Spectral induced polarization response of soil organic matter

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The spectral induced polarization (SIP) method is increasingly used for the exploration of the subsurface in numerous hydrological and environmental applications. Since the early use of the SIP method a tremendous progress in the understanding of the mechanisms that govern the SIP response of porous media was achieved. Many models that explain the relations between the SIP signature of soil and the soil physical and physicochemical properties were developed (e.g. electrochemical and membrane polarization models). All these models predict that soil polarization is dependent on the surface charge (often measured through the cation exchange capacity, CEC), and that increase of the surface charge will result in an increase of the soil polarization. While these models were calibrate/validate for mineral soil, to the best of our knowledge the effect of soil organic matter (SOM), which although relatively small in volume/weight significantly contribute to the surface charge, on the SIP signature of soil was not directly studied.

Here, we report experimental evidence that demonstrate the impact of SOM on the SIP response of soil. The experiment includes SIP measurements of sandy soil with negligible amount of organic matter, and a mixture of natural organic matter with the same soil. The experiment procedure can be summarized as follow:
(1) air dry soil were mixed with different amount of air dry organic matter (0, 0.1 and 1 % w/w);
(2) water (10 % w/w) was mixed with the dry material using a kitchen mixture for 10 minutes;
(3) a constant amount of soil was packed in a glass box of known volume (271 cm^3), resulting in a consistent water saturation between the samples ($S_w = 43.7$);
(4) five days after the packing, SIP measurements (10 mHz – 10 kHz) of all the samples (triplicate for each treatment) were taken using four non-polarized electrodes.
In addition to the electrical measurements, the composition of the soil solution, the cation exchange capacity and the exchangeable cation composition were determined.
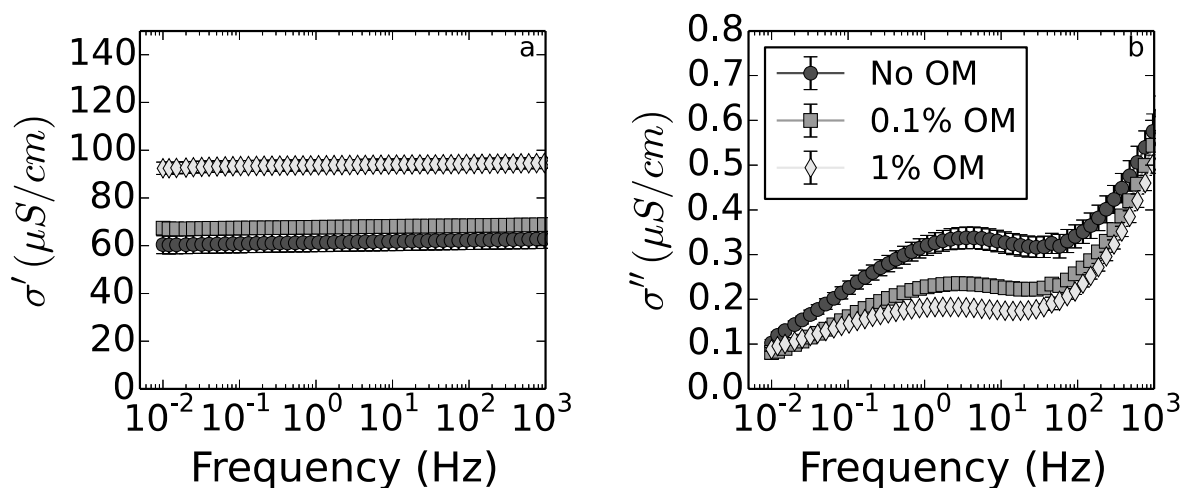

Fig. 1: Mean values and standard deviation (error bar) of the in phase (a) and quadrature (b) conductivity for the three treatments (no organic matter, 0.1 % w/w and 1 % w/w). Note the decrease in relaxation frequency with increasing OM content.

The mean values of the in-phase and quadrature conductivities for the different treatments are shown in Figs 1a and 1b, respectively. The results show that addition of 0.1 % OM to the soil did not significantly change the in-phase conductivity, while addition of 1 % OM resulted in an increase (~60 %) of the in-phase conductivity. The increase of the in-phase conductivity is explained by the presence of soluble salts in the organic matter. Interestingly, addition of organic

matter to the soil resulted in a significant decrease of the soil quadrature conductivity (a measure for the soil polarization) and relaxation frequency (see Fig. 1b). A decrease of ~43 % and ~87 % at 3.5 Hz in the quadrature conductivity for the soil containing 0.1 % and 1 % OM, respectively, was observed. In addition, the relaxation frequency decreases from 1.66 Hz for the 0 % treatment to 1.48 Hz for the 0.1 % treatment and to 0.88 Hz for the 1 % treatment.

The decrease in polarization for soil containing organic matter is not trivial. That is as the CEC of the added OM (103 meq / 100 g) is much higher than the CEC of the soil (2.5 meq / 100 g) and therefore, naively we would expect to see an increase of the soil polarization. To explain the decrease in the soil polarization due to the addition of OM, the interactions between OM and the soil mineral surface is needed to be considered. Interactions between OM and mineral surface can occur, for example through metal bridge, hydrogen bonds, van der Waals interactions and exchange process between natural organic cation and metal cation. These processes are expected to increase the binding energy between the metal cations and the mineral surface, which can explain the observed decrease in polarization and relaxation frequency. Indeed, increase in the binding energy means lower mobility of the metal cation on the soil mineral surface, results in a decrease of polarization and relaxation frequency, as observed in this study.