RAHMANN G & AKSOY U (Eds.) (2014) Proceedings of the 4th ISOFAR Scientific Conference.
'Building Organic Bridges', at the Organic World Congress 2014, 13-15 Oct., Istanbul, Turkey (eprint ID 23806)

Growth of barley (*Hordeum vulgare* L.) roots in biopores with differing carbon and nitrogen contents

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Key words: pore wall, earthworms, *Hordeum vulgare* L., carbon, nitrogen, subsoil

Abstract

Large sized, vertical biopores can provide preferential pathways for root growth, hence facilitating the exploration of great soil depths by crop roots. This is of particular importance for organic production systems, where crops are more dependent on nutrient acquisition from the solid soil phase than under conditions of mainstream agriculture. The relevance of biopores for nutrient acquisition from the subsoil can possibly depend on their individual properties. The aim of this study was to test how different chemical pore wall properties affect the growth of barley (Hordeum vulgare L.) roots in large sized biopores. Bulk soil, pore wall material and roots from individual biopores were collected from three depth layers in 45-75 cm soil depth. C and N contents in the pore walls were up to 3 times higher than in the bulk soil. A large variation of C and N contents between the walls of individual biopores indicated that the quality of the pore wall is a function of pore colonization by earthworms over time. N-rich pores hosted more roots than N-poor pores. It is concluded that elevated C and N concentrations in pore walls can facilitate the exploration of the subsoil by crop roots.

Introduction

Crop roots often have only limited access to nutrient and water stored in the deep subsoil because of adverse conditions for root growth such as high mechanical resistance and low O_2 concentrations (Kautz et al. 2013a). Large sized, vertical biopores, created by deep burrowing earthworms and taproot systems, can provide preferential pathways for root growth, hence facilitating the exploration of great soil depths by crop roots (McMahon and Christy 2000). Furthermore, these biopores are assumed to be hot spots of nutrient acquisition by crop roots, because pore walls were reported to provide high concentrations of N, P, K and other nutrients (Pankhurst et al. 2002, Parkin and Berry 1999) and a high microbial activity (Jégou et al. 2001, Tiunov et al. 2001). However, recent studies have shown that the nutrient content of pore walls can considerably vary between biopores of different origin (Athmann et al., in this volume). Hence, the relevance of biopores for nutrient acquisition from the subsoil can possibly depend on their individual properties. The aim of this study was to test how different chemical pore wall properties affect the growth of barley (*Hordeum vulgare* L.) roots in large sized biopores.

Material and methods

The investigation was carried out in a field experiment on a Haplic Luvisol (WRB) derived from loess (loamy silt) in Klein-Altendorf near Bonn, Germany (50°37'9''N 6°59'29''E, 9.6 °C mean annual temperature, 625 mm annual rainfall). The samples were taken in early July 2011 under winter barley. Soil was removed down to a depth of 45 cm on an area of 50x50 cm adjacent to a 1.5 m deep trench dug by a shovel excavator. In a sampling area of 25x40 cm, the surface was cleaned from smeared soil and overlaying particles using a vacuum cleaner. Within the sampling area all visible biopores >2 mm in diameter were carefully opened, starting from a cutting edge of 10 cm height. Material from the pore walls was collected using small spoons and scrapers for determination on C and N contents with elementary analysis (Euro EA 3000, HEKAtech, Germany). Additionally, samples from the bulk soil were taken in four replicates for analysis of C and N contents. Roots from pores and bulk soil were collected seperately, washed, scanned (Epson Expression V700, 400 dpi) and quantified by image analysis (WinRhizo Pro, Version 2009c, Regent Instruments Canada Inc). In total, 3 soil layers of 10 cm each in 45-75 cm depth were investigated.

Results

In all depth levels under study the C content of the bulk soil was approximately 0.45 %. The C contents in the walls of individual biopores varied between 0.45 % and 1.24 %. Correspondingly, the N content in the bulk soil was approximately 0.05 % throughout the three depth levels (Fig. 1). N contents in the walls of individual

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biopores normally varied between 0.05 % and 0.12 %, however in one sample 0.14 % N were recorded (Fig. 1).

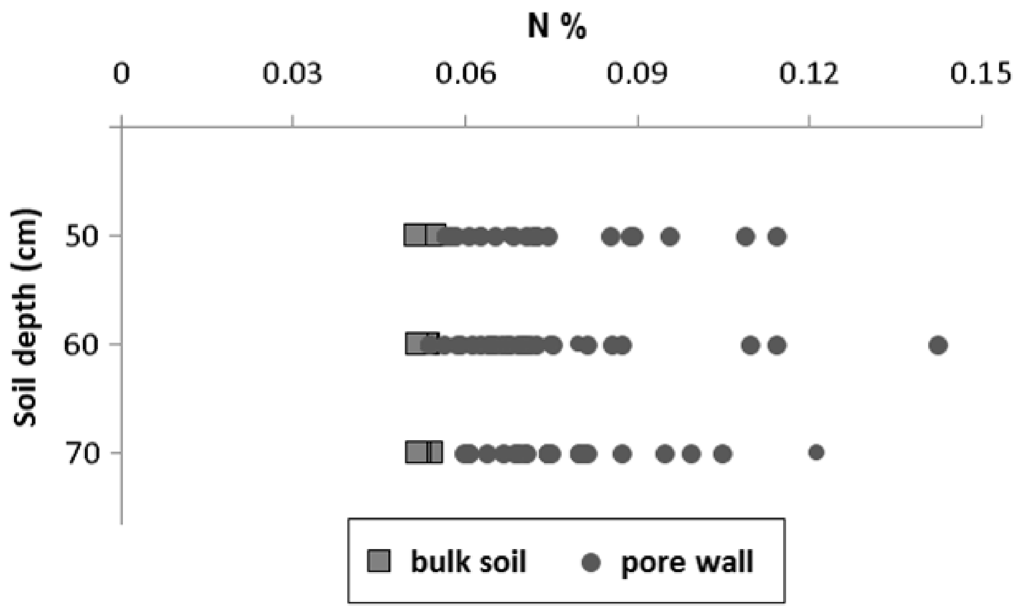

Figure 1. N contents in bulk soil and walls of individual biopores in three different soil layers (45-55 cm, 55-65 cm and 65-75 cm depth)

No significant correlation between N content in the pore wall and root length in biopores was found (Fig. 2). Individual biopores were grouped into one ‘N-poor’ class (N % < 0.07) and one ‘N-rich’ class (N ≥ 0.07). The average root length in N-poor biopores was 3.3 cm root cm pore^{-1} whereas it was 5.7 cm cm^{-1} in N-rich biopores (Fig. 2). This difference was significant at $p < 0.01$ (Mann-Whitney-U-test).

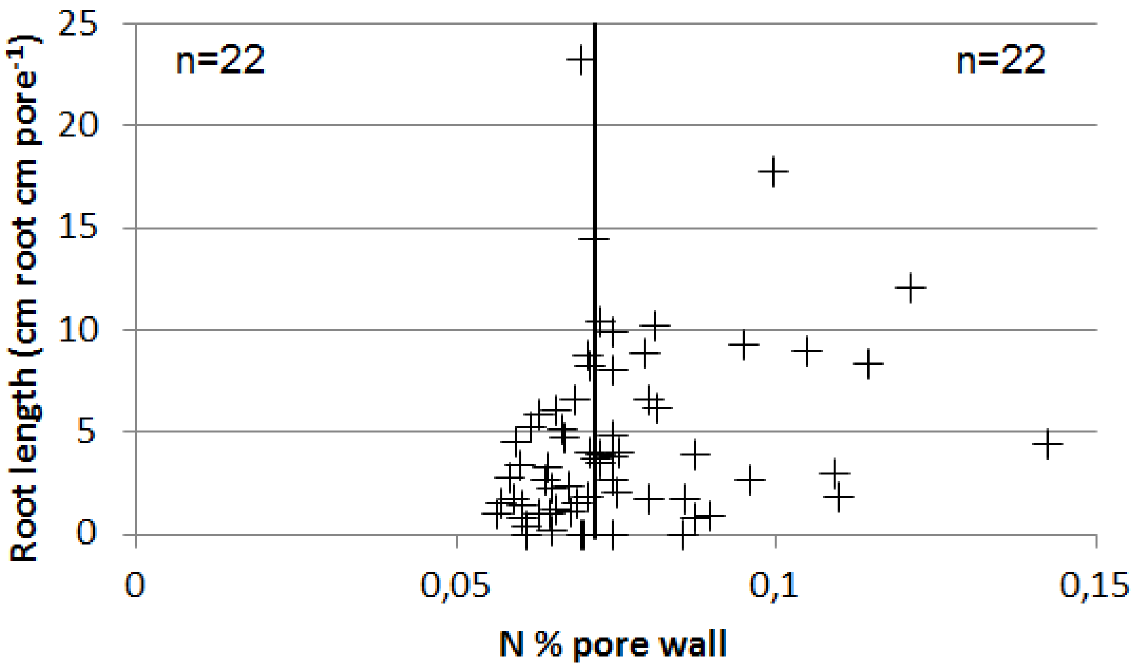

Figure 2. N contents in pore walls and root length in individual biopores

Discussion

In the soil under study, the soil depth from 45-75 cm is comparatively homogeneous and entirely belongs to the Bt horizon. Accordingly, no differences in the C and N contents between the soil layers were recorded.

A large variation of C and N contents between the walls of individual biopores was found, but it was not possible to differentiate between pores formed by earthworms or roots. We assume that a simple classification into two different classes of origin would not reflect the properties of biopores under field conditions: It is well established, that preferential flow paths such as biopores can be stable at least for decades (Hagedorn und Bundt, 2002). As long as a pore is colonized by an earthworm, the walls are frequently coated with N-rich faeces, thus, the N contents of the pore wall are assumed to rise or maintain on a comparatively high level. However, when the pore is abandoned, the N contents of the pore wall are assumed to drop as a consequence of leaching and probably N uptake by roots growing through the pore. Furthermore, abandoned earthworm channels can be recolonized by earthworm juveniles or adult earthworms (Kautz et al. 2013b). Hence, the development of pore wall properties must be understood as the consequence of interaction by earthworm and root activity. Whereas large sized biopores are often primarily formed by roots (Kautz et al. 2013b), the quality of the pore wall is a function of pore colonization by earthworms over time.

The lack of correlation between C and N contents in the pore wall and root length in biopores indicates that nutrient contents of the pore wall do not principally determine root length in biopores. Previous studies have shown that reduced mechanical resistance is the main factor driving roots into biopores (Logsdon und Linden 1992). However, pores with N-poor walls often contained very few roots only, whereas high root lengths were generally found in N-rich pores. Thus, our results provide evidence that the properties of the pore wall have an influence on root growth in biopores.

Conclusions

Elevated C and N concentrations in pore walls can facilitate the exploration of the subsoil biopores by crop roots. Provided that the conditions for nutrient uptake from the subsoil are beneficial (e.g. drought or scarcity of nutrients in the topsoil) biopores with pore walls enriched in nutrients can promote nutrient acquisition from the subsoil.

Acknowledgments

This study was supported by the German Research Foundation (Deutsche Forschungsgemeinschaft – DFG) within the framework of the research unit DFG FOR 1320. Details of the field trials potentially open for external researchers: www.for1320.uni-bonn.de.

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