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Analysis of root-wood in Scots pine

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Introduction

Trees are made up of three main parts: a crown, stem (branches and leaves) and root system. It has been established that in pines the branches account for 8–10 %, the stem for 65–77 % and the root system for 15–25 % of the total tree volume (Perelygin & Ugolev 1971). Until now most scientists have been concerned with the stem-wood. However, the roots in pine represent up to a quarter of the total tree volume (Manwiller 1972).

Dendrochronological analysis

So far very little research has been done on the growth rings of the root system. The aim of the dendrochronological analysis presented in this paper is, therefore, to find a relationship (possibility of synchronization) between the growth rings of the root system and the growth rings of the tree stem. Glock (1937) was very pessimistic about the possibility to obtain any ecological information from the roots. In his opinion the roots provide virtually no readable ecological record. Later however, scientists succeeded in synchronizing the growth ring widths from the large roots of two Douglas fir trees in Southern Arizona (Schulman 1945). Since then, extreme growth changes found within different sections of the same root have been discussed in other studies (Fayle 1968, Krause & Eckstein 1992).

Anatomical analysis

Due to their irregular shape and small dimensions, the roots are not of any particular value for the timber industry. The main use of the roots is likely to be found in the fibre industry. For this reason it is essential to specify the dimensions of the root-wood tracheids. Therefore, a second aim of this study is to describe the variability of the tracheid dimensions (radial diameter and cell wall thickness) in the root-wood and to examine the changes in tracheid dimensions along the root.

General differences between roots and stem

In living trees, the roots have the same functions as the stem: conduction, mechanical support and storage. The most significant differences between mature wood of the root and stem occur in plants with highly organized wood (Lebedenko 1962). Riedl (1937) argued that the difference between stem and root wood is clearer in hardwoods than softwoods. However, a pith is absent in the roots of both dicotyledonous trees and gymnosperms due to the different processes of primary tissue formation (Jeník 1964, Gebauer & Martinková 2005). While the anatomy of the root-wood is different from the structure of the stem, those parts of the root that are closer to the stem have a more similar structure to the stem

(Trendelenburg 1939). The growth rings usually contain fewer cells than those of the stem and the boundary between the successive rings is usually less clearly defined (Fayle 1968). The growth ring widths at a distance > 40 cm from the tree stem along the horizontal root are always narrow, while the growth rings at a distance of 10–35 cm are always wide (Krause & Eckstein 1992).

The variation of the tracheid dimensions in the root system of the softwoods must be considered on a threefold basis: in relation to the distance from the root collar, in relation to the radial direction, and in terms of the direction of the root orientation (Panshin & Zeeuw 1980). An increase in size of the root tracheid both in terms of its length, and the radial and tangential diameters has been observed (Göhre 1958, Panshin & Zeeuw 1980). Manwiller (1972), who was analysing the root-wood of the Southern pine (*Pinus palustris* Miller), found that the cell dimensions were determined by the root orientation (horizontal, oblique, vertical).

Material and methods

One tree of Scots pine (*Pinus sylvestris* L.) was sampled in the Forest District Utechov (49° 14´ N; 16° 36´ E), Training Forest Enterprise Krtiny. The tree was cut down and its root system was subsequently uncovered using an Air-Spade (Nadezhdina & Cermak 2003). Four horizontal roots were taken for analysis. One sample from each of the four roots was taken for dendrochronological investigation. Five discs were taken from a fifth root for anatomical investigation. Each of the five discs was taken at different distances from the stem base (0.2 m, 1.2 m, 2.2 m, 5.2 m and 7.2 m). Three discs were taken from the stem at 0.3 m, 1.3 m and 5 m from the stem base.

The growth ring width was measured on a transverse section. If the measurement could not be conducted on macroscopic samples, permanent microscopic slides were made using standard methods (see Ives 2001, Vavrčík & Gryc 2004). The growth ring curves were synchronized using the PAST32 software. The microscopic slides of the transverse sections were analysed using the Lucia image analysis software.

The radial diameters and tangential cell-wall thickness of the tracheids were measured for the purposes of the anatomical analysis. The relative position within the ring of each tracheid was calculated as $RP = P / N$; P standing for the order of the tracheid within the ring and N for the number of the tracheids within the same ring.

Results

A) Dendrochronological analysis

The measurement of the growth ring width was followed by the synchronization of the growth ring curves. We managed to synchronize four curves obtained from five main horizontal roots (Fig. 1). The average curve for the whole horizontal root system was constructed from the well synchronized curves.

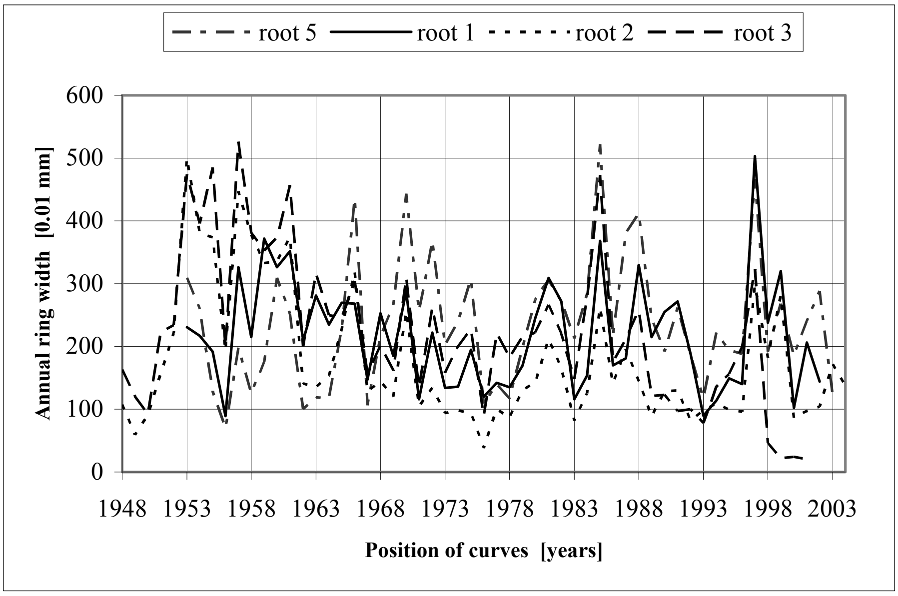


Figure 1: Synchronization of the mean growth ring curves from particular roots.

The t-test values for the synchronization of the mean curves from the different roots were the lowest for root 2 and 3 ($t = 3.72$, $p < 0.01$). This value is, however, statistically sufficient because by overlapping the curves of forty growth rings the critical value of the Student's t-distribution ($p < 0.01\%$) rises to 3.551. By contrast, the highest synchronization ($t = 8.24$, $p < 0.01$) appeared in the mutual synchronization between the mean curves of root 1 and root 2. Furthermore, the synchronization of the mean growth ring curve of the whole root system and the mean curve of the root cross section at 1.2 m was significant ($t = 6.12$, $p < 0.01\%$). The value of the *Gleichläufigkeit* of the curves was 83 %. The curves are consistent in the majority of extreme values (Fig. 2).

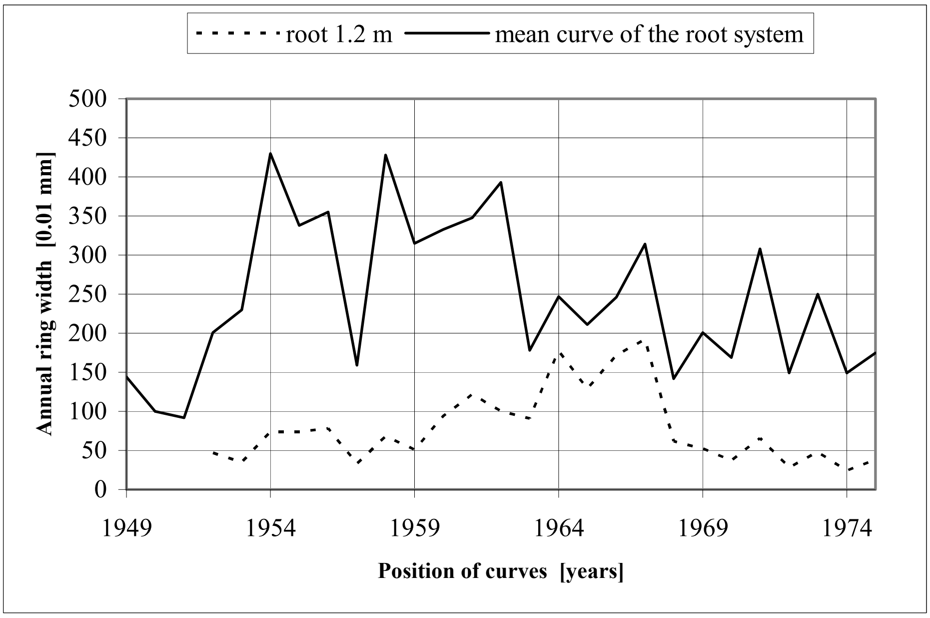


Figure 2: Synchronization of the mean growth ring curve of the whole root system with the mean curve of a root section 1.2 m from the stem.

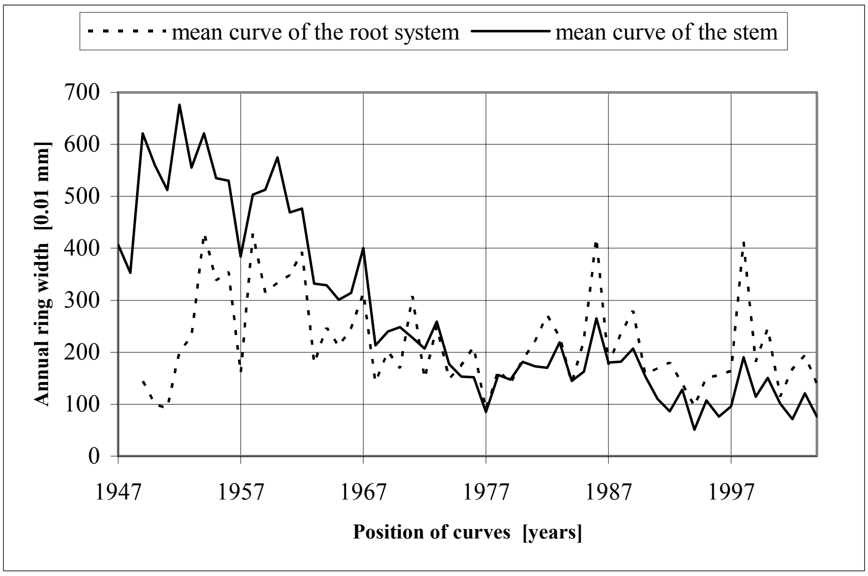


Figure 3: Synchronization of the mean growth ring curve of the whole root system with the mean growth ring curve of the stem.

The average curve of the horizontal root system as constructed above was synchronized with the average curve from the tree stem (Fig. 3). It was found that the best synchronization had been achieved between the mean curve of the stem at 5 m and the average curve of the root system ($t = 7.33$, $p < 0.01$). The value of *Gleichläufigkeit* of the curves is 70 %. The curves are consistent in the majority of the extreme values.

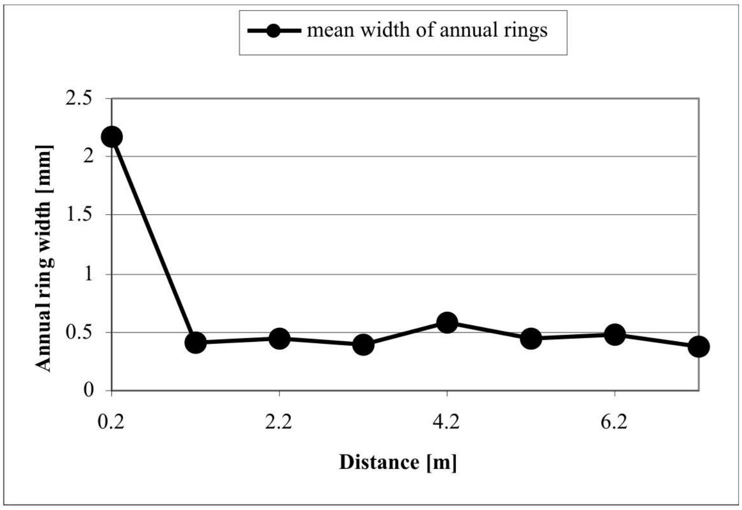


Figure 4: Growth ring width along the Scots pine horizontal root (root 5).

The diameter of the fifth root at 0.2 m from the tree stem was 251 mm and 61 mm at 1.2 m from the stem. The diameter of the root was more than four times smaller at the father distance. The mean width of the growth rings in the stem at a height of 1.3 m above the ground was 2.05 mm. The mean width of the growth rings in root five at 0.2 m from the stem was 2.18 mm and was 0.4 mm at 1.2 m from the stem. Moreover, the growth ring width was roughly constant at about 0.5 mm for most of the root (Fig. 4).

B) Anatomical analysis

The variability of the tracheid radial diameter along the root radius

Analysis at 0.2 m from the stem base

Differences in the tracheid dimensions were found between the inner and the outer rings (Fig. 5A). In the outer rings, the radial diameter of the tracheids increased in the first part of the first ring (the ring closest to the cambium). A maximum value was observed at a relative position 0.1 in the ring, after which the radial diameter decreased. The diameter decreased further from the earlywood to the latewood. The earlywood tracheid diameters ranged from 40 to 60 µm, whereas the latewood tracheid remained between 10 and 15 µm. A different trend was observed in the inner rings. The tracheid diameters increased up to a relative position of 0.4, after which the diameter remained more or less constant. The maximum tracheid radial diameter (60–80 µm) was observed at a relative position of 0.8 to 0.9 of the in the ring. The diameters decreased dramatically at the end of each of those rings. Only one or two latewood tracheids were observed within each ring per one radial row. Their mean diameter was 10–15 µm. In comparison with the inner rings, the outer rings contained a higher number of tracheids.

Analysis at 2.2 m from the stem base

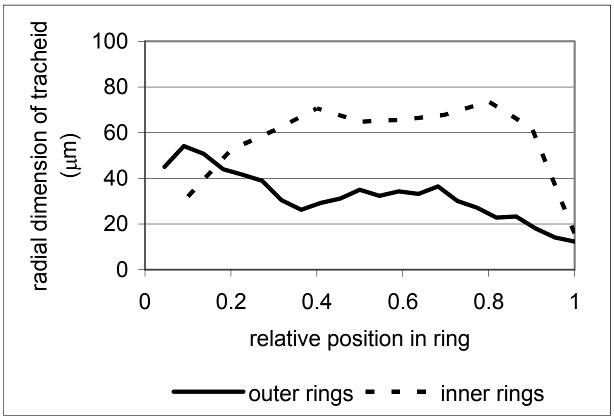
The radial diameters of the tracheids differed from the trends observed at 0.2 m distance from the stem base. A large variation in tracheid diameter (50–80 µm) was observed in the first half of the ring (Fig. 5B). In the second half of the ring, the diameters decreased almost linearly. The diameter varied from 10 to 30 µm at the end of each ring.

Analysis at 7.2 m from the stem base

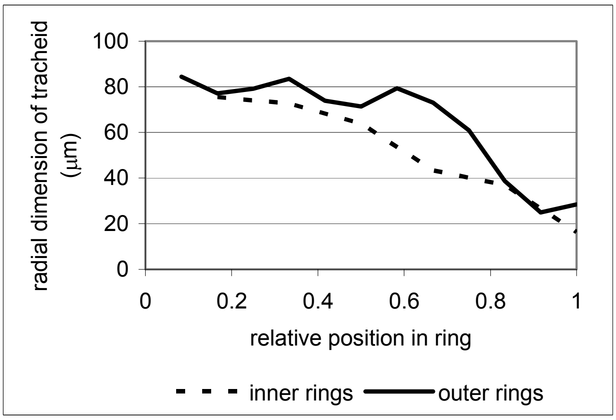
The trends of the tracheid radial diameters were very different at 7.2 m from the stem base as compared to closer to the stem base. We found that the radial dimension of the tracheids reached the maximum value at a relative position 0.55 (outer rings), respectively 0.9 (inner rings) (Fig. 5C). The tracheid diameter ranged between 45–80 µm for the earlywood and between 20–35 µm for the latewood. The latewood was composed of maximum two tracheid rows.

The variability of the tracheid radial diameter along the stem radius

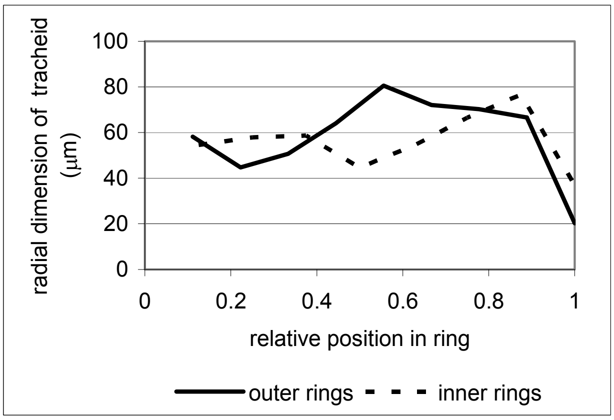
The radial diameters of stem tracheids were steadily decreasing throughout the growing season in all analysed rings (Fig. 5D). In comparison with inner rings, the outer rings manifested an earlier transition from the earlywood to the latewood.



A



B



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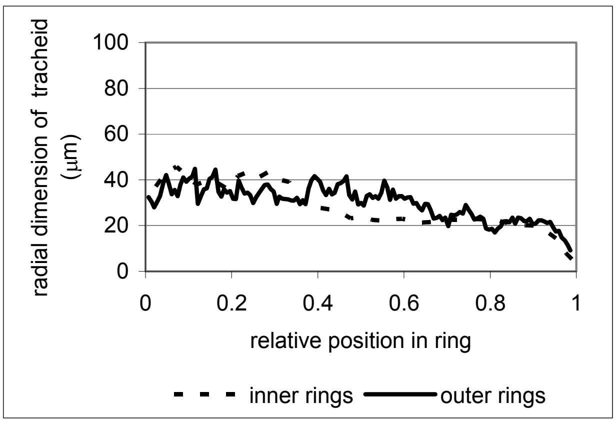

D

Figure 5: Radial diameters of the tracheid in relation to the relative position in a growth ring. A – root 0.2 m from the stem base, B – root 2.2 m from the stem base, C – root 7.2 m from the stem base, D – stem.

The variability of the tracheid radial diameters along the root

The comparative analysis of the tracheid radial diameters at various distances from the stem base was performed only on the ring adjacent to the cambium. While the number of tracheids decreased, their radial diameters increased with increasing distance from the stem base (Fig. 6).

The variability of the tracheid cell-wall thickness

The cell-wall thickness at 0.2 m distance did not vary as much as the radial diameters of the tracheids. The cell-wall thickness ranged between 2–3 μm at the beginning of each ring, and between 2–6 μm in their remaining parts. There were only negligible changes in the cell-wall thickness within each ring in samples taken at 7.2 m from the stem base. The variability of the tracheid cell-wall thickness is shown in Fig. 7.

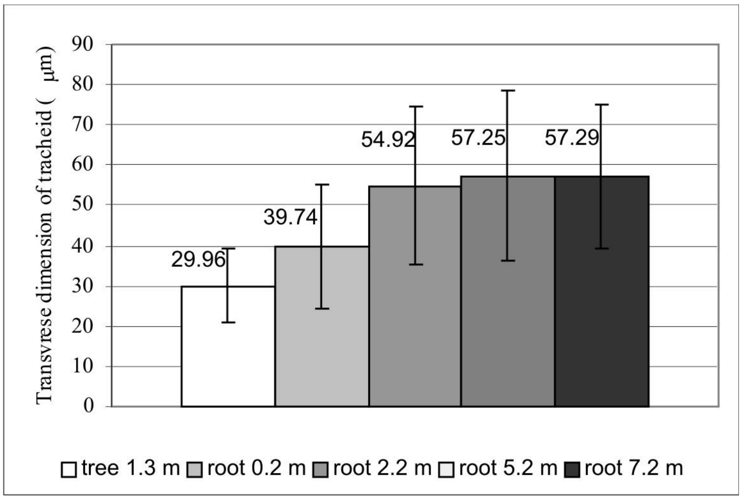

Figure 6: Mean radial diameters of the tracheids at different distances from the stem base.

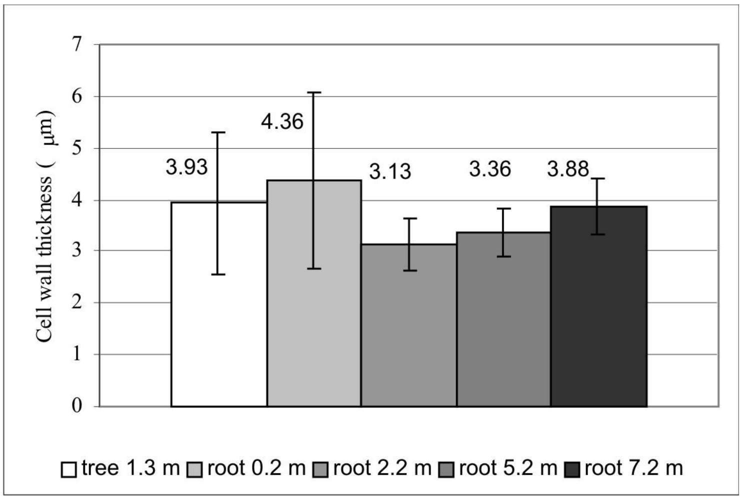

Figure 7: Mean cell wall thickness of the tracheids at different distances from the stem base.

Discussion and Conclusion

Dendrochronological analysis

We have succeeded in synchronizing four of the five main horizontal roots studied. The mean growth ring curve of these four horizontal roots has been reliably synchronized with the mean growth ring curve from the tree stem. It has been demonstrated that the sharply decreasing root diameter is determined by the growing distance from the tree stem (Krause & Eckstein 1992). The diameter of a root at the stem base was more than four times bigger than the diameter of a root taken at 1.2 m from the stem base.

The mean growth ring width in the stem at a height of 1.3 m above the ground was 2.05 mm, whereas the mean growth ring width in a root 0.2 m from the stem base was 2.18 mm. This striking similarity between the mean growth ring widths is explained by the fact that the growth ring widths of the roots were measured in a compression zone that gave rise to abnormally wide growth rings. The mean width of growth rings in a root 1.2 m from the stem base was 0.4 mm. From that point towards the root tip, the growth ring width remained virtually constant (about 0.5 mm). These values support the theory that the root diameter (as well as the growth ring width) is falling rapidly at a distance > 40 cm from the tree stem (Krause & Eckstein 1992).

This study has shown that the horizontal roots of Scots pine (*Pinus sylvestris* L.), and its roots up to 40 cm from the tree stem in particular, could be a very suitable source of ecological information. It has been illustrated that the growth ring curves from different roots are synchronizable. Moreover, it has been found that a partial synchronization is also possible between the growth ring curves from different cross sections of one root at various distances from the stem base. Finally, this showed that growth ring width curves from a root system can be reliably synchronized with growth ring curves from the tree stem.

Anatomical analysis

As expected, the wood structure in the horizontal root was different from the stem-wood. It was found that the relative amount of latewood along the horizontal root decreases from the stem base to the root tip, which corresponds to the findings made by Riedl (1937) and Bannan (1941). Similarly, it was observed that the percentage of the mechanical supporting cells declines in proportion to the distance from the stem base - the narrow roots near the root tips performing mostly conductive functions. For better xylem permeability, most tracheid cell-walls exhibited paired bordered pits. In pine stems uniseriate bordered pits have been reported (Wagenführ 1999, Schweingruber 1990). Due to the smaller proportion of the latewood in the rings, the ring boundaries of the horizontal root wood were not clearly visible (Fig. 8).

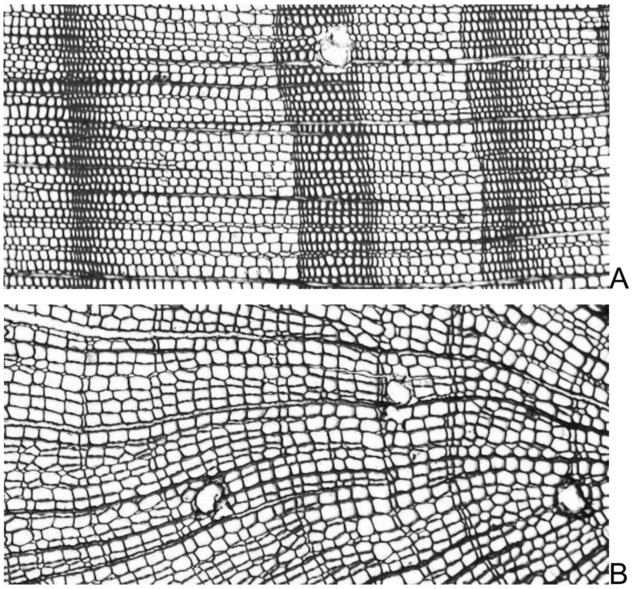

Figure 8: Transverse section of a root 0.2 m (A) and 7.2 m (B) from the stem base.

Manwiller (1972) found that the cell diameter tends to increase along the growth layer in horizontal roots. The same trend was observed in a root with a smaller diameter (7.2 m) and in the inner part of a root with a bigger diameter. The average radial diameter of the horizontal root tracheids increased proportionally to the increasing distance from the stem base. This confirms the findings reported for other species by Göhre (1958) for Douglas fir, by Bannan (1941) for Larch and Spruce and Manwiller (1972) for Southern pine. Futhermore, it has been shown that those parts of the root closer to the stem have a more similar structure to the stem itself (Trendelenburg 1939), which was also observed in our study

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