In situ observation of soil macropores using infrared thermography

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In-Situ-Beobachtungen von Bodenmakroporen mit Hilfe der Infrarotthermographie

1 Introduction

Macropores and water flow in soils are complex topics and have been the subject of many studies (e.g. BEVEN & GERMANN, 1982, 2013). A macropore is defined as a pore space which allows water to move through the soil under gravity without being restrained by capillary tension (BEVEN & GERMANN, 1982) and can be formed by the cracking of the surface material or by biological activity (e.g. ants, earthworms, burrowing mammals, roots). Some root systems, earthworm and ant burrows extend for many metres below the surface and might have a significant effect on the infiltration rate.

Since macropores affect soil permeability they directly influence other hydrological processes (e.g. surface runoff and associated transport processes). Macropores convey water to greater depths with higher speed, thus influencing infiltration. According to VILLHOLT (1998), in shallow unsaturated soils the effect of macropore flow can be manifested through very short arrival times of surface-applied or derived substances to the groundwater. Macropores also directly affect the flow of air into the soil, the root growth of plants and biological activity (e.g. PERRET et al., 1999; JARVIS, 2007).

The development of simple cost effective approaches for determining the occurrence of preferential flow (e.g. through macropores) is a challenging task, of potential application to identifying risks of agrochemical mobilisation to groundwater (e.g. HARDIE et al., 2013), for example. A review of different approaches for identifying the occur-

Zusammenfassung

Kenntnisse über die Bodenmakroporen verbessern das Verständnis für hydraulische Eigenschaften und für bodenhydrologische Prozesse. Die Studie zeigt ein Verfahren zur Vor-Ort-Erfassung der oberflächlichen Makroporenstruktur des Bodens anhand von Temperaturgradienten infolge thermischer Bodenerwärmung. Diese Methode kann erfolgreich zur kostengünstigen und raschen Erfassung der Makroporenverteilung angewendet werden, obwohl fallweise das Vorhandensein von oberflächlichen Störkörpern (Samen, Steine, Vegetation) die Anwendung erschwert.

Schlagwörter: Makroporen, Thermographie, Feldarbeiten, Bevorzugte Fließwege.

Summary

Soil macropores characterization improves the understanding of hydraulic behaviour and soil hydrological processes. This study presents an exploratory *in situ* assessment of soil surface macropores using an infrared thermography technique based on temperature gradients originating from soil surface heating with hot air. Although the presence of seeds, pebbles, stones and vegetation may create difficulty in the application of the technique, in particular because they might mask the presence of the macropores, the technique was successful in identifying surface macropores, providing a low cost and fast methodology to assess mapping soil surface macropores.

Key words: Macropores, thermography, field work, preferential flow.

rence and extent of preferential flow through the soil is presented in ALLAIRE et al. (2009). Some of the currently most advanced techniques (e.g. X-ray, magnetic resonance imaging, computed tomography) result in very good representations of the network pore system with very high spatial resolution. However, most of the times they require expertise with very specific technical knowledge, being very expensive and requiring soil samples transporting to the scanning site, which, in general, is not feasible. There is also the limiting issue of studying disturbed soil samples.

Other approaches identified by ALLAIRE et al. (2009) adopt dye tracers. These techniques consist in the application of a dye at the soil surface, excavation of the soil profile after a specified infiltration time, analysis of visual and/or photo interpretation of dye distribution with proper computer software (ALLAIRE et al., 2009). These approaches are easy to apply, inexpensive and give insight into a range of macroporosity levels and other features causing preferential flow. However, they are imprecise and, the characteristics of the dye may affect interpretation. Also, these methods are destructive and labour intensive.

Recently, infrared (IR) thermography based methods have been used as high resolution imaging tools in hydrology, in particular those using portable hand-held IR cameras due to their easy handling and low cost. Infrared thermographic techniques were used in recent studies to assess different surface hydrological processes in controlled laboratory conditions; see DE LIMA & ABRANTES (2014a, 2014b), DE LIMA et al. (2014a, 2014b). In these studies the temperature gradients inherent to the methods were created at the soil surface by applying hot water. By flowing into the soil, the hot water accumulates on pores or other surface irregularities, which produces thermal marks on the thermograms that can be identified and sized. DE LIMA et al. (2014a) aimed to map soil surface macroporosity, a study that was conducted at a small laboratory scale, using an IR video camera. Using this method, macropores presented higher temperatures and were detected by identifying pixels associated to higher temperature (i.e. pixels with temperature values above a certain temperature threshold), thus distinguishing them from the remaining (low temperature) pixels that cover the soil surface of the remaining scanned area.

This exploratory study aimed to evaluate the applicability of an infrared thermography technique relying on heating the soil surface with hot air for mapping soil surface macropores; the method was applied in the field and the observations were undertaken on natural soil conditions. In contrast to hot water (DE LIMA et al., 2014a), hot air has no destructive impact on the soil.

2 Hot air infrared thermography technique

In this study a new infrared thermography technique is proposed as a tool to assist studying soil surface macropores, in the field. Tests are conducted *in situ*, on natural, undisturbed, soil surfaces. It is a two phase technique – see Figure 1 – that relies on the application of hot air to heat the soil surface (using a hot air blowing system, Figure 1a) and on a portable hand-held infrared camera to obtain thermograms (i.e. thermal images, which are records of the temperature on the soil surface, Figure 1b). This technique and the thermal images are then analysed to identify the existing macropores in the soil surface; their location and size can be studied as described in DE LIMA et al. (2014a). The infrared camera used in this tests is a thermal imager with MSX technology (camera Model E6 from Flir Systems), with an optical resolution of 160 × 120 pixels.

The soil surface heating system comprised a hot air blowing device with a power of 2000 watts; the hot air was blow into a limited volume of air in contact to the soil surface (Figure 1a), to concentrate hot air and evenly heat the soil surface. To uniformly distribute the hot air over the soil surface, the blowing device was kept oscillating inside a plastic container.

Soil surface thermal uniformity should be achieved to obtain the best identification of the macropores. This thermal evenness should extend to the different elements at the soil surface (e.g. vegetation, stones, debris) and thus highlight the macropores structures. Therefore, the heating time should depend on the reflectivity characteristics of the soil elements present at the surface and the capacity of the hot air blowing device. In this technique, which uses hot air to heat the soil surface, macropores likely end up presenting lower temperatures than other elements on the soil surface; this happens because the development of the pores inside the soil structure causes the soil moisture to maintain lower temperatures in the macropores than the temperature on the surface, heated by the hot air. Thus, by detecting and identifying the pixels on the scanned area that are associated with lower temperature (i.e. pixels with temperature values below a certain temperature threshold) we get information on the macropores. However, it is expected that results are affected by the presence of other elements on the surface, such as such as vegetation, stones and debris.

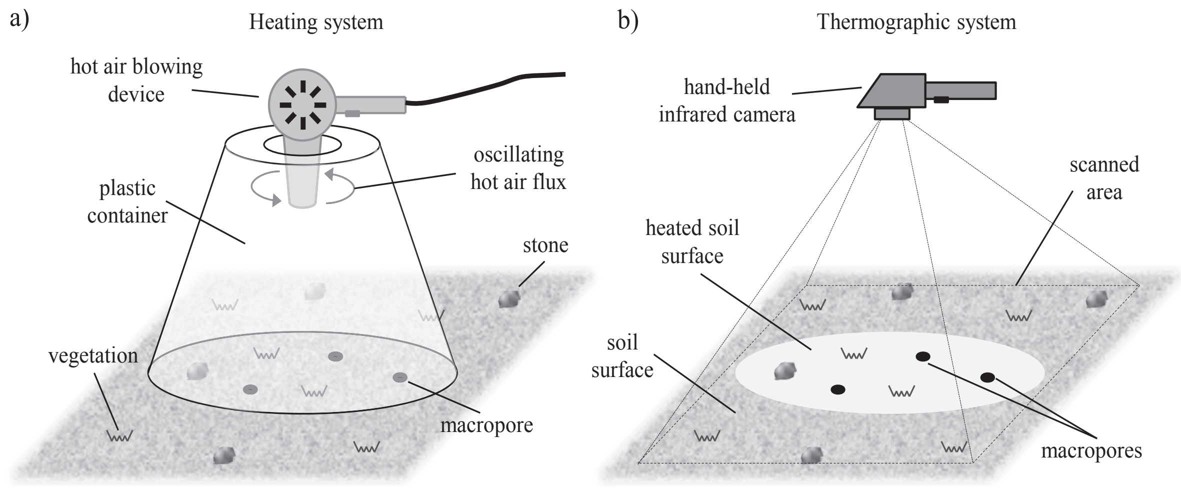

Figure 1: Two phase technique: a) Soil surface heating with hot air blowing system; and b) Thermal scanning of soil surface
Abbildung 1: Zwei-Phasen-Technik: a) Aufheizung des Bodens mit Heißluftgebläse (Fön); b) Abtasten der Bodenoberfläche mit Thermoscanner

Field tests were conducted in: (*i*) campus of the Federal Rural University of Pernambuco (UFRPE), neighbour to the Agricultural Engineering Department, in Dois Irmãos, in the city of Recife, Brazil; and (*ii*) representative catchment of Mimoso, also operated by UFRPE, which is part of the Alto Ipanema catchment, located in the Brazilian semiarid region in the Pernambuco State, close to the city of Pesqueira. The first site is located in the *Zona da Mata* (Forest Area) which is a tropical (hot and humid) narrow coastal plain between the Atlantic Ocean and the drier *Agreste,* where the second site is located.

The soils are classified as Abruptic Eutrophic Yellow Argisol (Santos et al., 2010) and Neosol (Carvalho, 2013), respectively, at the two sites.

3 Results and discussion

Thermograms and photographs of four field experimental tests, in Recife, of the infrared thermography technique are presented in Figure 2.

In the thermograms it is possible to identify the macropores location, perceptible by the presence of groups of pixels exhibiting a darker colour. These thermal marks are the result of the lower temperatures produced by the non-existence of heated soil particles; the temperature in the macropores is also influenced by the soil moisture content in the soil profile. The larger the macropore, the larger are the thermal marks exhibiting lower temperatures. Thus, analysis of the thermograms allows mapping the soil surface macropores, yielding the identification of their spatial distribution and position in the soil surface.

Results show that the natural conditions of the soil surface, which involve the presence of vegetation, stones and seeds, bring additional difficulties to identifying macropores at the soil surface, since these elements tend to create a more heterogeneous soil surface temperature distribution. Therefore, it is more difficult to perceive what thermal marks represent the macropores. This can be seen in Figure 2c, where some seeds distributed over the soil surface disturbed the identification of soil macropores.

It was observed that, in some cases, the macropores could be detected on the soil surface by IR cameras without any artificial heating of the soil surface. We give here three examples recorded in the semiarid region of Pernambuco (*Agreste*, Brazil), where the surface of extremely dry soil heats up sometimes to above 50 ºC during day time, exposed typically to a near surface air temperature above 35 ºC and strong near-to-vertical incident solar radiation. Also in this case, the slightly higher water content in the soil profile guarantees lower temperatures in the pores, promoting the necessary temperature contrast for allowing the presence of the macropores to be detected in the thermograms: the macropores appear colder (dark colour dots on the thermograms of Figure 3) than the soil surface.

Similarly to the images collected after heating artificially the soil (by applying hot air), the presence of vegetation, stones, pebbles and seeds bring sometimes ambiguity to the

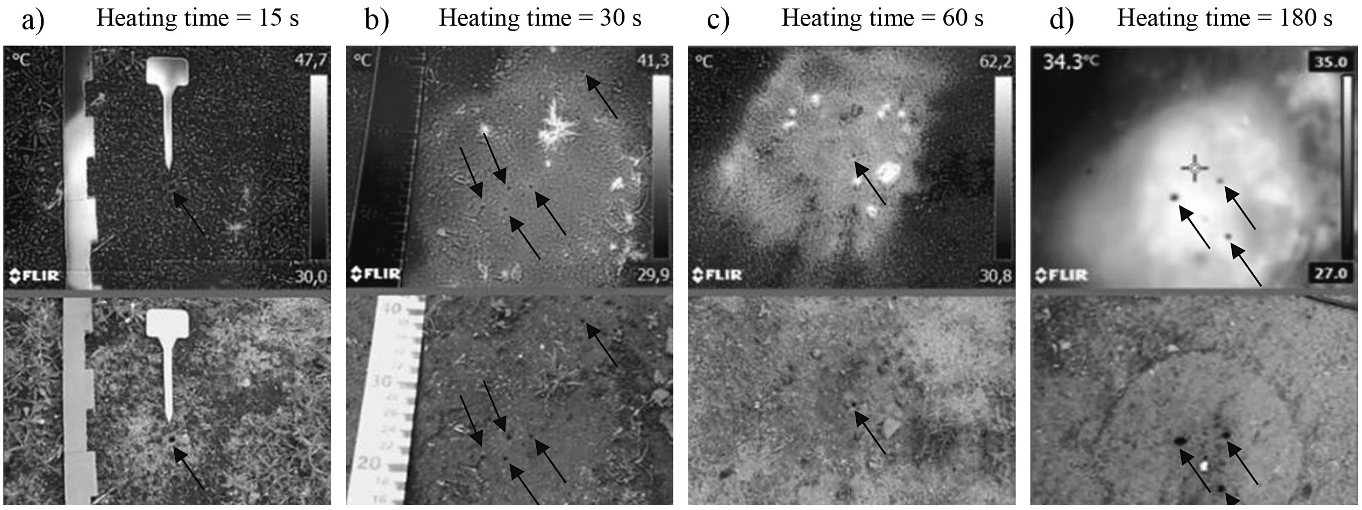

Figure 2: Thermograms (top) and photographs (bottom) of four soil surface conditions recorded *in situ*, in the field. The location of the images, in Recife, is not always the same. The black arrows point out the location of the macropores, created by ants, at the soil surface. The macropores, with a few millimetres are visible at naked eye. The big circles perceptible in the images were created by the plastic container hold against the soil surface (see Figure 1)

Abbildung 2: Thermogramm (obere Zeile) und Fotografien (untere Zeile) von vier Bodenzuständen im Feld. Die Lage der Bildaufnahmen ist verteilt. Die schwarzen Pfeile zeigen durch Ameisen verursachte Makroporen und können mit freiem Auge erkannt werden. Der kreisrunde Abdruck (d unten) ist durch den Plastikrahmen bei der Bodenerwärmung bedingt (vgl. Abb. 1)

interpretation of the thermograms. In fact, the "dark colour dots" can also be seen in the photograph. However, they are much easily identified in the thermogram (white area with dark dots) than in the photograph (grey full of many dark dots). Note that the thermograms shown in Figures 2 and 3 are printed in a grey scale and not in the original colour, which spans a rich chromatic range. Thus, eye interpretation of the thermograms is more difficult here than when using the original records.

4 Conclusion

An infrared thermography technique used to locate and size soil surface macropores was presented; exploratory in situ applications of this technique in the field are discussed. The technique, based on heating the soil with hot air, could identify the presence of macropores at the soil surface. However, the presence of seeds, stones and vegetation may mask the presence of the macropores and hamper the reliability of the results.

This study raised several questions which could not be discussed namely: imaging processing techniques (in this exploratory work the handling of the thermograms was made in matrix format in a spread sheet); assessment of vegetation and mulch impact on the assessment procedure; definition of threshold temperature from the frequency distribution curves; sampling strategies and its relation to the infrared camera resolution.

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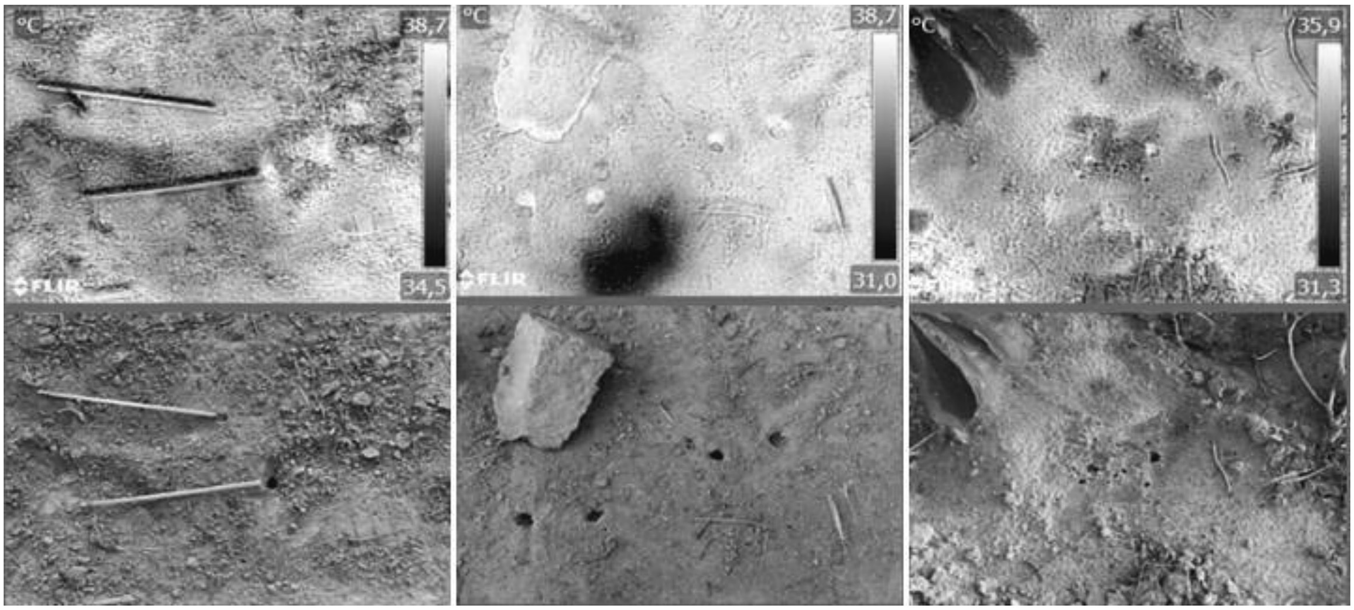

Figure 3: Thermograms (top) and photographs (bottom) for three soil surface conditions tested in the field, without providing any artificial heating of the soil surface

Abbildung 3: Thermogramme (oben) und Fotografien (unten) dreier Bodenzustände im Feld, ohne künstlicher Erwärmung der Bodenoberfläche

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