Università degli Studi di Padova
DAFNAE Dipartimento di Agronomia Animali Alimenti Risorse naturali e Ambiente
Dipartimento di Geoscienze
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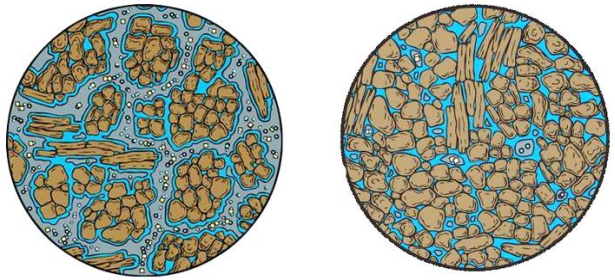
SOIL COMPACTION IMAGING THROUGH PEDOPHYSICAL JOINT INVERSION: A NORTHEASTERN ITALY CASE STUDY

Alberto Carrera[1], Mirko Pavoni[2], Ilaria Piccoli[1], Jacopo Boaga[2], Giorgio Cassiani[2], and Francesco Morari[1]

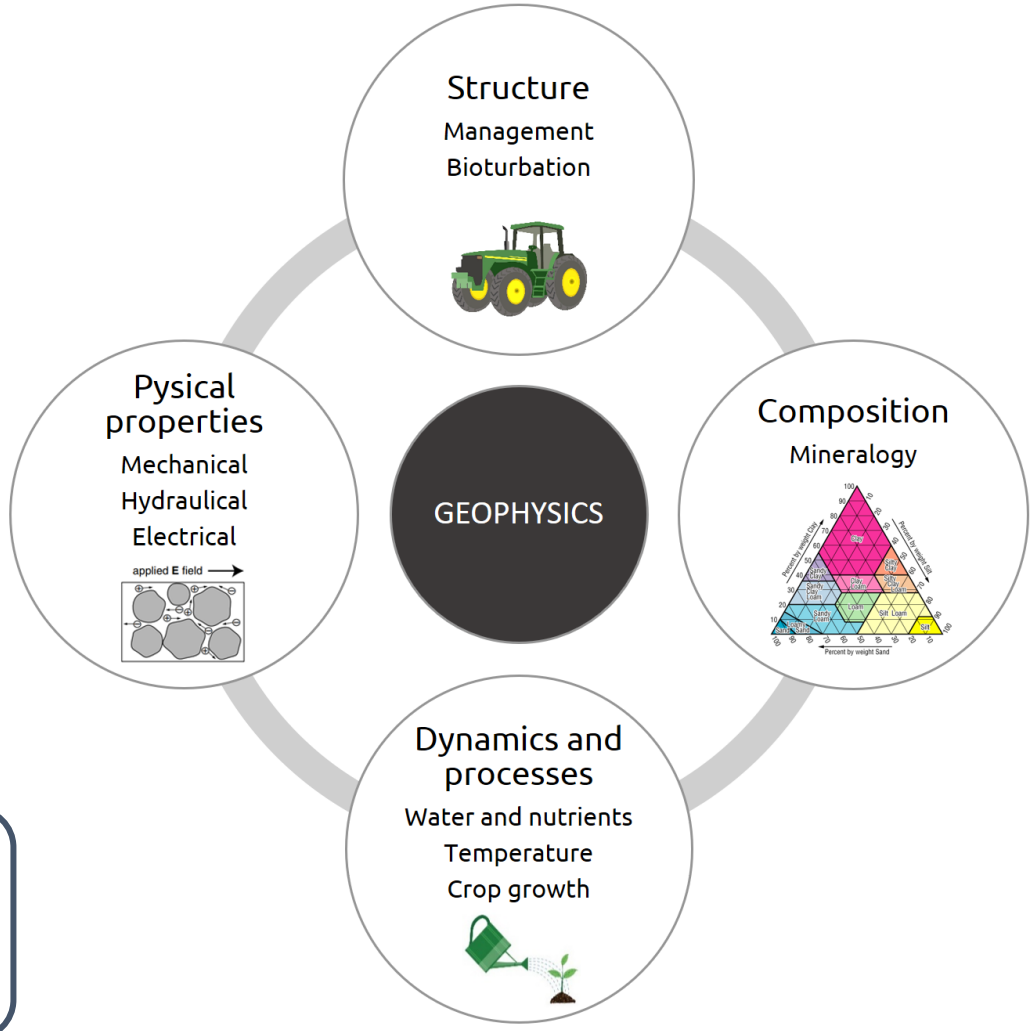
[1] DAFNAE Department, University of Padova, Legnaro, Italy
[2] Department of Geosciences, University of Padova, Padova, Italy

Introduction

Good soil Compacted soil



Lower	Bulk density	Higher
Lower	Weight	Higher
Higher	Pore space	Lower



Key motivation for this preliminary study is to achieve the quantitative estimation of the investigated soil phases (e.g., air and water fractions) in a non-invasive way and to characterize compacted subsoil structures

From Petrophysical to Pedophysical Joint Inversion (PedJI)

- Stems from the four-phase model (4PM) developed by Hauck et al. (2011)

- System represented by a three-phase model (3PM)
(removal of ice-related terms from the 4PM)

$$f_w + f_a + f_r = 1$$

- The electrical conductivity is described based on Archie's second law (Archie et al. 1942), relying on electrolytic conduction

$$\rho = a\rho_w \phi^{-m} S_w^{-n}$$

- The seismic slowness of the system find its basis on the Wyllie's law (Wyllie et al. 1956) and it is described as

$$s = \frac{1}{v} = \frac{f_w}{v_w} + \frac{f_r}{v_r} + \frac{f_a}{v_a}$$

- Independent geophysical inversions and 3 phase medium equation

f_w	Volumetric water content	v_w	Water seismic velocity
f_a	Volumetric air content	v_a	Air seismic velocity
f_r	Volumetric rock content	v_r	Matrix seismic velocity
a	Tortuosity factor	n	Saturation exponent
m	Cementation exponent	P_w	Pore water resistivity
ϕ	Porosity	S_w	Water saturation

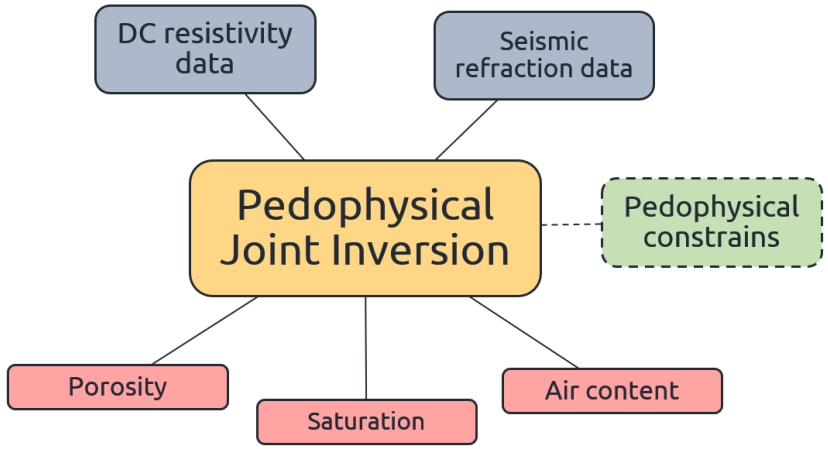
Model implementation (PedJI)

- Relies on the petrophysical joint inversion (PJI) developed by Wagner et al. (2019), modified to meet the equations of the 3PM

- The PJI framework works in python environment employing the modeling capabilities of pyGIMLi library (Rücker et al., 2017)

- We integrated a surface conduction factor within the Archie's law, as developed by Mollaret et al. (2020), to account for surface conduction processes which occur in agricultural soils

$$\rho = \frac{\rho_w}{1 + \varepsilon \rho_w} (1 - f_r)^{-m} \left(\frac{f_w}{1 - f_r}\right)^{-n}$$



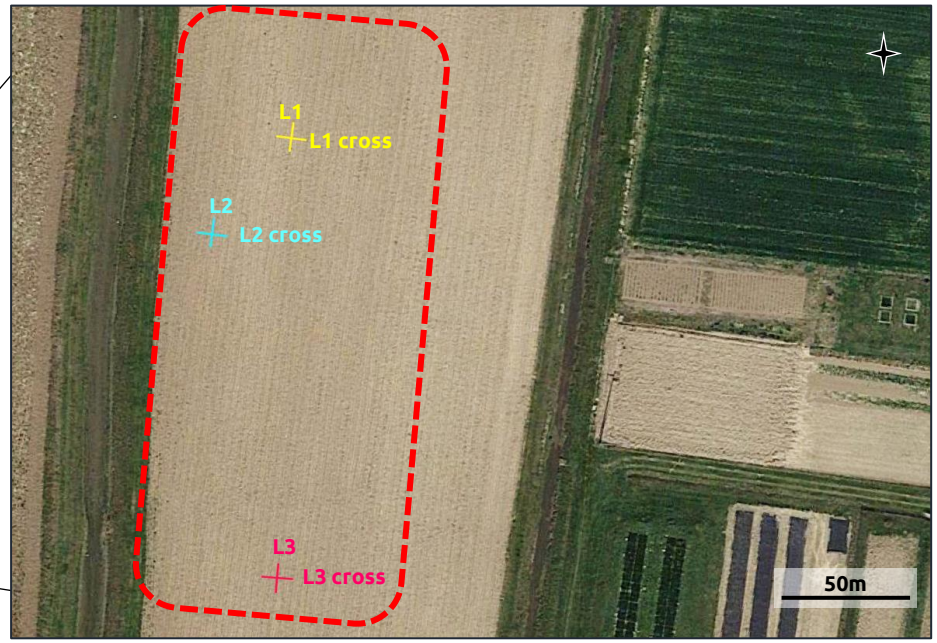
pyGIMLi

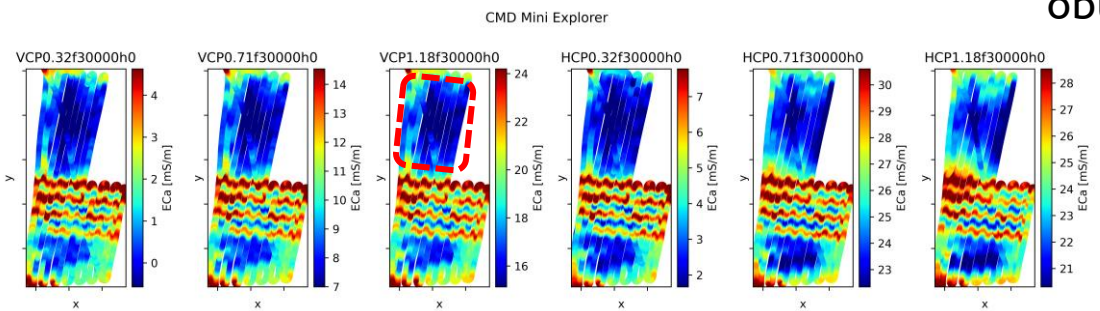
Data Acquisition

L.Toniolo experimental farm

- Sandy and silty loam
- Mainly arable land
- Rainfed irrigation
- Mineral fertilization

Legnaro, NE Italy
45°21'9.00"N 11°57'3.53"E



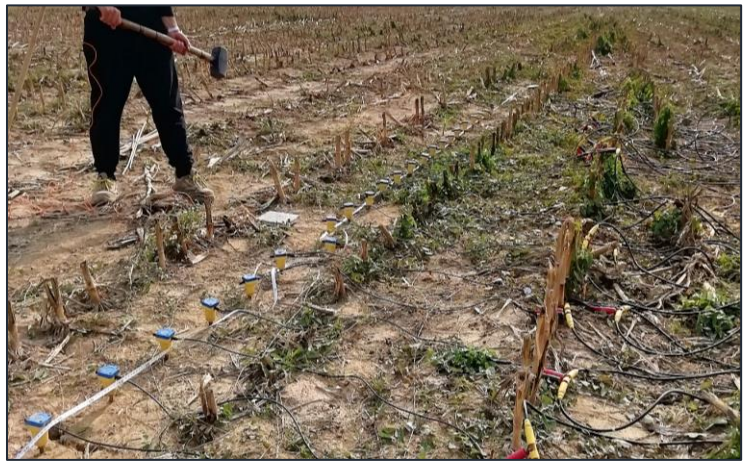


- We characterized the field through FDEM technique in order to select homogeneous ECa areas for the surveys
- We collected electrical and seismic datasets along three couples of orthogonal profiles, following and crossing maize rows
- We validated the model outcomes by direct Penetration Resistance measurements
- Here we will focus on the results obtained from lines L1 and L3cross

Data Acquisition

Refraction Seismic Tomography

- Equipment
  - Geode by Geometrics
  - 24 geophones of 4.5Hz (0.25m spacing)
  - 8kg sledgehammer
- Mesurements
  - shot points located between geophones + offset shots 1 m before and after the line
  - three hammer blows stacked to improve S/N ratio



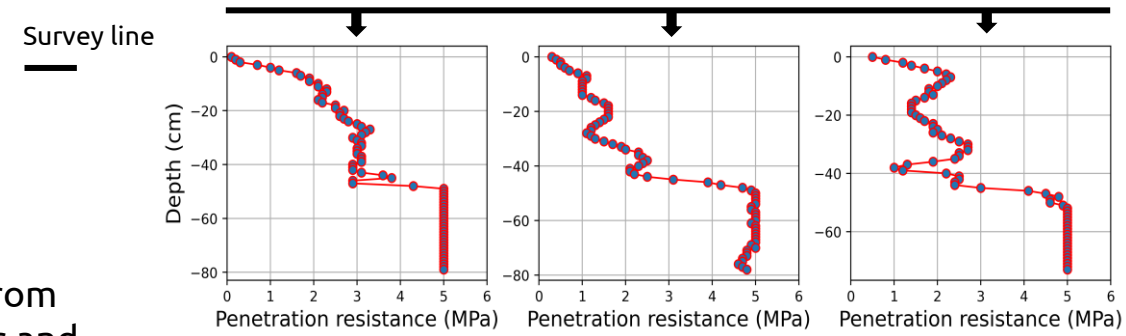
Electrical Resistivity Tomography

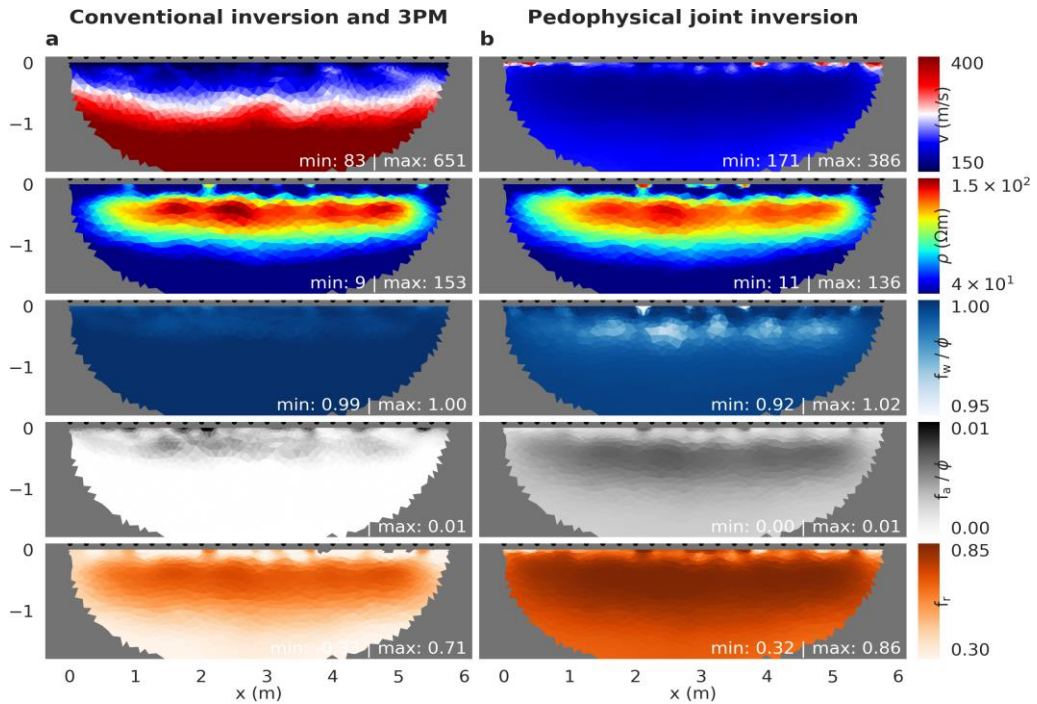
- Equipment
  - IRIS Instruments Syscal Junior
  - 24 stainless steel electrodes (0.25m spacing)
- Mesurements
  - optimized dipole-dipole skip0 configuration (with reciprocals)

Results

L1: Compacted structure

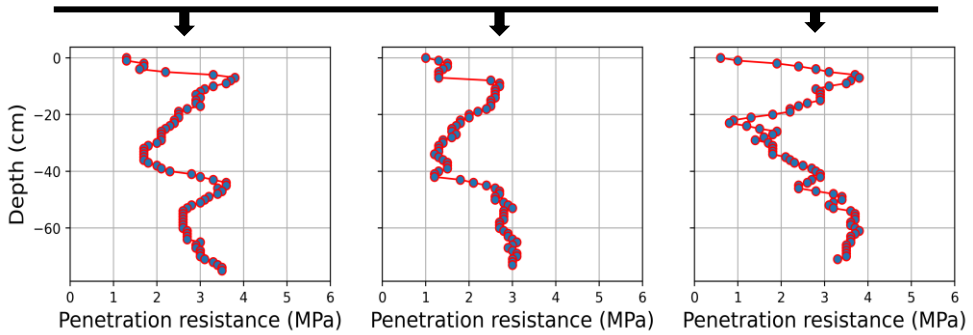
- The compacted plowing sole in depth can be delineated from the resolved water, air and matrix content for both models and confirmed by direct penetration measurements.
- Since the 3PM does not take into account the surface conductivity, we obtain a misleading soil phases estimation
- The 3PM seismic outcome highlights the refraction interface of the compacted structure, instead the PedJI seismic model detects it as a slow structure: the water content and its velocity play a stronger role than the increase in bulk density





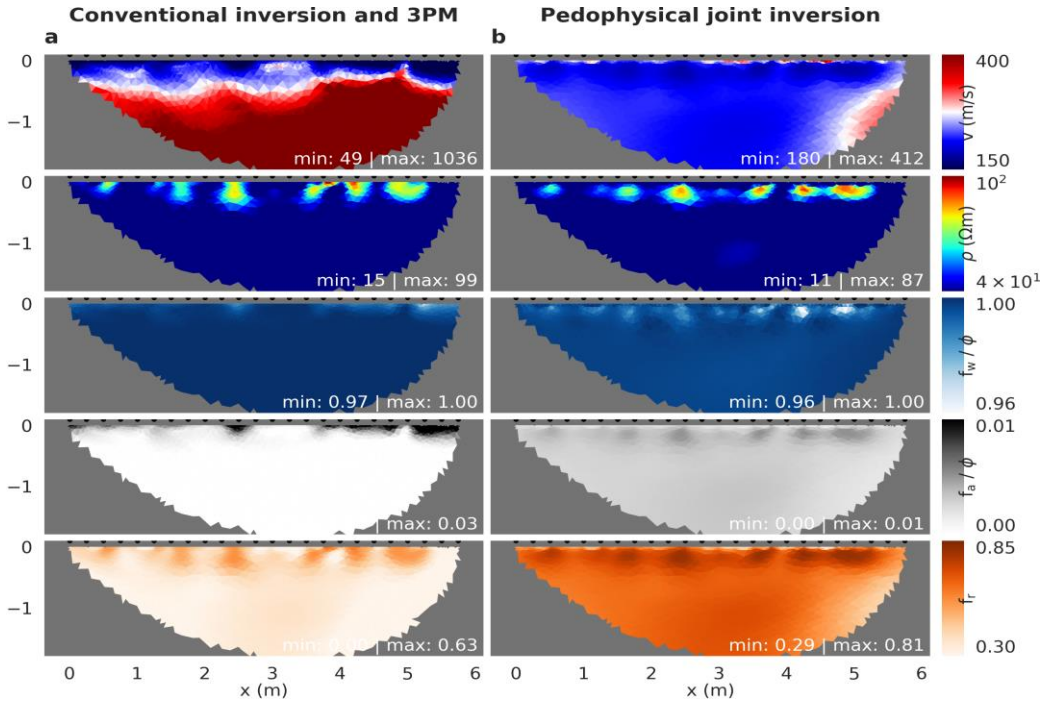
Results

Survey line



L3 cross: Shallow tractor footprints

- The superficial compacted tractor footprints can be delineated from the resolved water, air and matrix content for both models
- Since the 3PM does not take into account the surface conductivity, we obtain a misleading soil phases estimation
- The 3PM seismic outcome shows superficial heterogeneities with higher Vp, with a general increase of velocities with thickening in depth
- The PedJI seismic model still detects compaction as a slow structure



Outlook

Choose the correct pedophysical model

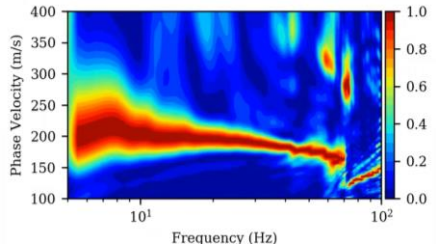
- test and implement a more correct pedoelectrical relationship inside the model accounting for surface conduction

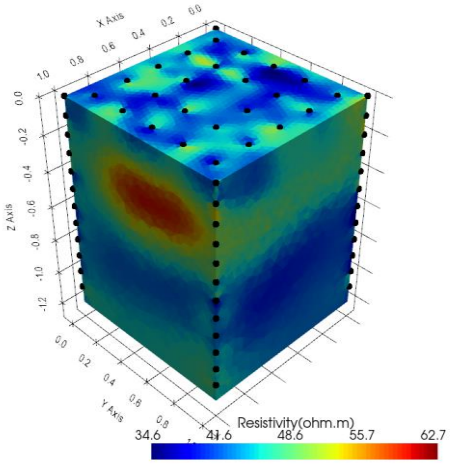
Recreate a field laboratory

- set up a controlled environment to reconstruct the soil compaction
- relate geophysical response with direct variable measurements (e.g. humidity, temperature, bulk density, penetration resistance)
- try different acquisition equipment and parameters (e.g. small and light seismic source, high freq geophonnes)

Further code and functionality implementations

- use of surface waves to investigate the soil matrix without the influence of fluids
- from 2D to 3D





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THANKS

alberto.carrera@phd.unipd.it

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