Architecture of root branches of Norway spruce trees (*Picea abies* [L.] Karst.) growing in gley soil

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ABSTRACT: In the locality Hnilé Blatá (the High Tatras Mts.), the structure was measured of root branches in the windthrown spruces (*Picea abies* [L.] Karst.). After cleaning the root plates, the number, diameter, and length of individual root branches were measured. Individual root branches were classified into twelve diameter classes – according to their diameters measured in the middle of the root branch length. We found out a high frequency of the root branches in the first three root-diameter classes; the values of the average frequency of root branches smoothly declined with their diameters increasing. We found out the lowest mean values of the root branch length in the first two root diameter classes. However, the values of total average length of root branches were the highest in the first root diameter class and these values continually decreased with increasing values of the root branch diameter. On the basis of the high values of root frequency and of total root length in the thinnest root-diameter classes, it seems that the spruce trees growing in gley soil form a similar root structure as those growing in podzolic brown soil.

Keywords: *Picea abies*; root branch; gley soil

The research into tree root systems is less frequent than the studies on the aboveground parts for various reasons. The root systems are not visible by the unaided eye, and they are of lower economic importance than the aboveground biomass. The research into the tree root systems is also very labour-demanding and its methods are not developed as well as the procedures for the aboveground biomass inventory. The methods for the belowground biomass inventory have been comprehensively described by Köstler et al. (1968), Kolesnikov (1972), Böhm (1979), and recently by Smit et al. (2000).

The main problem in the belowground biomass research is equivalent to the basic problem – how to obtain the roots from the soil substrate or how to get into the soil substrate up to their near proximity. Only overcoming this obstacle enables a proper study. For the rough root research of trees, the excavation method is the most common, thus, the roots are obtained from the soil by digging. Using trees which are naturally uprooted from the soil, e.g. by wind or by a winch, is also effective.

In Slovakia, extensive research into the root systems of forest woody plants has been done by Kodrík (2002) who investigated the root systems of principal forest tree species in terms of their static stability. Konôpka (2001, 2002) compared the root systems of trees in the dependence on soil drainage. Kodrík (2005) analysed the root biomass of forest trees in view of the production ecology. Jaloviar (2001, 2003) investigated the influence of the management system on the concentration of fine roots in the principal forest woody plants.

The morphology and size of tree root system is predetermined by the genetic properties of particular tree species, as manifested through interspecific differences. However, the environment (especially soil conditions) can influence the root

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system features considerably (Coutts 1987). In the case of undisturbed development, the spruce forms a typical shallow root system. Maximum depth of the root penetration can also be reduced by a high groundwater table. Kodrík (1998) mentions that the level of underground water has the strongest influence on the root system formation. Köstler et al. (1968) mention that the spruce forms an extremely shallow root system at poorly drained sites. According to Konôpka (2003), the roots do not need to or cannot penetrate through deeper soil horizons, and shallow and unstable root systems are formed at waterlogged sites.

The purpose of this paper is to evaluate the diameter and length structure of the root branches of spruce trees growing in gley soil.

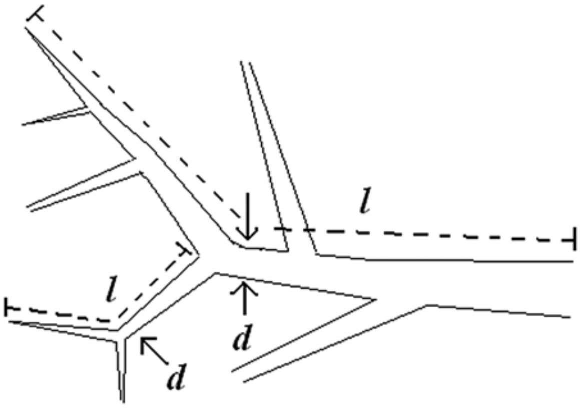

Fig. 2. Measurement of diameter (*d*) and length (*l*) of individual root branches

MATERIAL AND METHODS

The architecture of root branches was measured on the Norway spruce (*Picea abies* [L.] Karst.) in the locality Hnilé Blatá (20°03'E, 49°06'N) (the High Tatras Mts.). This site is uneven-aged, with the dominant stand layer 90 years old, south aspect, 5–10% slope, altitude about 950 m a.s.l. The management set of the forest types is waterlogged fir-spruces. The site consists of the following forest types: peaty fir-spruce (50%) that belongs to the vegetation unit *Abieto-Piceetum*, birch-alder on a fluvio-glacial substrate (40%) that belongs to the vegetation unit *Betuleto-Alnetum*, and bilberry-spruce with fir (10%) that belongs to the vegetation unit *Piceetum abietinum* higher stage (Križová 1995). The spruce is the dominant woody plant at the site, but the birch and alder are also quite abundant. The soil is rather waterlogged, with a low incidence of peats.

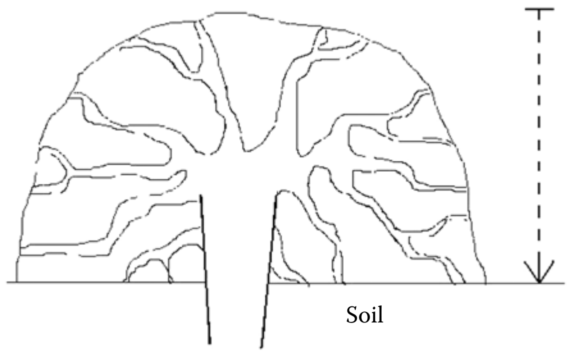

Fig. 1. Root-plate surface which contains the analysed root branches – cleaning of visible part of the root plate up to the soil surface (up to the hinge)

Using random sampling, 22 windthrown spruce trees were selected. These windthrown spruces were scattered across the stand. The root plates of the measured spruce trees were cleared of soil, by using hand tools. The root plates were cleared from soil up to the surface of soil. It means that we did not excavate the whole root plates, we cleared only the visible surface of the root plates up to the hinge (Fig. 1). After cleaning the root plates, the parameters of the root branches were measured. The number, length, and diameter of the individual root branches were measured according to Fig. 2. An individual root branch is defined as the most vigorous continual root branch forking into other smaller individual root branches. The length of an individual root branch was measured as the actual distance from its forking point up to the tip of its thickest (strongest) sub-branch. Individual root branches were classified into twelve diameter classes according to their diameters measured at the middle of the root branch length: 0.2–1.0 cm, 1.1–2.0 cm, 2.1–3.0 cm, 3.1–4.0 cm, 4.1–5.0 cm, 5.1–6.0 cm, 6.1–9.0 cm, 9.1–12.0 cm, 12.1–15.0 cm, 15.1–20.0 cm, 20.1–25.0 cm and 25.1–30.0 cm. The number and length only of the individual root branches in the first diameter class (0.2–1.0 cm) were estimated, consequently, these data are only approximate. Mean values of the number and length of the root branches were calculated for each diameter class.

RESULTS

Mean values of frequency and length of root branches according to the individual root-diameter classes are given in Table 1. We found out a smooth decline in the root branch numbers with their diameters increasing (Fig. 3). The value of average absolute frequency of the root branches was 342 root

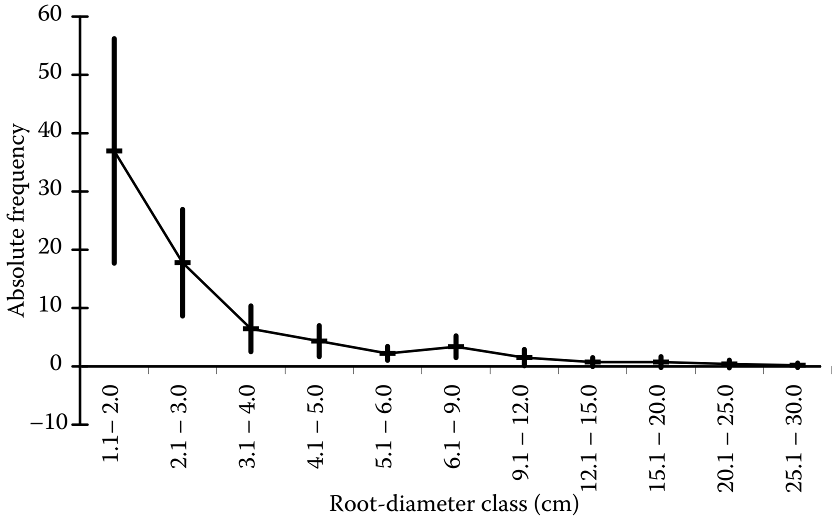

Fig. 3. Mean values of frequency of root branches according to individual root-diameter classes in Norway spruce (± standard deviation)

branches in the first root-diameter class, but it was only 0.18 in the last root-diameter class. We found out an unproportionally higher relative value of the average number of root branches in the first root diameter class (82%). On the other hand, the values of the relative average number of root branches were close to zero in the last root-diameter classes. After having excluded the roots belonging to the first diameter class, the frequency of which was only estimated, we found out that the relative frequency of roots in the second diameter class was relatively high – almost one half of all the other diameter classes.

The lowest mean values of average length of root branches were found out in the first two root diameter classes. It was 31 cm in the first and 83 cm in the second root-diameter classes. We found out the highest values of average length of root branches in the last three root diameter classes. Similarly, the values of relative average length of root branches were the highest in the last three root-diameter classes. However, the values of total average length of root branches were the highest in the first root diameter classes, and these values continually decreased with increasing values of the root branch diameter (Fig. 4). The value of total average length of root branches was 109 m in the first root-diameter class, but on the other hand, it was only 0.28 m in the last root-diameter class. Similarly, the highest values of total relative average length of root branches were found out in the first root-diameter classes and the lowest values of total relative average length of root branches were found out in the last root-diameter classes.

DISCUSSION AND CONCLUSIONS

We found out that the frequencies of roots in the first diameter classes were relatively high in comparison with the frequencies of root branches in the

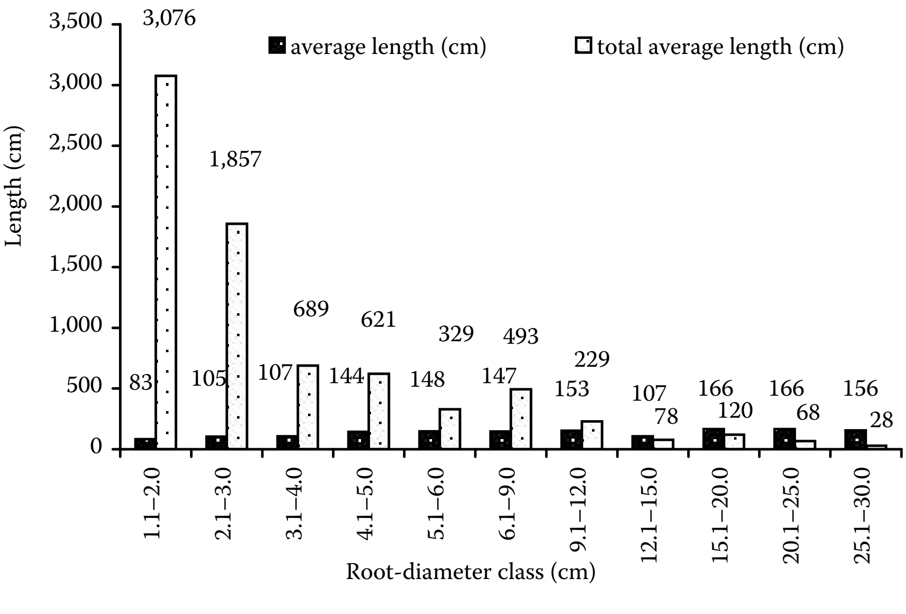

Fig. 4. Mean values of length of root branches according to individual root-diameter classes in Norway spruce

Table 1. Mean values of frequency and length of root branches according to individual root-diameter classes in Norway spruce

Parameter \ Diameter class	0.2–1.0	1.1–2.0	2.1–3.0	3.1–4.0	4.1–5.0	5.1–6.0	6.1–9.0	9.1–12.0	12.1–15.0	15.1–20.0	20.1–25.0	25.1–30.0
n (*p*)[1]	342.86	36.95	17.77	6.45	4.32	2.23	3.36	1.50	0.73	0.73	0.41	0.18
n (%)[2]	82.12	8.85	4.26	1.55	1.03	0.53	0.81	0.36	0.17	0.17	0.10	0.04
n without 0.2–1.0 (%)[3]	–	49.51	23.81	8.65	5.79	2.98	4.51	2.01	0.97	0.97	0.55	0.24
l (cm)[4]	31.81	83.25	104.50	106.74	143.85	147.88	146.70	152.92	107.00	165.50	165.50	156.00
l (%)[5]	2.10	5.51	6.91	7.06	9.52	9.78	9.70	10.12	7.08	10.95	10.95	10.32
l without 0.2–1.0 (%)[6]	–	5.63	7.06	7.21	9.72	9.99	9.91	10.33	7.23	11.18	11.18	10.54
$n \times l$ (cm)[7]	10,904.76	3,076.34	1,857.31	688.93	621.17	329.38	493.45	229.38	77.82	120.36	67.70	28.36
$n \times l$ (%)[8]	58.96	16.63	10.04	3.72	3.36	1.78	2.67	1.24	0.42	0.65	0.37	0.15
$n \times l$ without 0.2–1.0 (%)[9]	–	40.53	24.47	9.08	8.18	4.34	6.50	3.02	1.03	1.59	0.89	0.37

[1]Average number of root branches, [2]relative average number of root branches, [3]relative average number of root branches without the first root-diameter class, [4]average length of root branches, [5]relative average length of root branches, [6]relative average length of root branches without the first root-diameter class, [7]total average length of root branches, [8]total relative average length of root branches , [9]total relative average length of root branches without the first root-diameter class

higher root-diameter classes. Kodrík and Hlaváč (1994) analysed the root architecture of the Norway spruce in well-drained sites. They found out that the relative frequency of roots with the diameter smaller than 2 cm was about 50%, the relative frequency in the diameter class 2.1–7.0 cm was around 30%, and the rest was found out to belong to the diameter class 7.1 cm and higher. According to our results, the root frequency of up to 2 cm diameter was much higher in waterlogged sites. This phenomenon can be caused by high groundwater table in the site, resulting in the formation of a high amount of thin and long roots. Similarly, Konôpka (2005) found out larger quantities of roots, especially those with middle diameter and thin ones, on poorly drained sites. According to his results, the root systems were extremely long in poorly drained sites, so they were abundant in thinner roots. Kodrík (2002) analysed the frequency and thickness of the root branches with the diameter exceeding 1 cm in spruce trees growing in well-drained sites. He found out that the relative amount of roots with the diameter not larger than 3 cm was 59.5%, with the diameter 3.1–9.0 cm it was 28% and with the diameter exceeding 10 cm it was only 12.5% of the total root numbers in windthrown spruce trees. He, however, met a different situation with standing spruce trees. In this case, the relative amount of the roots with the diameter under 3 cm was 46.6%, with the diameter 3.1–9.0 cm 32.5% and with the diameter over 10 cm 20.9%, respectively. We found out higher amounts of root branches in the second and third diameter classes (together 73.4% in these two root diameter classes) after having excluded the first (only estimated) root-diameter class.

Schmid and Kazda (2001) discovered that the total number of roots per m^2 in the case of the diameter of 2–5 mm was 406, in the case of the diameter of 5–20 mm it was 63, while in the case of the diameter exceeding 20 mm two roots were observed in the spruce trees growing in well-drained monocultures. Kodrík (1992) observed the lowest weight of the underground biomass in the first (< 0.5 cm) and the highest weight of the underground biomass in the highest (> 10.0 cm) root-size classes in the Norway spruce growing in sites loaded with air pollution. Acoording to his results, the highest weight of the underground biomass of up to the 10.0 cm root diameter was found out in the third root-size class (2.1–5.0 cm). Vyskot (1993) found out the highest values of fresh weight of the Norway spruce underground biomass for the root thickness exceeding 10.0 cm, while the values of fresh weight of the underground biomass gradually decreased towards the smaller root diameters.

We found out the lowest values of the average length of root branches in the first two root-diameter classes, but, in opposite, the average values of total root branch length were the highest in these root-diameter classes. Similarly, Konôpka (1997) observed the highest value of total length of root branches in the first root diameter class (1.0–3.0 cm) in the spruce growing in well-drained sites. After a re-calculation of his data, we found out that the relative value of the total length of root branches with the diameter of 1.0–3.0 cm was 57.8% out of all root branches together. Similarly, after another re-calculation of our data, we found out that the relative value of total length of root branches with the diameter of 1.1–3.0 cm was 65.0% out of all root branches together (without the first root diameter class). This difference is not great, so it seems that there are no substantial differences between poorly drained and well-drained sites in total relative length of root branches in these root diameter classes.

Konôpka (2005) made a detailed comparison of the root system architecture between spruce trees growing in well-drained or poorly drained sites. He found out great differences in total length of roots between these two groups. He reports that the mean value of total root length was 58 m in poorly drained sites and 33 m in well-drained sites (trees with $D_{0.2}$ from 6.5 cm to 49.0 cm). He suggests that the average total length of root branches in the root-diameter class 1.0–2.5 cm was 33.3 m (after re-calculation it is 63.4% out of all root-diameter classes together) in the spruces growing on well-drained sites, and 72.4 m (after re-calculation it is 71.1% out of all root-diameter classes together) in those growing on poorly drained sites (selected trees with $D_{0.2}$ from 25.1 cm to 35.0 cm). It seems that the differences in relative values of total root length in the first root-diameter classes between trees growing in well-drained and poorly drained sites are not very great, although the differences in the absolute values of total root branch length are considerable. Based on this large total length of roots in poorly drained sites, we can predict higher weights and volumes of roots of spruce trees growing in these sites. Kodrík (2005) discovered the highest values of mean root length in the first diameter class (≤ 0.5 cm) while the mean values of root length decreased gradually towards the higher root diameter classes in the spruce trees growing in well-drained sites.

Gruber and Lee (2005) found out that the root structure of the Norway spruce in colluvial soil showed a distinct "sinker" type with many fine roots developed deeply into deep soil layers (over 140 cm). The spruce trees growing in brown soil showed, in spite of the fact that their roots were well developed, small numbers of roots thick in diameter. The root structure of the spruce trees growing in podzolic brown soil was of flat type or diagonal growing type with an intensive branch formation (Gruber, Lee 2005). The authors found out that the total mass of fine roots was 2,470 kg/ha in brown soil, 3,190 kg/ha in colluvial soil, and 5,680 kg/ha in shallower podzolic brown soil. Similarly, the high weight of fine roots in podzolic brown soil corresponds to our results: high values of root frequency and of total root length in the thinnest root-diameter classes in the spruce trees growing in shallow gley soil. It seems that the spruce trees growing in gley soil form a similar root structure as those growing in podzolic brown soil.

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Architektúra koreňových vetiev smrekov obyčajných (*Picea abies* [L.] Karst.) rastúcich na glejovej pôde

ABSTRAKT: V lokalite Hnilé Blatá (Vysoké Tatry) bola meraná štruktúra koreňových vetiev na vetrom vyvrátených smrekoch (*Picea abies* [L.] Karst.). Po vyčistení koreňových koláčov bola meraná početnosť, hrúbka a dĺžka jednotlivých koreňových vetiev. Jednotlivé koreňové vetvy boli zatrieďované do dvanástich hrúbkových tried – podľa ich hrúbky meranej v polovici dĺžky koreňovej vetvy. Zistili sme vysokú početnosť koreňových vetiev v prvých troch koreňovo-hrúbkových triedach; hodnoty priemernej početnosti koreňových vetiev plynule klesali s ich stúpajúcimi hrúbkami. Zistili sme aj najnižšie stredné hodnoty dĺžky koreňových vetiev v prvých dvoch koreňovo-hrúbkových triedach, avšak hodnoty celkovej priemernej dĺžky koreňových vetiev boli najvyššie v prvej koreňovo-hrúbkovej triede a postupne klesali so stúpajúcimi hodnotami hrúbky koreňových vetiev. Na základe vysokých hodnôt početností koreňov a celkovej dĺžky koreňov v najtenších koreňovo-hrúbkových triedach sa vidí, že smreky rastúce na glejovej pôde vytvárajú podobnú koreňovú štruktúru ako tie, ktoré rastú na podzolovej hnedozemi.

Kľúčové slová: *Picea abies*; koreňová vetva; glejová pôda

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