Assessing the root-soil contact in biopores

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ABSTRACT

Biopores are preferential ways for root growth in the subsoil, especially due to reduced mechanical resistance. In case of biopores formed by anecic earthworms, biopore walls are often covered with linings rich in soil organic matter and nutrients. However, it remains unclear, to which extent roots penetrate the drilosphere and exploit the nutrients stored therein. Precise quantification of the contact area between roots and soil in biopores is of particular interest for future modelling of nutrient uptake from subsoil.

Observations of roots growing in biopores undertaken with “classical” destructive methods, such as the profile wall method, suggest that roots often grow within the biopore lumen without touching the biopore wall. However, these findings may be based on dislocations of roots by excavation tools and therefore displaying artefacts. We suppose that the use of minimum-invasive imaging *in situ* techniques based on endoscopy can extend our knowledge on the soil-root interface. Preliminary endoscopic investigations were undertaken in a field experiment on a Haplic Luvisol from loess (loamy silt; Klein-Altendorf near Bonn, Germany). Continuous biopores below the plough-layer were excavated by removing topsoil down to 30 cm soil depth and visually investigated using a flexible videoscope with an outer diameter of 3.8 mm. We were able to differentiate four categories of root segments growing in biopores: (1) vertical without contact to the biopore wall, (2) vertical in contact to the biopore wall, (3) lateral branching from vertical roots and (4) entering the biopore horizontally from the bulk soil.

KEYWORDS: endoscopy, root-soil contact, biopores, nutrient uptake

1. INTRODUCTION

Soil biopores are formed by root growth and by the activity of earthworms. Various studies have shown that the soil adjacent to biopores differs considerably from the bulk soil in terms of containing higher amounts of organic matter and nutrients (e.g. Graff, 1971; Pankhurst et al., 2002). Presumably, the nutrient contents of the pore wall vary between biopores of different origin (root growth vs. root growth + earthworm activity) and different age. Biopores are preferential pathways for water flow (Beven and Germann, 1982) as well as root growth especially due to reduced mechanical resistance (Böhm and Köpke, 1977; Ehlers et al., 1983; Watt et al., 2006). When compared with the bulk soil, biopores are also considered as favourable locations for nutrient uptake, particularly in deeper soil layers where oxygen availability, nutrient availability (Dou et al., 2007) and densities of microorganisms (Vinther et al. 1999; Fierer et al., 2003) are gradually decreasing in the bulk soil. Under the conditions of a hardsetting clay soil of South-Eastern Australia, Pierret et al. (1999) found up to 80 % of roots in the subsoil in direct vicinity of macropores which indicates their potential relevance for nutrient uptake.

The extent of contact between roots growing in biopores and soil is largely unknown, particularly when roots grow through biopores that are much larger than their own diameter. Furthermore, the root’s spatial orientation within the biopore is likely to be effected by the pore’s tortuosity which may depend on site conditions and crop and earthworm species involved in pore formation (Bastardie et al., 2002). Thus, it is not yet understood to which extent roots are exploiting the nutrient resources located in the biopore walls. Supposably, nutrients in the biopore wall are also assessed by roots growing vertically within the biopore as well as by roots entering the biopore horizontally from the bulk soil. Volkmar (1996) hypothesized that lateral roots could be tightly pressed against the biopore wall, thereby facilitating nutrient transfer, but direct evidence is lacking. Observations made when using the profile wall method (Böhm and Köpke, 1977) or other excavation methods might be based on artefacts, i.e. roots that are determined as ‘without contact to the biopore wall’ may have been positioned there by excavation tools or scrapes that are unavoidable to be used with this method. Investigations on root-soil contact undertaken by thin-section techniques (Kooistra et al., 1992; Noordwijk et al., 1992; Veen et al., 1992) gave first insights into the distribution of roots in macropores and revealed that in pot experiments the degree of root-soil contact was greater than expected from random positioning. Schoonderbeek and Schoute (1994), also using the thin-section technique, found differences in the average percentage of root-soil contact between two differently managed fields for the upper soil layer (8-15 cm). However, this method requires a large number of thin-sections for quantifying the root-soil contact in the field. Moreover, the thin-section method is less suitable for deeper soil layers. Schoonderbeek and Schoute (1994) omitted the investigation of thin sections taken from at 45 cm depth due to the low rooting density. Furthermore, roots growing horizontally along the vertically orientated biopore walls (appearing elongated in horizontal thin-sections) are not normally distributed over soil depth, which could result in misinterpretations of root-soil contact.

Thus, we think that there is need for new methodological approaches for assessing root-soil contact in biopores. We suppose that the use of minimum-invasive imaging *in situ* techniques based on endoscopy can extend our knowledge on the soil-root interface.

2. MATERIAL & METHODS

Preliminary endoscopic investigations were carried out from September 3rd – 12th 2008 in a field experiment on a Haplic Luvisol from loess (loamy silt; Klein-Altendorf near Bonn, Germany). Continuous biopores below the plough-layer were excavated by removing topsoil down to 30 cm soil depth using a spade. Thereafter, biopores were uncovered from overlying particles using a vacuum cleaner. Only large biopores (diameter ≥ 6 mm) were considered for investigation. Biopores containing strong tap roots or being densely filled by several fine roots were not taken into account.

We used a flexible videoscope with an outer diameter of 3.8 mm and a flare angel of 80° (Karl Storz GmbH, Germany) plugged into a mobile computer with a “Hauppauge WinTV” software package installed. Illumination was provided by a cold light projector. The flexible tip was used to examine the biopore wall in an angel of 360°. Snapshots were taken and saved to the computer’s hard disk in JPEG format for later analysis and documentation.

3. RESULTS

We found that the method is suitable primarily for straight-lined biopores. Despite the possibility to move the endoscope`s flexible tip it was hardly possible to follow turnings without scraping the pore wall, thus disrupting the pore`s native state. However, in our experimental field it was generally possible to move the endoscope down to a distance of at least 10 cm from the entry point. Roots growing within biopores were frequently found to be associated with small soil aggregates. We were able to differentiate four categories of root segments growing in biopores (Fig. 1 a-d):

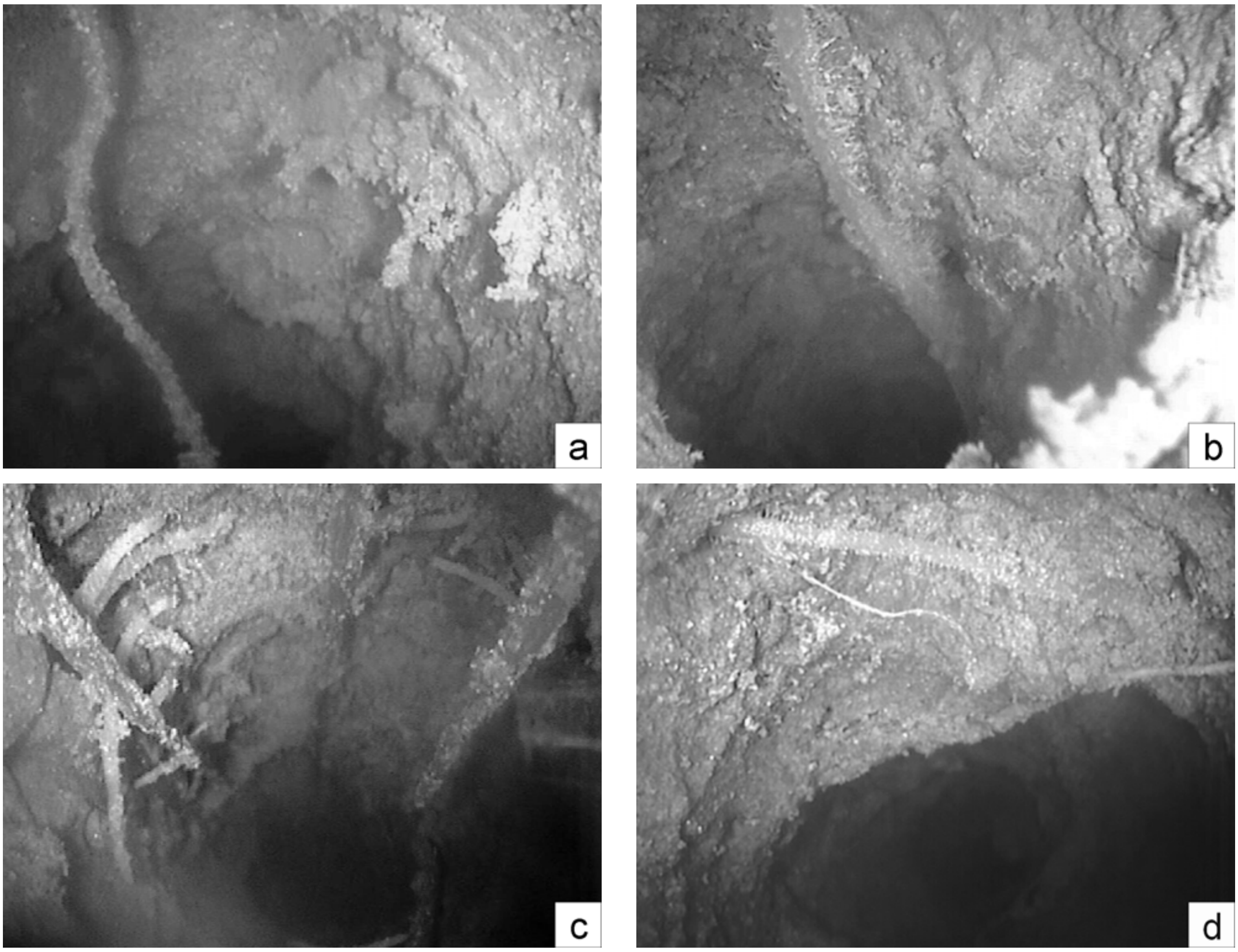

Figure 1. Categories of root segments growing in biopores

a. Category I: vertical without contact to the biopore wall (Fig. 1a)

b. Category II: vertical in contact to the biopore wall (Fig. 1b)

c. Category III: lateral branching from vertical roots (Fig. 1c)

d. Category IV: entering the biopore horizontally from the bulk soil (Fig. 1d).

4. DISCUSSION

With the aim of developing nutrient efficient, economically reasonable and ecologically sound land use strategies, mathematical models of plant growth and development as decision tools are of increasing relevance. Many advances were made during the past decades (van Ittersum and Donatelli, 2003), however to date we are still lacking a system model for quantifying water and nutrient uptake from subsoil. Precise quantification of the contact area between roots and soil is essential for modelling nutrient uptake. Previous approaches to calculate the effects of root distribution on nutrient uptake (e.g. Kohl et al., 2007, also see Wang and Smith, 2004 for review) have neglected the root-soil contact which may result in considerable deviations from the actual nutrient uptake.

We have shown that *in situ* endoscopy allows visualizing different categories of root growth in biopores. In future studies, these categories will be quantified with increasing soil depth in 1 cm steps. Thus, quantification of root-soil contact by endoscopy is considered to provide an important data source for novel modelling approaches, supposed to facilitate a more accurate estimation of nutrient acquisition from the subsoil.

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