Consolidation and surface sealing of nine harrowed Swedish soils

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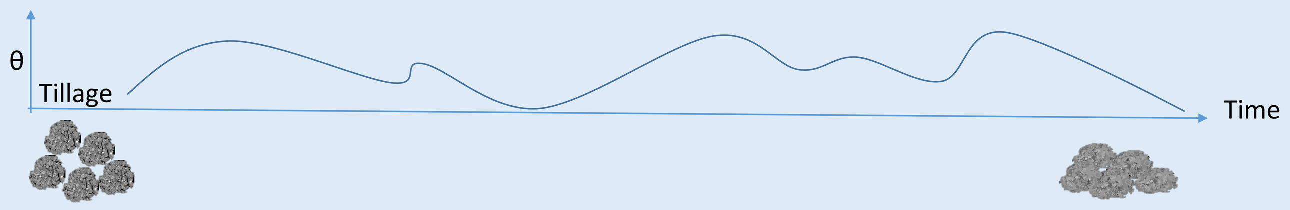
BACKGROUND

- The structure of agricultural top soils varies considerably throughout the year due to interactions between climatic and biological factors and agricultural management practices.
- Tillage decreases soil density and increases macroporosity, but the resulting arrangement of aggregates is sensitive to stresses exerted by wetting and drying and the soil eventually reverts back to its denser pre-tillage condition.



- Accounting for post-tillage changes in soil structure and related hydraulic properties could greatly improve model predictions of hydrological and transport processes.
- Model testing, development and parameterization is, however, currently hampered by a lack of direct measurements of the changes occurring in the structural pore system.
- We therefore designed an experiment using X-ray tomography and image analyses to quantify changes occurring in the properties of the pore system of recently harrowed soils subjected to repeated cycles of wetting and drying.
- Nine different Swedish soils covering a range of soil textures and organic carbon contents were examined.

OBJECTIVES

i) to generate data on temporal variations in porosity, pore size distribution and the connectivity of the pore space that could be used to develop, parameterize and test models of post-tillage soil consolidation of the harrowed layer

ii) to investigate the effects of soil texture and organic carbon content on consolidation and surface sealing

SOILS AND EXPERIMENTAL PROCEDURE

Table 1. *Particle size distribution and organic carbon content of the nine investigated soils*

Soil	USDA soil type	% clay	% silt	% sand	% OC
Cl I	Clay	57.0	38.5	4.2	2.4
Cl II	Clay	54.0	26.1	19.9	1.5
Cl III	Clay	50.7	37.6	11.7	1.2
SiClLo I	Silty clay loam	35.1	58.5	6.1	3.3
ClLo	Clay loam	33.7	32.4	33.9	1.4
SiClLo II	Silty clay loam	32.2	58.2	9.6	2.5
SaClLo	Sandy clay loam	23.2	17.5	59.3	1.2
SiLo I	Silt loam	21.5	66.6	11.9	1.6
SiLo II	Silt loam	7.1	74.7	18.2	4.0

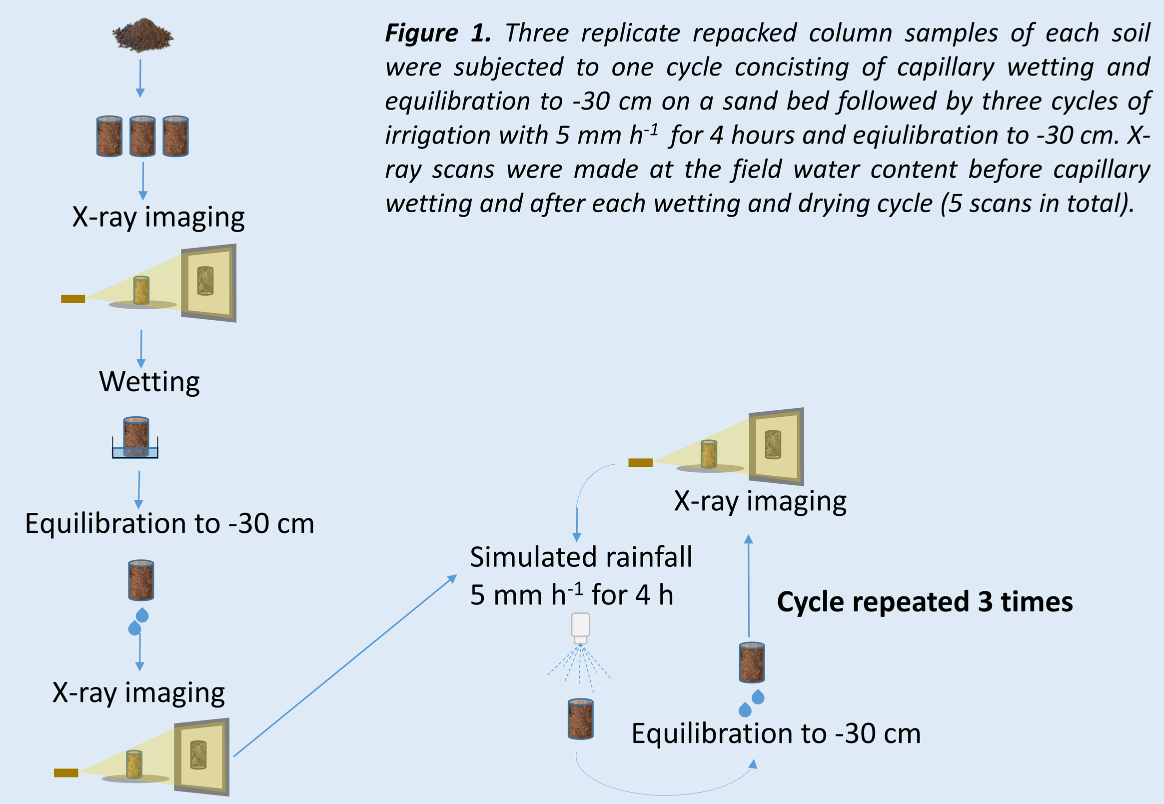


Figure 1. *Three replicate repacked column samples of each soil were subjected to one cycle concisting of capillary wetting and equilibration to -30 cm on a sand bed followed by three cycles of irrigation with 5 mm h^{-1} for 4 hours and eqiulibration to -30 cm. X-ray scans were made at the field water content before capillary wetting and after each wetting and drying cycle (5 scans in total).*

RESULTS

Evolution of total and surface porosity and the pore size distribution

- Total porosity decreased by 2%-23% in all soils except for the two, presumably swelling, clay soils Cl II where it increased slightly and Cl III where it remained unchanged.
- In these two clay soils, three of the clay loam soils (SiClLo I, ClLo II and SiClLo II) and to some extent in the silt loam soil SiLo II the pore size distribution shifted towards increasing proportions of smaller pore sizes.
- Porosity of the uppermost millimeter of the soil surface decreased most markedly (by 75% and 73%) in the two silt loam soils SiLo I and SiLo II.

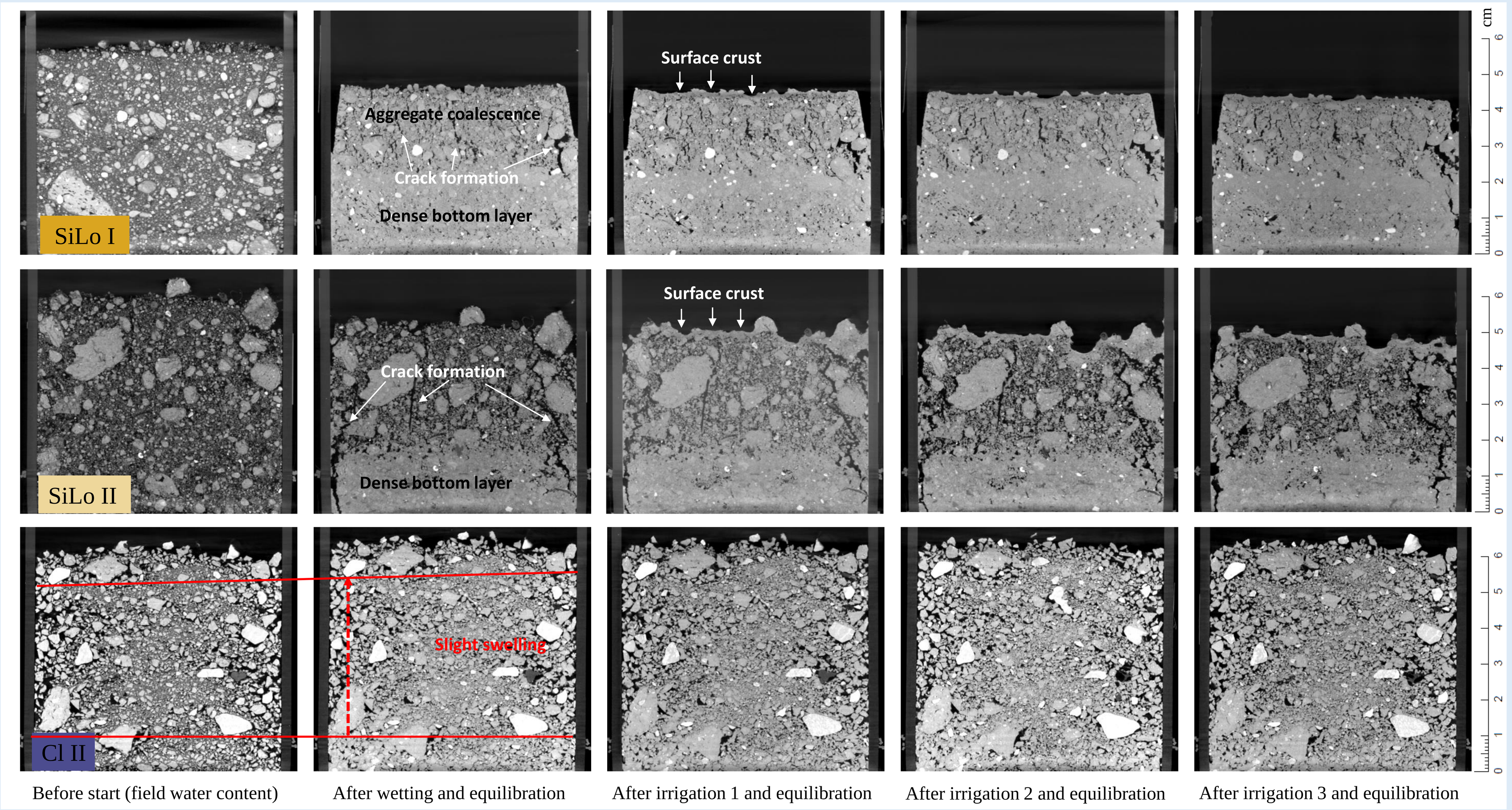


Figure 2. *Tomography images of one replicate sample from each of the silty soils SiLo I and SiLo II and from the clay soil Cl II at the five experimental stages as an example of the differences in soil structure evolution during the experiment.*

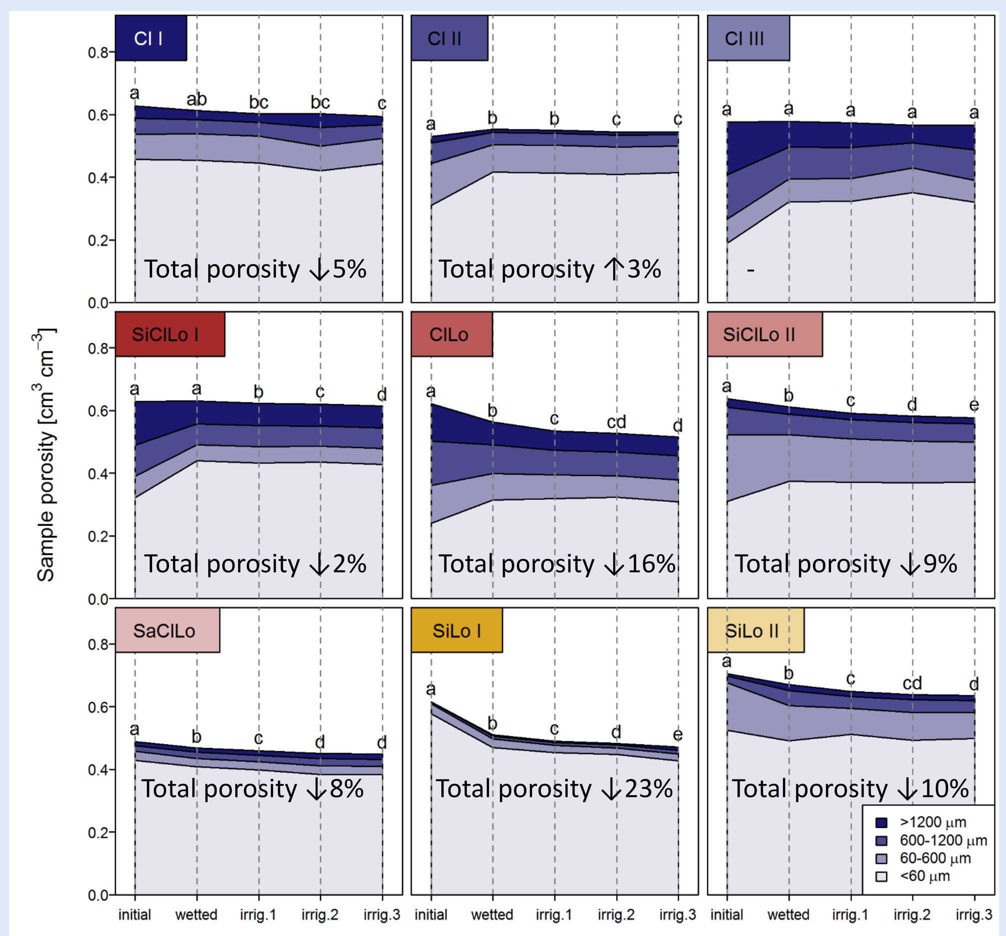


Figure 3. *Evolution of the total porosity (ε_{total}), partitioned between the four pore size classes >1200 µm, 600-1200 µm, 60-600 µm and <60 µm over the course of the experiment. Data is displayed as means of measurements made before and after wetting of the samples and after each of three four-hour irrigations. Different letters indicate statistically significant differences between ε_{total} means (p<0.05).*

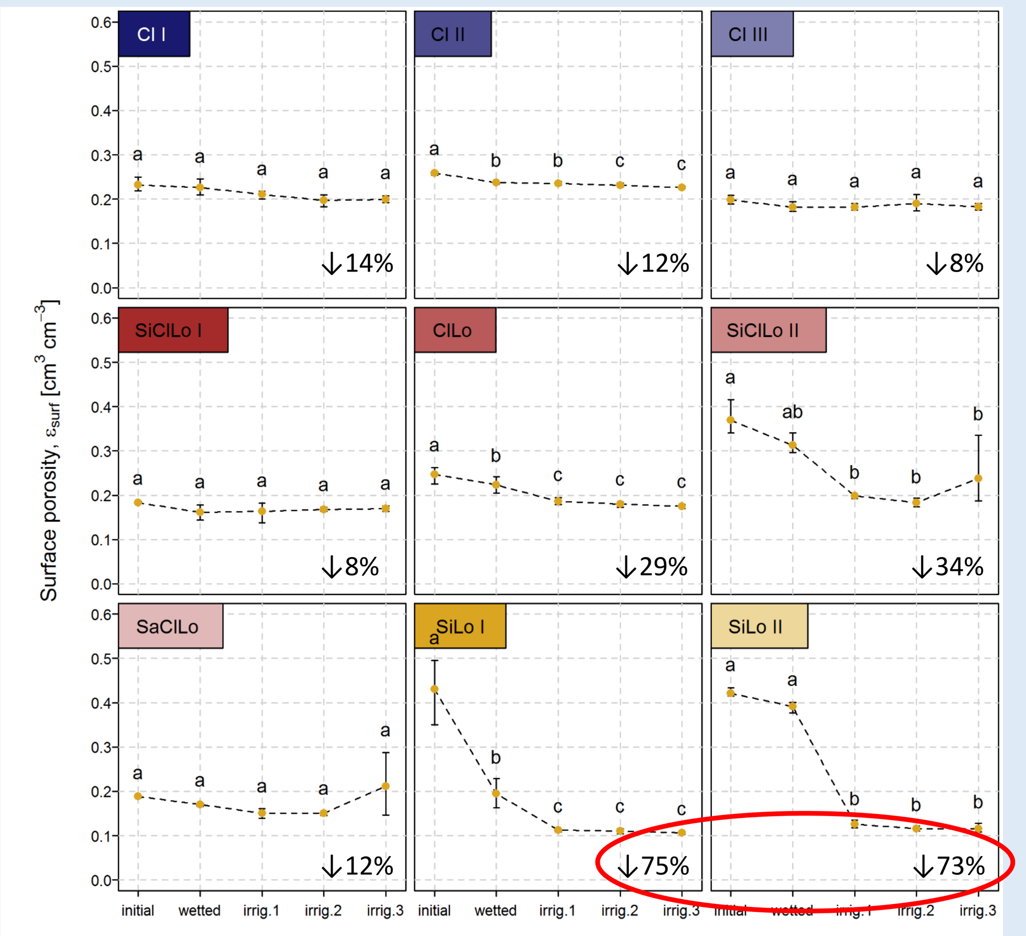


Figure 4*. Evolution of imaged porosity in the uppermost millimeter of the soil surface (ε_{surf}) in the nine investigated soils. Different letters indicate statistically significant differences between means (p<0.05) and the bars show the measured range.*

Changes in the connectivity of imaged pore networks

- Pore network connectivity was evaluated by the connectivity probability Γ (Renard & Allard, 2011; eq. 1) and the percolating fraction f_{perc} (eq. 2)

$$\Gamma = \frac{1}{{n_p}^2}\sum_{i=1}^{N} {n_i}^2 \qquad \text{(eq. 1)}$$

$$f_{perc} = \frac{\sum n_{i(perc)}}{n_p} \qquad \text{(eq. 2)}$$

N number of individual pore clusters *i*
n_i volume of pore cluster *i*
n_i volume of percolating pore cluster *i*
n_p total pore volume

- Connectivity of pores >60 µm decreased in the two clay soils Cl II and Cl III and the clay loam soils SiClLo I, ClLo and SiClLo II.
- Both connectivity measures were strongly correlated with imaged porosity.

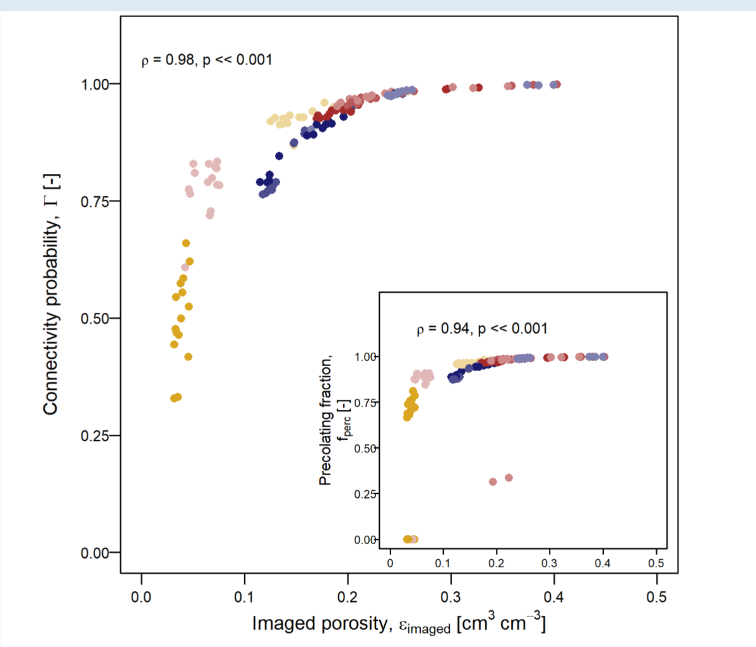


Figure 5*. Relationship between imaged porosity (ε_{imaged}) and the connectivity probability (Γ). Inset shows the corresponding relationship for the percolating fraction (f_{perc}) which was also significantly correlated with Γ (r = 0.75, p <<0.001).*

Effects of soil texture and organic carbon content on changes in total and surface porosity

- The changes in surface porosity were strongly and negatively correlated with silt content (r = -0.81, p = 0.009).
- Changes in total porosity, after wetting and after three irrigation cycles, respectively, were only weakly correlated with any of the variables reflecting soil texture and organic carbon content.
- The strongest correlations were found with the silt to organic carbon ratio and the clay content, respectively (r = -0.64 and 0.59, 0.05<p<0.1).

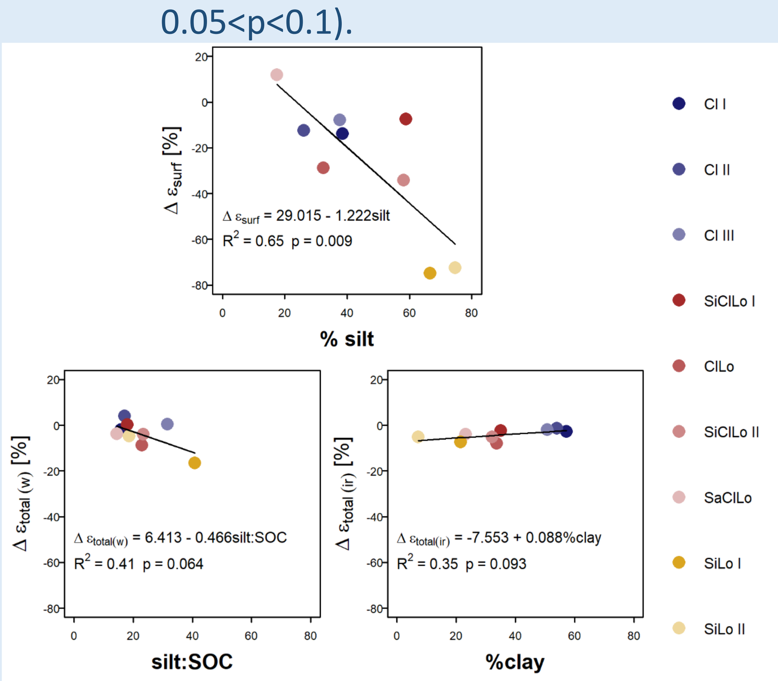


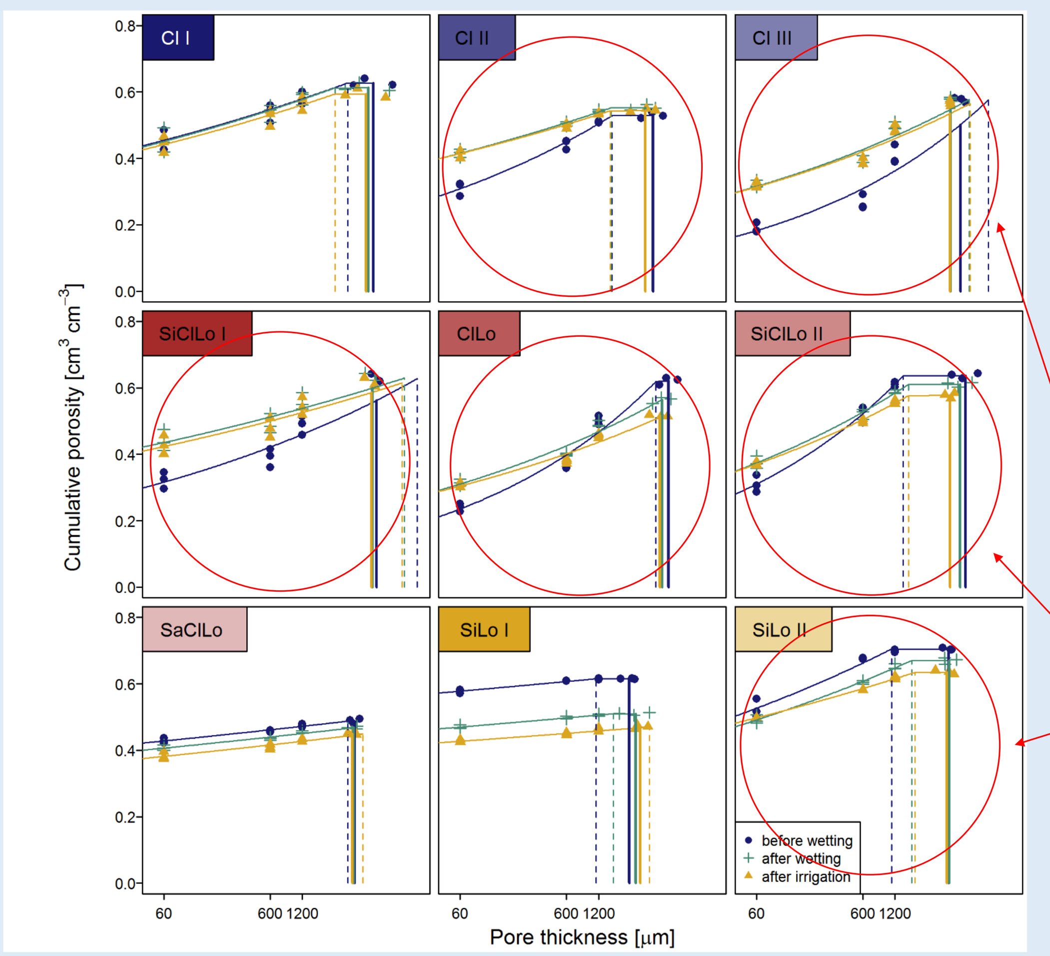
Figure 6*. Linear relationships between changes in surface porosity ($\Delta\varepsilon_{surf}$, top) and total porosity after wetting ($\Delta\varepsilon_{total\ (w)}$, bottom left) and after three irrigations ($\varepsilon_{total\ (ir)}$, bottom right) and the most strongly correlated soil particle size and SOC variables.*

Modelling post-tillage structural evolution

A power law model (eq. 3) similar to Campbell's (1974) equation for the soil water retention curve was fitted by least-squares regression to the pore size distribution data (R^2 0.86 to >0.99, 0.99 on average).

$$V_f = \left(\frac{d}{d_{max}}\right)^{\lambda} \qquad \text{(eq. 3)}$$

V_f volume fraction < pore thickness d
d_{max} maximum pore thickness
λ exponent reflecting the spread of the pore size distribution



Decreasing slope = decreasing λ = decreasing proportion of larger structural pores

Figure 5*. Equation 3 fitted to the pore size distributions of the nine investigated soils before wetting, after wetting and after three 4-hour irrigations events. Solid vertical lines indicate the measured maximum pore thickness (mean of three replicates) and dashed vertical lines mark the estimated maximum pore thickness.*

CONCLUSIONS

- Repeated cycles of wetting and drying led to changes in surface and total porosity, the pore size distribution and the connectivity of large structural pores in repacked samples of recently harrowed fine- and medium-textured soils.
- Decreases in surface porosity were strongly correlated with soil silt content whereas only weak correlations were found between changes in total sample porosity and texture and soil organic carbon content.
- The exponential model fitted to the pore size distribution generally described the data well, suggesting that post-tillage structural changes could be modelled as changes in total porosity, the slope of the pore size distribution curve and the maximum pore diameter.
- A larger number of soils than the nine investigated in the present study would need to be examined in order to determine whether the magnitude of these changes can be predicted from basic soil properties such as soil texture and SOC.

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References
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