Characterization of soil structure and water infiltration spatial variability using electrical resistivity tomography at decimetre scale. A study of two contrasted soil tillage modalities

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Abstract
Simplification of tillage practices is often considered as a solution for reducing time constraints and costs, and also for limiting soil erosion. Simplified tillage practices adopted over several years progressively induce modifications of soil physical properties in the top soil layer at decimetric scale. The general aim of this study was to test the capacity of electrical resistivity tomography to characterize the spatial variability of soil structure, bulk density and water flow in a loamy Cambisol with two modalities of tillage (conventional tillage, no tillage). For each tillage treatment, the experiment combined: 1) a description of the soil structure profile, 2) measurements of bulk density and soil hydraulic conductivities; 3) 2D electrical resistivity tomographies measured before and after an irrigation to characterize the spatial variability of soil water fluxes. These geophysical data are correlated to the spatial variability of soil structure and hydrodynamics properties.

Key Words
Electrical resistivity tomography, bulk density, hydraulic conductivity, structure, tillage.

Introduction
Agricultural soil structure evolves in space and time with tillage practices, climate and crop growth. Simplified tillage practices were adopted by farmers for several reasons: i) reduce their production costs, ii) increase the organic matter content in the top soil layer; iii) increase the soil structural stability to limit soil erosion. These new practices induced changes in soil structure and soil physics properties in the cultivated horizon at decimetric scale. The description of soil structure spatial variability is usually based on soil profile observations, soil properties measurement as bulk density and porosity. Moreover, water infiltration depends on soil structure. Tools actually available to study soil structure or water flow in soil are limited by their point-to-point measurement. They are also generally destructive. The geophysical methods are non invasive. They disturb neither the structure nor the water dynamics of the soil. Recent papers showed the relevance of electrical resistivity prospecting to detect some structural heterogeneity of the tilled soil (Seger *et al.* 2009; Besson *et al.* 2004) or to detect soils cracks that form during shrinking and swelling phenomena (Samouëlian *et al.* 2004). Besson *et al.* (2004) linked soil electrical resistivity changes with bulk density variations. Moreover, Michot *et al.* (2003) have shown that water infiltration could be monitored in space and time using electrical resistivity tomographies. The aim of this work was to test the efficiency of 2D electrical resistivity tomography (ERT) to characterize the spatial variability of soil structure, bulk density and water infiltration of a loamy Cambisol according to two different tillage modalities (conventional tillage, no tillage).

Methods
The experiment was conducted on the experiment site of Kerguéhennec (Morbihan, France). The soil was a pebbly loamy Cambisol developed on a micaschist. Two plots were studied : i) a plot with a conventional tillage until 25 cm depth realized 18 month before; ii) a plot with zero tillage for 8 years. The experimental setup is presented in Figure 1. It is composed of a row of 64 electrodes lined up at the soil surface with a spacing of 10 cm. The measurements were realised by a multielectrodes system. The electrodes were connected to 4 multinodes linked to a Syscal R1 resistivimeter (Iris Instruments) and numerous measurements were performed rapidly thanks to a pre-recorded sequence of quadripoles with a dipole-dipole array. ERT were measured before and after irrigation by sprinkling. Simultaneously, hydric potential profiles, soil water electrical conductivity, soil temperature and irrigation inputs were measured. Each measured resistivity section was inverted with RES2DINV software (Loke and Barker 1996). Water infiltration was monitored by electrical resistivity changes, *i.e.* soil electrical resistivity decreases when the soil water content increases, and vice versa. After ERT measurements, soil structure was described along a 6m long soil profile.

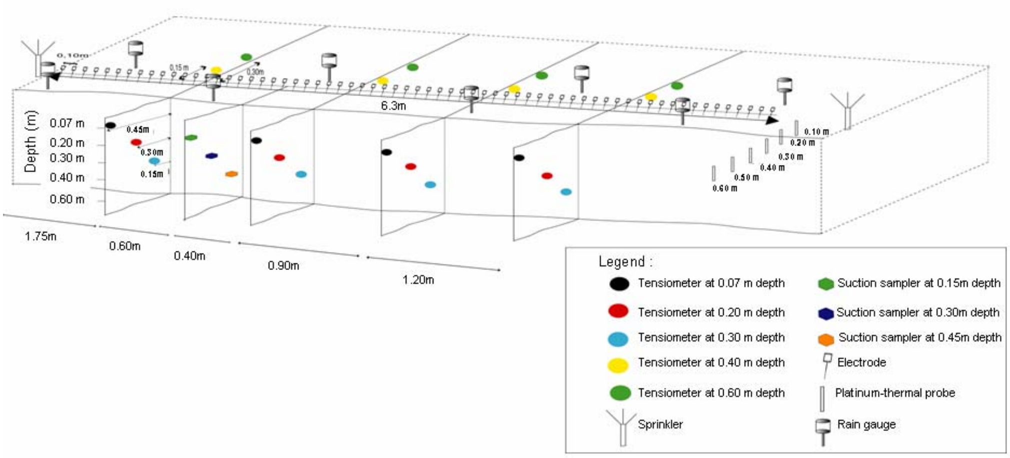

Figure 1. Experimental setup of water flow monitoring by 2D electrical resistivity tomography.

Structural and hydrodynamic properties were also characterized with bulk density and hydraulic conductivity measurements to be compared with electrical resistivity results. Hydraulic conductivity K(h) was measured using infiltrometer « decagons » (Soils Physics Instruments Decagon Devices, Washington, USA) at 3 water potentials at - 0.05, - 0.2 and - 0.6 kPa.

Results

First results indicate that conventional tillage modality induced higher spatial variability of top soil soil structure, soil bulk density (Figure 2) and hydraulic conductivity at -0.05 kPa and -0.20kPa hydric potentials (Figure 3), than the no tillage modality. From soil surface to 5 cm depth, hydraulic conductivities values were significantly higher for the conventional tillage treatment than for the no tillage treatment. Globally, the no tillage modality showed a general phenomenon of settling of the top soil layer with higher bulk density and lower hydraulic conductivity at water potentials of -0.20 hPa (Figures 2 and 3) by comparison with conventional tillage.

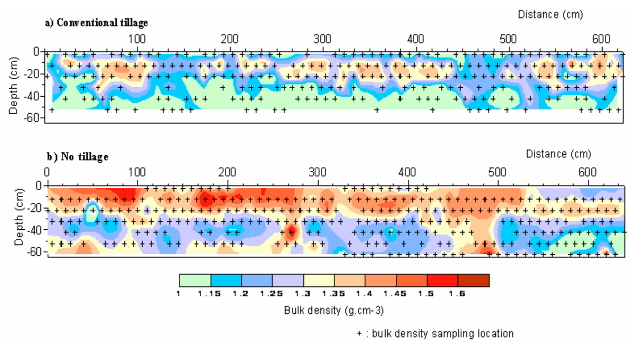

Figure 2. Maps of soil bulk density for the two tillage treatments: a) for conventional tillage treatment; b) for no tillage treatment.

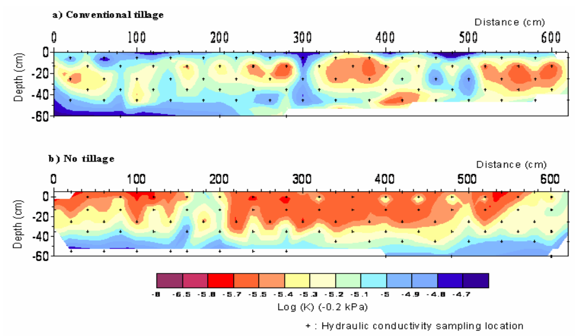

Figure 3. Maps of hydraulic conductivity at -0.20 kPa hydric potential: a) for the conventional tillage treatment; b) for the no tillage treatment.

Electrical resistivity changes (Figure 4) are clearly linked to water infiltration according to hydric potential gradients in the whole profiles for both modalities. But, for the no tillage modality, we observed some lower decrease of electrical resistivity in the top soil layer. These data will be compared to the spatial variability of soil structure and hydrodynamics properties.

Conclusion

Cultivated soil profiles present spatial heterogeneities of physic and structural properties which explain water flow variability at soil profile scale. Electrical resistivity tomographies could be a help to characterize the spatial variability of soil structure and water infiltration without disturbing the soil. The results of the individual applied methods complement each other. The geophysical data will be confronted to the spatial variability of soil structure and hydrodynamics properties measured with conventional methods.

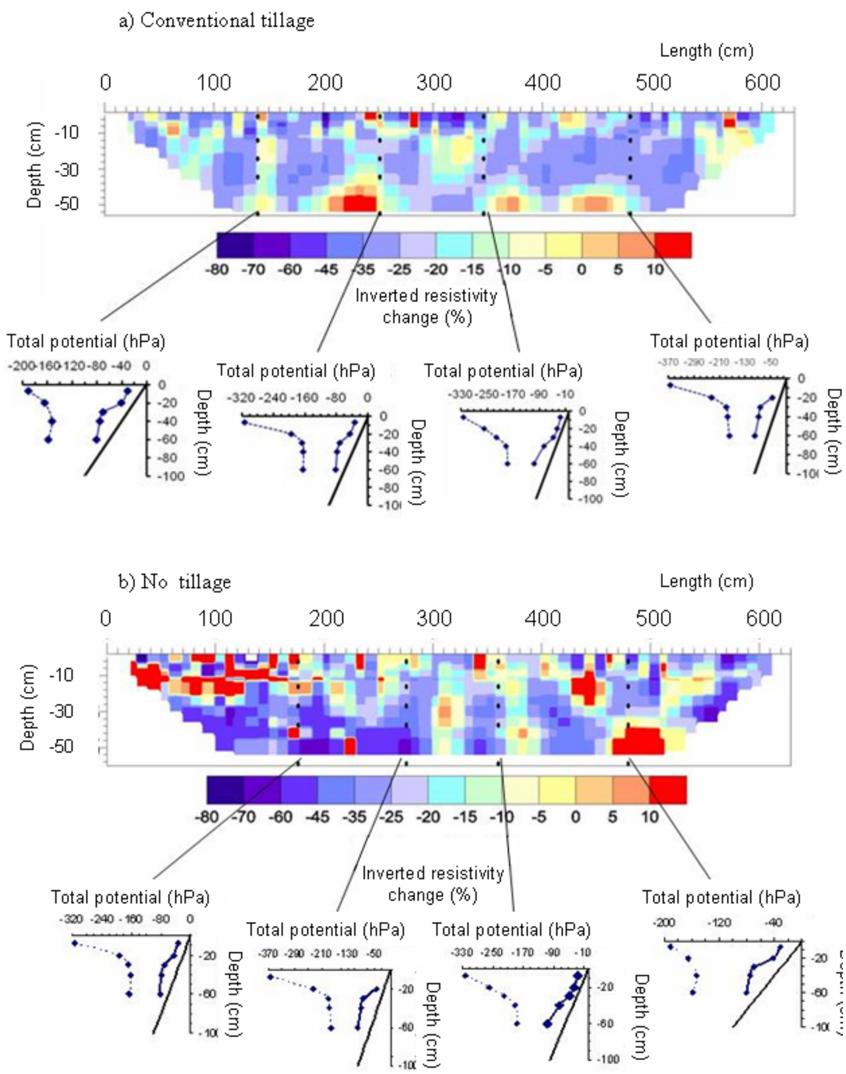

Figure 4. Soil section of relative resistivity changes measured over time during the soil wetting phase after irrigation: a) for conventional tillage treatment; b) for no tillage treatment.

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