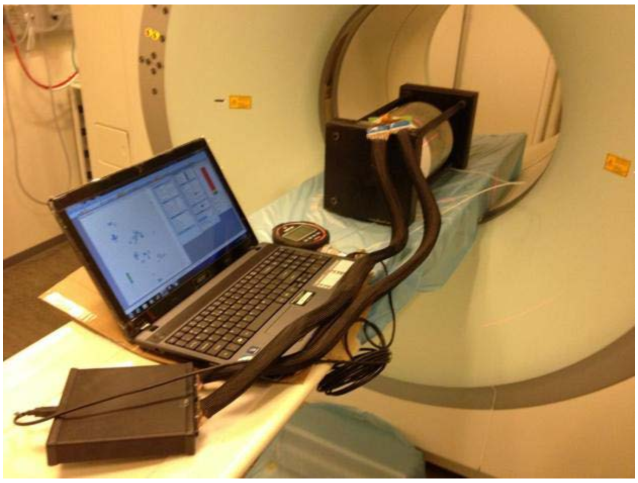
Project summary

Most research on soil compaction and its influence on soil functions rely on the assumption of soil being a homogenous elastic material. Attenuation of stresses applied to an elastic material is easily described based on the loaded area and the stress distribution in that area. However, agricultural soils, and in particular regularly tilled topsoils, are very heterogenous. In the StressSoil project, we wanted to acknowledge these material properties and elucidate stress transmission, soil failure and the resulting impacts on soil functions without a priori assumptions. We hypothesized that mechanical strength of agricultural soils shows a scale-dependency related to soil structural units. This would mean that inter-aggregates bonds and aggregate strength are crucial in understanding the stress transmission patterns through agricultural soils as well as deformation. We formulated three hypotheses at the beginning of the StressSoil project: (i) inter-aggregate bonds are the relevant soil mechanical parameters for the definition of the soil failure criterion; (ii) inter-aggregate bonds follow a continuous probability distribution integrating their scale dependency; (iii) the parameters of the probability distribution describing mainly cohesion and friction will enhance the prediction of soil compaction.

In the following, we refer to publications produced as part of the investigations (please consult list of publications).

We performed controlled experiments in the laboratory as well as field experiments, we developed a distinct element model and performed simulations to test our hypotheses. Methodological aspects needed particular attention during the project to ensure the use of state-of-the-art methods and accurate measurements in the field (Keller et al., 2013; Lamandé et al., 2015). Results from controlled experiment in the laboratory on undisturbed topsoils, subsoils and beds of dry and wet aggregates confirmed that heterogeneity of structure in topsoils have a large influence on stress transmission (Naveed et al., 2016), see Figure 1. We found that the stress transmission pattern of tilled topsoil is similar to what was observed for a bed of aggregates. These results helped understanding why stress transmission as characterized in the field did not follow the elasticity theory for the top of the soil profile but did for the subsoil (Keller et al., 2014; Messmer, 2014; Lamandé and Schjønning, 2018). We chose to address the scale-dependency of soil strength through aggregate tensile strength measurements and uniaxial confined compression tests.



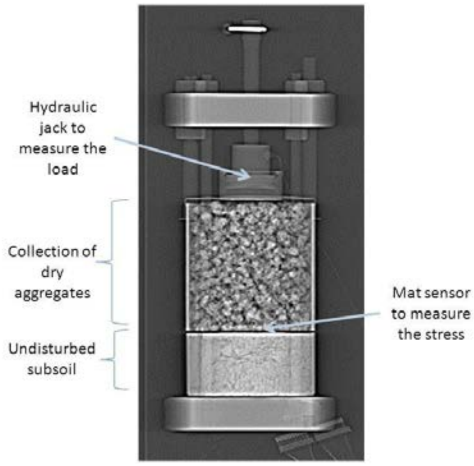


Figure 1. Experimental setup in laboratory studies. Left: Core with collection of soil aggregates analyzed by X-ray CT. Right: Stress application to bed of aggregates situated on a stress sensor mat monitoring transmitted stress through the sample.

We showed that scale dependency of agricultural soil strength depends on agricultural management practices (organic matter amendment, tillage and traffic; Abdollahi et al., 2014). Through tensile strength measurements and distinct element model simulations, we established that inter-particle bonds followed a Weibull distribution integrating their scale dependency. The multi-scale character of the strength of soil structural units lead us to develop a new methodology for better estimation of the soil failure criterion related to field traffic (Lamandé et al., 2017). This failure criterion was tested in field experiments, where we evaluated the effects of a range of applied stresses on various soil functions (Schjønning et al., 2013; 2016; 2017). For these field experiments, applied stresses were either predicted using a model system developed during the StressSoil project (Schjønning et al., 2015) or measured (Lamandé and Schjønning, 2018) using the field method validated during the project (Lamandé et al., 2015). The results from the tests of the failure criterion lead us to the development of a pedo-transfer function to predict strength of agricultural soils in relation to traffic in the field from their intrinsic properties (Schjønning and Lamandé, submitted). In parallel, some new aspects of the stress-strain behavior of agricultural soils were explored using a distinct element model that was developed during the project. 2D simulations were performed to compare stress transmission and deformation for an idealized distinct element soil where soil strength followed a classical uniform or a Weibull distribution. Implementation of the distinct element model for stress-strain relationships in the topsoil in the Terranimo® decision support tool could not be done during the StressSoil project. Finally, we co-organized an international workshop to demonstrate and discuss how field methods for qualitative description of soil structure could supply classical soil physics methods to better understand, describe and model the mechanical behavior of agricultural soils (Guimarães et al., 2017ab).

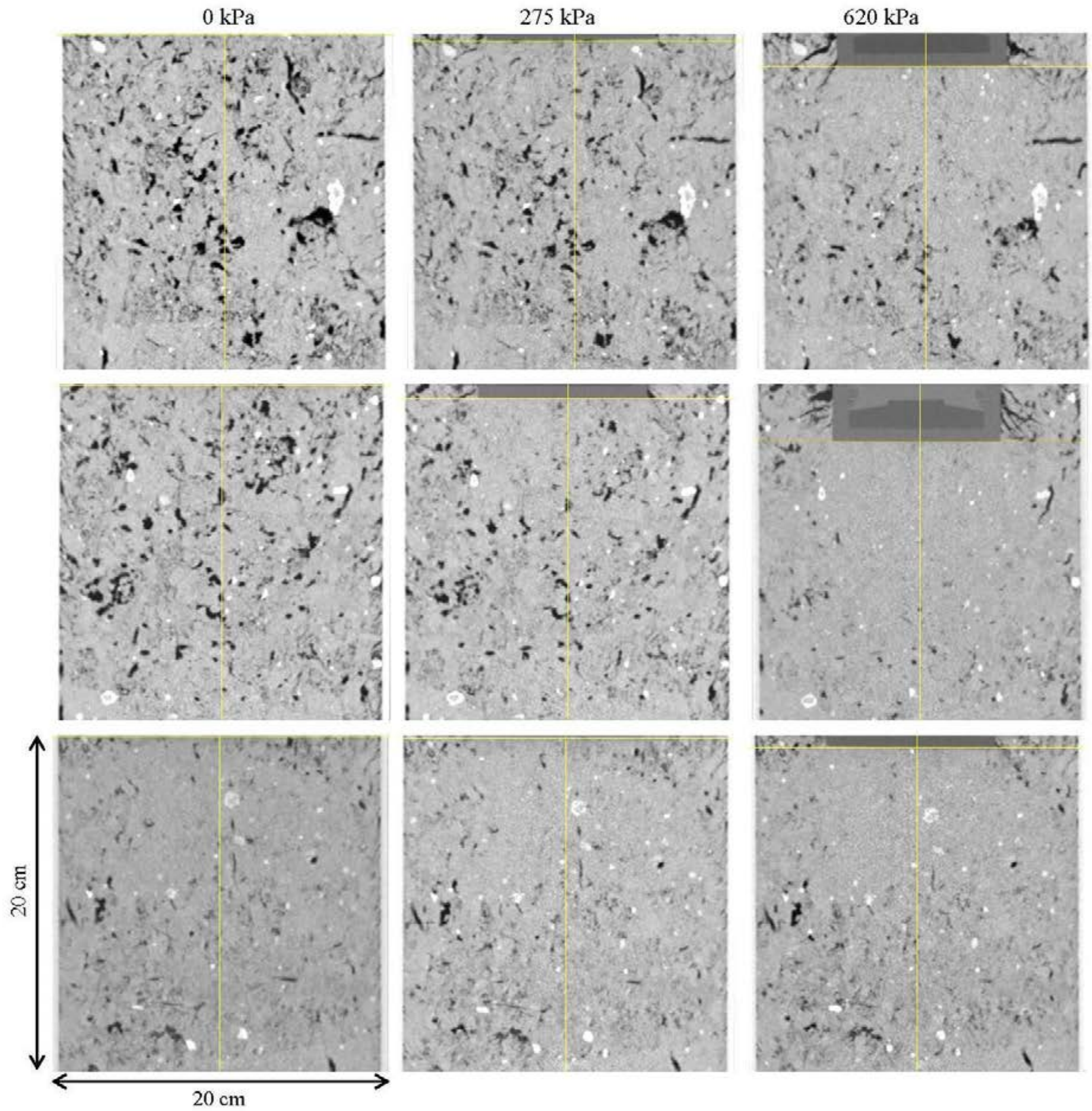


Figure 2. Images from X-ray CT of intact topsoil columns (20cm diameter and 20cm height) submitted to partially confined uniaxial compression tests. Three different samples with decreasing initial bulk density from top to bottom at three loads (0 kPa; 275 kPa; 620 kPa) are presented here. The horizontal yellow line shows the depth of the lower face of the piston used to apply the load. From Naveed et al. (2016).

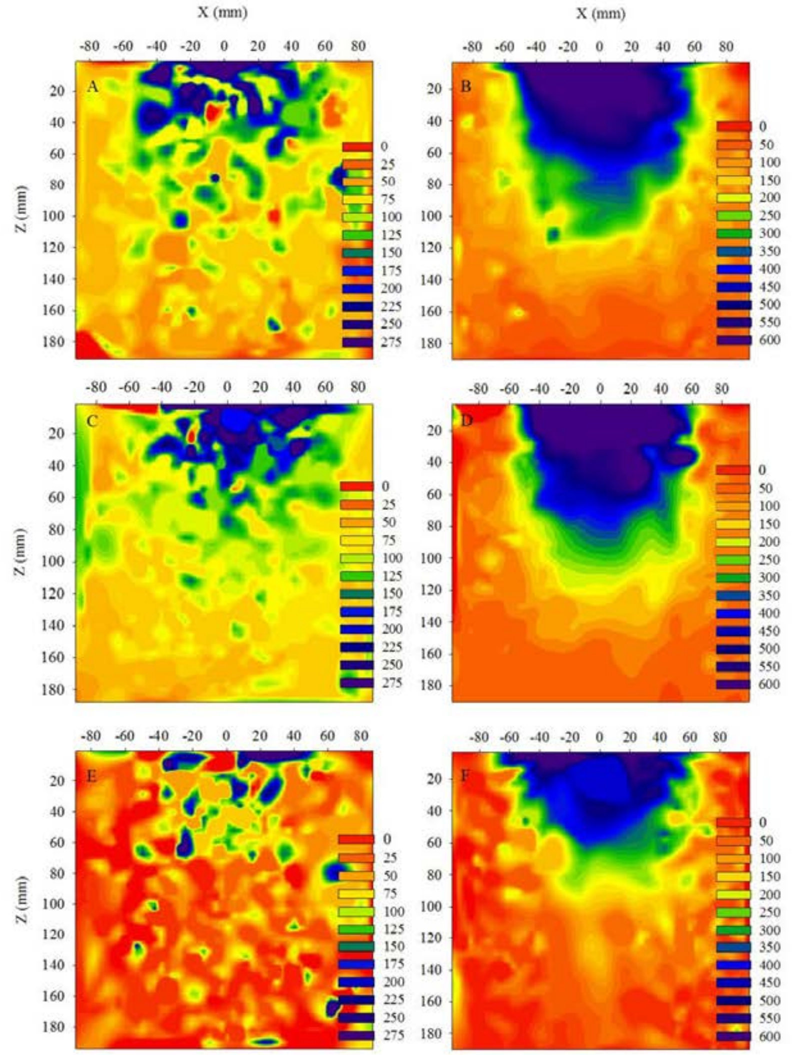


Figure 3. Stress transmission patterns (with stress in kPa) within the three topsoil columns at two loads: 275 kPa on the left; 620 kPa on the right. Stress were calculated from the measured strain of stones using X-ray CT for each load. Discrete stress transmission patterns through topsoil are observed at 275 kPa applied stress (left), whereas elastic stress transmission patterns (stress isobars) are observed at 625 kPa applied stress (right). From Naveed et al. (2016).