Macropore-network evolution in a garden soil

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Summary: The quantitative evolution of the soil macrostructure and root distribution in a Swedish garden was investigated in the course 25 months using 3-D X-ray imaging. The results indicate that the soil macrostructure evolution was dominated by biotic factors and that soil saturated hydraulic conductivity may fluctuate by at least two orders of magnitudes within a few months.

1. INTRODUCTION

The majority of soil system models assume temporally stable soil physical properties at scales of months and years. Several studies have meanwhile demonstrated that this is not true since the soil macrostructure and associated properties like the soil hydraulic functions may vary strongly within weeks and months [1]. The respective evidence has so far been collected in an indirect, statistical fashion which was made necessary by the destructive nature of traditional measurement methods like profile excavation and production of soil thin-sections. In these studies it has for example been shown that the saturated soil hydraulic conductivity is positively correlate with the soil macroporosity [2]. Non-invasive 3-D imaging methods now renders a quantitative observation of the temporal evolution of soil macrostructure in an individual soil sample possible. Such an approach has to my knowledge never been tested before. It was therefore the aim of this study to investigate the potential and limitations of such an approach.

2. EXPERIMENTAL METHOD

A soil column (10 cm height, 6.8 cm diameter) was sampled shortly after seedbed preparation in a Swedish garden plot (Figure 1a) near Uppsala in June 2013. The soil column was thereupon taken to the X-ray facility of the Institute of Soil and Environment at the Swedish University of Agricultural Sciences (GE Phoenix v|tome|x 240 industrial X-ray scanner). The image resolution was set to 65 µm. After the image acquisition, the column was installed back into the garden plot, with its top surface plane to the soil surface and its bottom surface open to the subsoil. Over the course of the next 25 months, the column was sampled, X-rayed and installed back into the field on eight further occasions. ImageJ/FIJI [3] was used together with BoneJ [4] and SoilJ [5] for image analyses. The images were corrected for illumination heterogeneities and normalized to a standard grey-scale [5]. The images were then approximately aligned upon visual inspection, using a reference feature within the soil column. Regions of interest of identical sizes were subsequently cut out from all nine 3-D images. Their boundaries were chosen with respect to the above mentioned reference feature. The images were then segmented into regions corresponding to air, fresh organic matter and roots, soil matrix and soil minerals by global thresholding, using the joint histogram of all nine images [5]. The morphological features of the air phase were then calculated using BoneJ [4].

3. RESULTS

Within the first four months, the soil structure was strongly modified by the soil macrofauna (Figure 1b), most likely by earthworms. After the first winter, only occasional new burrows appeared but the existing ones bear signs of re-use. In the second growing season, the soil structure was strongly reshaped by the growth of a dandelion root (Figure 1b). In the third growing season the dandelion root was starting to decay and red ants were significantly altering the soil macropore system using the already existing burrow-system as a basis for their own burrow (not shown).

Soil structure modification by abiotic influences like wetting/drying or freezing/thawing cycles appeared to be of minor importance in this soil sample. Empirical knowledge on the relationship between soil macroporosity and saturated hydraulic conductivity [2] suggests that the saturated hydraulic conductivity of this individual sample has been changing at least three times during the observation period by two orders of magnitude within periods of 3 to 4 months. Such large dynamics may explain why the saturated hydraulic conductivity cannot be successfully predicted from relatively static soil properties like texture, bulk density or soil organic carbon.

References

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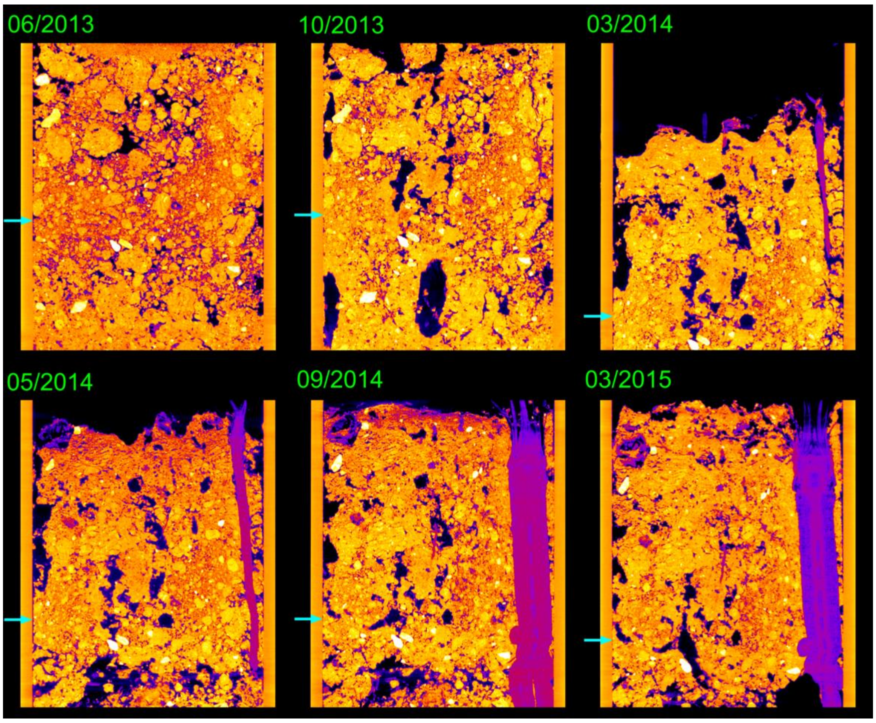
(a)



(b)

Figure 1: (a) Soil sample used in the study; (b) X-ray-derived 2-D vertical cross-sections of the evolution of soil macrostructure and plant roots in the course of 21 months. The blue arrows indicate the depth of a reference object.