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Impact of soil compaction on the tracheid diameter and the theoretical hydraulic conductivity of Norway spruce seedlings

Roman Gebauer, Milena Martinková, Daniel Volařík

Mendel University of Agriculture and Forestry in Brno, Zemdelska 1, Brno, 61300, Czech Republic
Contact: Ing. Roman Gebauer PhD., phone: +420545134057, e-mail: gebo@email.cz

ABSTRACT

Soil compaction was brought about by the long-term load of soil in root containers planted with 2-year-old Norway spruce seedlings. After finishing the experiment the high of seedlings were measured. Sections for histology were carried out behind the root tip and also proximally from older places. The lumen diameter along and across root radii were measured. The theoretical potential hydraulic conductivity was calculated using the modified Hagen-Poiseuille equation. Statistical analyses were carried out using program R. Control seedlings were statistically higher and had bigger lumen diameter along and across root radii than experimental seedlings. We can conclude that seedlings, which growth under impact of pressure, were smaller and develop narrower tracheids. The lower growth (ie shorter water path) of the experimental seedlings enabled them the same or even higher theoretical potential hydraulic conductivity than was calculated for control seedlings. Shortening of water path is general characteristic of plant, which growth under influence of stresses.
KEYWORDS: anatomy, fine roots, metaxylem, soil compaction

1. INTRODUCTION

If we consider that roots grow through the soil, it is presumable that they shall be influenced by the mechanical pressure. On the microscopic level, there are changes in the xylem structure. The structure of xylem is maximally adapted to its main function, i.e. water transport and therefore a reduction of transport diameters of conductive xylem pathways, caused e.g. by insufficient mineral nutrition, lack of water or soil compaction may have a deep impact on the function of different parts of the conductive system. The more the growth of roots is limited and the smaller the soil space occupied by roots the slower the growth of trees in the aboveground part. That is why it is necessary to fully understand the process of compaction and its effects on the soil and growth of vegetation. The aim of this study is to learn how seedlings of Norway spruce react to the soil compaction in terms of size and flow diameter of tracheids.

2. METHODS

In order to measure the impact of the soil pressure on the tracheid diameter the method of root boxes was applied. Two boxes were control ones, i.e. they were not loaded and two were loaded Boxes were planted with 2-year-old seedlings of Norway spruce (*Picea abies* /L./ Karsten). After the experiment had ended te root systems were cleaned thoroughly and 10 fine roots were sampled of each seedling. In the case of the root systems, sections for the histology purposes were sampled from behind the root tip (metaxylem) and then from proximally older places (secondary xylem). Selected photos were treated in the AdobePhotoshop program and a black and white image recording only selected lumens was obtained. The processed pictures were analysed by computer using the ImageTool3.00 program. The tracheid diameter in two directions were determined:, i.e., major axis length and minor axis length ($\mathbf{d_{max}}$ and $\mathbf{d_{min}}$, respectively)**.** After the tracheid distribution of particular size classes was calculated. The theoretical potential hydraulic conductivity (**L_{th_lum}**) was calculated using the Hagen-Poiseuille equation. Since the shape of xylem cell lumen was not circular, we applied a slightly different modification of this formula for one vessel as recommended by Nobel (2005) (eq. 1 and 2):

$$L_{th\_lum} = \sum_{i=1}^{i=n} (\pi r_{lum}^{4} \Delta\varphi)/(8\eta\Delta x) ; \qquad [\mathrm{g.hod}^{-1}] \qquad (1)$$

and
$$r_{lum}^{4} = d_{max}^{3}\ d_{min}^{3} / (8\, d_{max}^{2} + 8\, d_{min}^{2}); \qquad (2)$$

Statistical analyses were carried out using program R (R Development Core Team 2007).

3. RESULT AND DISCUSION

Our research shows that pressure limits lumen tracheid diameter growth in all the studied parts of seedlings. The tracheids of primary xylem (metaxylem) had larger lumens than those of secondary xylem, as was also found by Krasowski and Owens (1999). The fact that tracheid lumens in experimental seedlings were smaller may be explained as a defense reaction against forming of air bubbles within the conductive system (McElrone et al. 2004). Air cavities in the conductive system cause e.g. dryness; and roots, especially fine roots, are more predisposed to this stressor than branches (Martínez-Vilalta et al. 2002). The cumulative curve of theoretical hydraulic conductivity was higher or relatively comparable in experimental seedlings, whose tracheid lumen diameters were smaller than they were in control seedlings. However, the lengths of conductive pathways in experimental seedlings were shorter, i.e. distance from root tip to leaves, than in control seedlings. That is why at comparable values of water potentials in roots and leaves, i.e. a higher gradient of water potential in experimental seedlings, the final flow speed could be higher even with tracheid lumens of smaller diameters. Shortening of conductive pathways is a well-known reaction of trees to stress (Marron et al. 2002, Schulze et al. 2005), and our results show that this reaction enables them to retain the same speed of water flow, therefore the follow-up physiological processes.

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