activity. *European Journal of Soil Science* **9**:759–772.

**Reganold J P. 1995.** Soil quality and profitability of biodynamic and conventional systems: a review. *American Journal of Alternative Agriculture* **10**:36–45.

**Rowell D L. 1994.** *Soil Science: Methods and Applications.* Harlow: Longman Scientific & Technical.

**Shepherd M A, Harrison R, Webb J. 2002.** Managing soil organic matter – implications for soil structure on organic farms. *Soil Use and Management* **18**:284–292.