Structure of root branches in Norway spruce with respect to soil drainage

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Abstract

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We studied root branch structure in uprooted spruce trees (*Picea abies* [L.] Karst.) in the localities Hnilé Blatá (the High Tatra Mts.) (waterlogged) and Zemská (the Low Tatra Mts) (well-drained). After cleaning the root plates, we measured the number, diameter and length of individual root branches. Individual root branches were classified in twelve diameter classes – according to their diameter measured in the middle of root branch length. Mean values of absolute frequency of root branches in the first eight root-diameter classes (0.2–12.0 cm) were higher in spruce trees growing on well-drained sites, but for the same sites, we found out lower mean values of absolute frequencies of root branches in the last four root-diameter classes (12.1–30.0 cm). We found out unproportionally higher mean values of root branch length in all root-diameter classes in spruce trees growing on waterlogged sites. The mean value of total length of root branches was two times higher in the first root-diameter class (0.2–1.0 cm); and, similarly, mean values of total length of root branches were noticeably higher in the last four root-diameter classes (12.1–30.0 cm) in spruce trees growing on waterlogged sites. Based on our results, it seems that there is practically no difference in total mean length of root branches (all root-diameter classes together) with diameter exceeding 1 cm between spruce trees growing on waterlogged and well-drained sites. According to our results, spruce trees growing on well-drained sites form shorter root branches in the thinner root-diameter classes, but the frequency of these root branches is higher in comparison with spruce trees growing on waterlogged sites. Therefore, the total length of root branches (with diameter exceeding 1 cm) in spruce trees growing in waterlogged and well-drained sites is almost the same.

Key words

Picea abies, root branch, waterlogged sites

Introduction

The morphology and size of tree root system is predetermined by the genetic properties of particular tree species, as manifested through inter-specific differences. However, the environment (especially soil conditions) can influence root system features considerably (Coutts, 1987). In case of undisturbed development, the spruce forms a typical shallow root system characterised by presence of large, horizontal, lateral roots just below the soil surface and small roots branching down vertically from the first ones. A high groundwater table can also reduce maximum depth of root penetration. Kodrík (1998) mentions that the level of underground water considerably influences the root system formation. Köstler et al. (1968) report that spruce forms extreme shallow root system on poorly drained sites. According to Konôpka (2003), the roots do not need or cannot penetrate through deeper soil horizons, and shallow and unstable root systems are formed on waterlogged sites.

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Crow (2005) mentions that poor gas exchange in waterlogged soils causes depleting these soils of oxygen and brings about anaerobic conditions resulting in root death. In general, soils with permanently high water tables cause trees to develop very shallow, widespread rooting systems.

The main problem in 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. Overcoming this obstacle is a necessary condition for the correct study. In preliminary research on tree roots, the excavation method when the roots are obtained from the soil by digging is the most common. Using trees which are naturally uprooted from the soil, eg by wind or by a winch, is also effective.

The aim of this paper is to compare the diameter and length structure of root branches between spruce trees growing in waterlogged and well-drained sites.

Material and methods

The structure of root branches was measured on Norway spruce (*Picea abies* [L.] Karst.) in the locality Hnilé Blatá (the High Tatra Mts) (waterlogged site) and the locality Zemská (the Low Tatra Mts) (well-drained site). The forest stand 396A (waterlogged) is uneven-aged, with the dominant stand layer 90 years old, south aspect, 5–10% slope, altitude is about 950 m asl. The stand consists of three forest biotopes (see Table 1). The properties of soil are given in Table 2. Spruce is the dominant woody plant on the site, but the birch and alder are also quite abundant. The soil is rather waterlogged, with low incidence of peat.

The forest stand 47A (well-drained site) is uneven-aged, with the over storey 80 years old, north exposure, 40% slope, altitude is about 950 m asl. The stand consists of one forest biotope (see Table 1). The soil properties are given in Table 2. The forest stand 47A consists of Norway spruce with 100% proportion.

The study ran on 22 uprooted spruce trees on waterlogged site and 9 uprooted spruce trees on well-drained site. The examined trees were selected by random sampling from uprooted spruces scattered across the stand. The root plates of the measured spruce trees were cleared of soil up to the soil surface, by using hand tools. It means that we did not excavate the whole root plates. We only cleared visible surface of root plates up to the hinge (see Fig 1). After cleaning the root plates, the parameters of root branches were measured. The number, length and diameter of the individual root branches were measured as illustrates Fig 2. An individual root branch is defined as the most vigorous unbroken 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 in twelve diameter classes according to their diameter measured at the middle of 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

Table 1. Habitat classification of the analysed stands (according to Stanová and Valachovič, 2002)

Stand	Stand area [%]	Forest type according to Slovak forest typology		CORINE[1)]		EUNIS[2)]	
		Code	Name	Code	Name	Code	Name
396A (waterlogged)	50	0023	Peaty fir-spruce	44.A4	*Sphagnum* spruce woods	G3.E6	Nemoral bog *Picea* woods
	40	0012	Birch-alder on a fluvio-glacial substrate	44.21	Montane grey alder galleries	G1.121	Montane *Alnus incana* galleries
	10	6124	Bilberry-spruce with fir	42.1	Fir forests	G3.1	[*Abies*] and [*Pinus*] woodland
47A (well-drained)	100	6232	Nutritive spruce-firs of higher degree	42.1	Fir forests	G3.1	[*Abies*] and [*Pinus*] woodland

[1)]According to classification by Commission of European Communities

[2)]According to EUNIS Habitat classification

Table 2. Soil characteristics of the analysed forest stands

Stand	Soil type[1)]	Soil skeleton / average size	Proportion of skeleton
396A (waterlogged)	Haplic Stagnosols	Stony / 20 cm	20%
47A (well-drained)	Dystric Cambisols	Gravel / 4 cm	50%

[1)]According to classification of WRB (World Reference Base for Soil Resources, 1994)

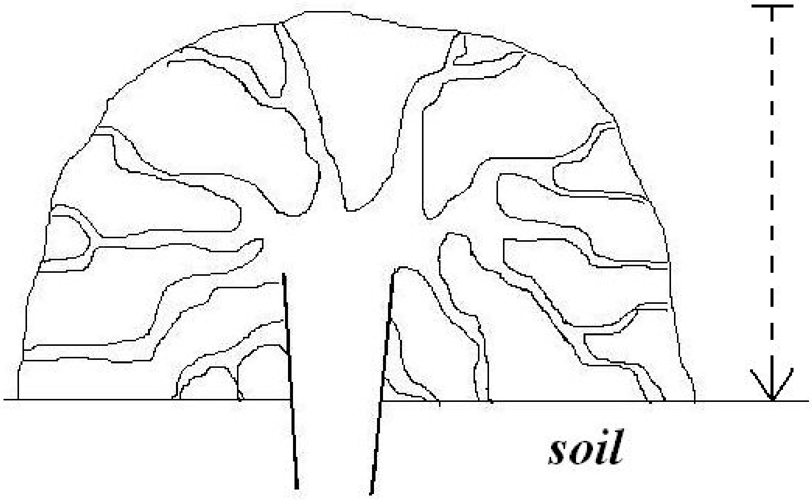

Fig 1. Root-plate surface containing the analysed root branches – cleaning of the visible part of the root plate up to the soil surface (up to the hinge)

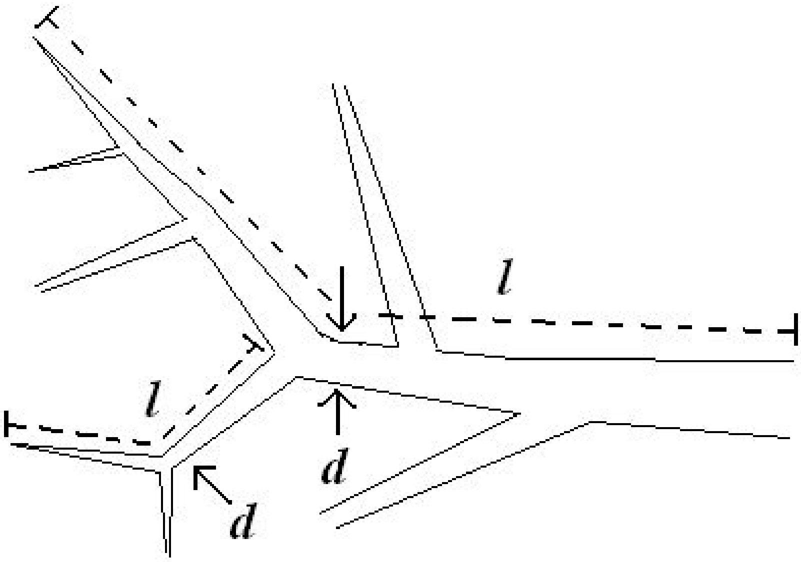

Fig 2. Measurement of diameter (*d*) and length (*l*) of individual root branches

25.1–30.0 cm. Number and length of the individual root branches in the first root-diameter class (0.2–1.0 cm) were only estimated, consequently, these data are only approximate. Mean values of the number and length of root branches were calculated for each root-diameter class.

Results

Mean values of aboveground parameters of analysed spruce trees are given in Table 3. Mean values of frequency and length of root branches according to individual root-diameter classes are given in Table 4. We found out differences in the diameter and length structure of root branches between spruce trees growing on waterlogged and well-drained sites. Average values of absolute frequencies of root branches in the first eight root-diameter classes (0.2–12.0 cm) were higher for spruce trees growing on well-drained sites. Moreover, these values were more than two times higher in the first four root-diameter classes. On the contrary, in the last four root-diameter classes (12.1–30.0 cm), we found out lower mean values of absolute frequencies of root branches in spruce trees growing on well-drained sites (Figs 3 and 4). The differences in the relative frequencies of root branches in individual root-diameter classes were not such significant, and higher mean values of relative frequency of root branches were found out in the last four root-diameter classes (12.1–30.0 cm) on waterlogged sites. 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 root branches was higher especially in the second (1.1–2.0 cm) root-diameter class – 57.12% in spruce trees growing on well-drained sites and 49.51% in spruce trees growing on waterlogged sites. On the other hand, after having excluded the roots belonging to the first diameter class, the mean values of relative frequency of root branches in the last four root-diameter classes (12.1–30.0 cm) were unproportionally higher for spruce trees growing on waterlogged sites.

We found unproportionally higher mean values of length of root branches in all root-diameter classes in spruce trees growing on waterlogged sites (Figs 5 and 6). These values were approximately two times higher in the first eighth root-diameter classes in spruce trees growing on waterlogged sites. Interestingly, on waterlogged sites, the mean value of length of root branches was four times higher in the first root-diameter class in comparison to well-drained sites. The differences in the relative values of length of root branches between waterlogged and well-drained sites were not so noticeable. Only in the first (0.2–1.0 cm) root-diameter class, the mean value of relative length of root branches was 2.5 times higher in spruce trees growing on waterlogged sites.

Table 3. Mean values of aboveground parameters of the analysed spruce trees

Stand	Stem diameter at breast height	Stem diameter 20 cm from the ground level	Tree height	Crown width	Crown length	Crown proportion index
	DBH	$D_{0.2}$	H	CW	L	L / H × 100
	[cm]	[cm]	[m]	[m]	[m]	[%]
396A (waterlogged)	31.2	40.6	22.3	5.3	17.2	76.8
47A (well-drained)	45.5	62.5	32.2	6.9	18.5	57.6

Table 4. Mean values of frequency and length of root branches corresponding to the individual root-diameter classes in Norway spruce

Diameter class (cm) / Parameter	Site	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]	Waterlogged	342.86	36.95	17.77	6.45	4.32	2.23	3.36	1.50	0.73	0.73	0.41	0.18
	Well-drained	773.33	99.00	38.33	16.17	6.17	4.17	5.00	3.17	0.50	0.55	0.17	0.11
n [%][2]	Waterlogged	82.12	8.85	4.26	1.55	1.03	0.53	0.81	0.36	0.17	0.17	0.10	0.04
	Well-drained	81.69	10.46	4.05	1.71	0.65	0.44	0.53	0.33	0.05	0.06	0.02	0.01
n without 0.2–1.0 [%][3]	Waterlogged	–	49.51	23.81	8.65	5.79	2.98	4.51	2.01	0.97	0.97	0.55	0.24
	Well-drained	–	57.12	22.12	9.33	3.56	2.40	2.88	1.83	0.29	0.32	0.10	0.06
l [cm][4]	Waterlogged	31.81	83.25	104.50	106.74	143.85	147.88	146.70	152.92	107.00	165.50	165.50	156.00
	Well-drained	7.42	31.29	45.41	77.73	76.70	78.06	78.61	67.92	91.28	101.02	119.05	147.28
l [%][5]	Waterlogged	2.10	5.51	6.91	7.06	9.52	9.78	9.70	10.12	7.08	10.95	10.95	10.32
	Well-drained	0.80	3.39	4.93	8.43	8.32	8.47	8.53	7.37	9.90	10.96	12.92	15.98
l without 0.2–1.0 [%][6]	Waterlogged	–	5.63	7.06	7.21	9.72	9.99	9.91	10.33	7.23	11.18	11.18	10.54
	Well-drained	–	3.42	4.97	8.50	8.39	8.54	8.60	7.43	9.98	11.05	13.02	16.11
n × l [cm][7]	Waterlogged	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
	Well-drained	5,796.94	3,101.98	1,743.14	1,238.12	472.60	337.32	390.00	209.03	45.82	55.35	19.83	16.20
n × l [%][8]	Waterlogged	58.96	16.63	10.04	3.72	3.36	1.78	2.67	1.24	0.42	0.65	0.37	0.15
	Well-drained	43.18	23.10	12.98	9.22	3.52	2.51	2.90	1.56	0.34	0.41	0.15	0.12
n × l without 0.2–1.0 [%][9]	Waterlogged	–	40.53	24.47	9.08	8.18	4.34	6.50	3.02	1.03	1.59	0.89	0.37
	Well-drained	–	40.66	22.85	16.23	6.19	4.42	5.11	2.74	0.60	0.73	0.26	0.21

[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

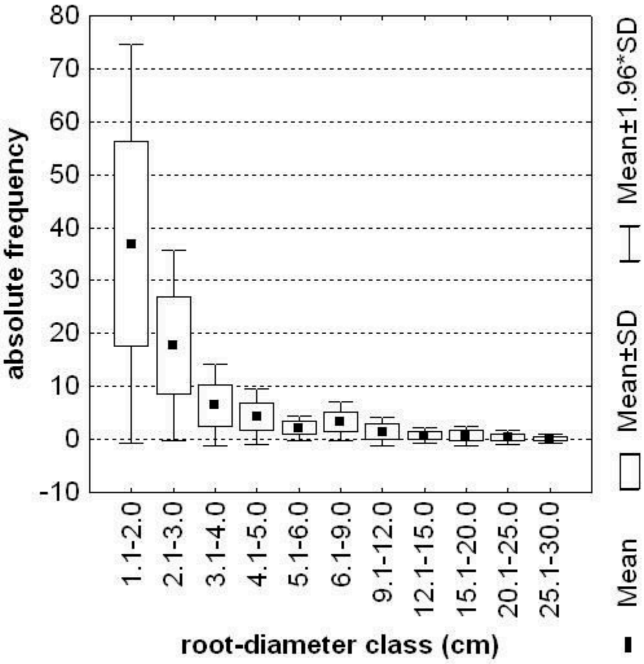

Fig 3. Mean values of frequency of root branches according to the individual root-diameter classes in Norway spruce growing on waterlogged sites

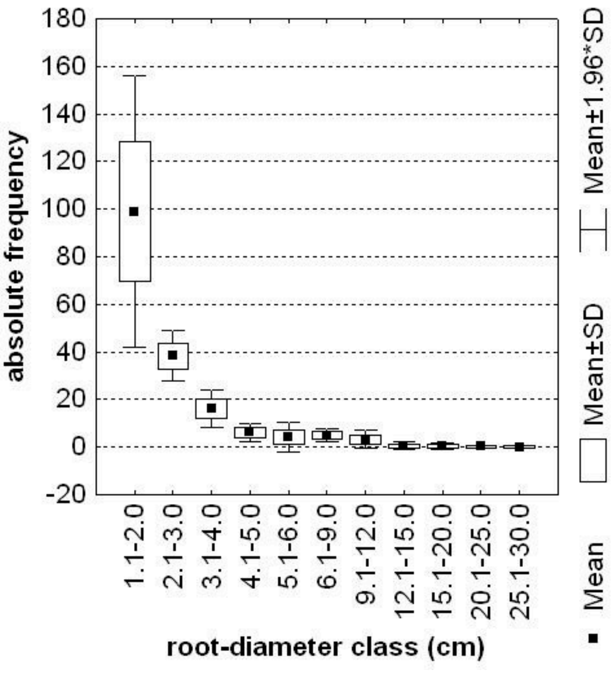

Fig 4. Mean values of frequency of root branches according to the individual root-diameter classes in Norway spruce growing in well-drained sites

Mean value of total length of root branches was two times higher in the first root-diameter class in spruce trees growing on waterlogged sites and these values were noticeably higher in the last four root-diameter classes (12.1–30.0 cm) on waterlogged sites, as well (Figs 5 and 6). Interestingly, we found that the mean value of total length of root branches was two times higher in the root-diameter class 3.1–4.0 cm in spruce trees growing in well-drained sites. We also detected a rather higher mean value of total relative length of root branches in the first root-diameter class in spruce trees growing on waterlogged sites. However, these values

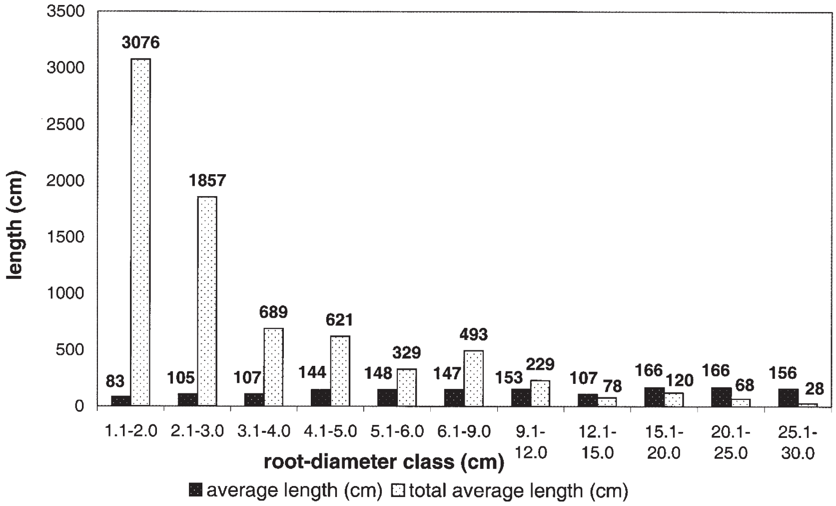

Fig 5. Mean values of length of root branches according to the individual root-diameter classes in Norway spruce growing on waterlogged sites

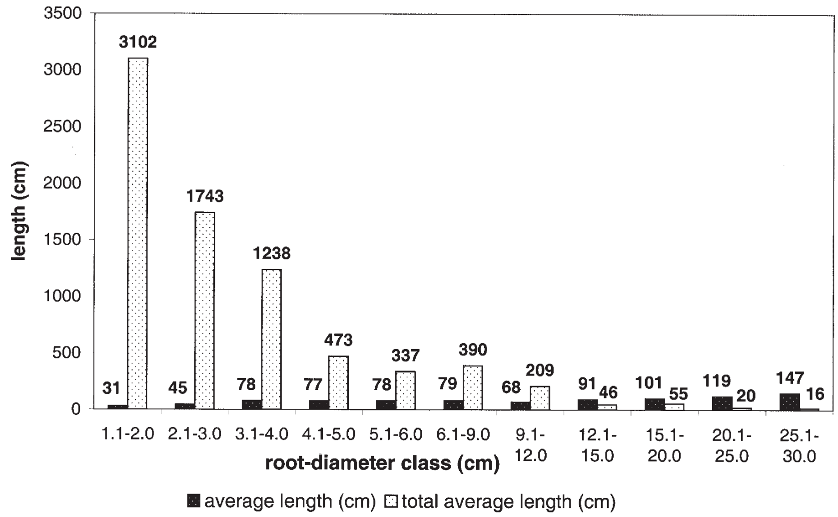

Fig 6. Mean values of length of root branches according to the individual root-diameter classes in Norway spruce growing on well-drained sites

were rather higher in the second (1.1–2.0 cm) and the fourth (3.1–4.0 cm) root-diameter class on well-drained sites. After having excluded the roots belonging to the first diameter class, we found out that the mean values of total relative length of root branches were higher especially in the fourth (3.1–4.0 cm) root diameter class in spruce trees growing in well-drained sites and these values were markedly higher in the last four root-diameter classes (12.1–30.0 cm) on waterlogged sites.

Discussion and conclusions

We found out that the frequencies of roots in the lower (thinner) root-diameter classes were higher in spruce trees growing on well-drained sites. Kodrík and Hlaváč (1994) analysed the root architecture of Norway spruce on well-drained sites. They found out that the relative frequency of roots with 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 belonging to the diameter class 7.1 cm and higher. According to our results, the root frequency up to 2 cm diameter was much higher on both sites. However, after having excluded the roots belonging to the first diameter class, we found out the relative frequency of root branches up to 2 cm diameter was slightly higher (57%) in comparison to the results of Kodrík and Hlaváč (1994). Interestingly, the frequency of root branches in the thicker root-diameter classes was higher in spruce trees growing on waterlogged sites. On the other hand, Konôpka (2005) found larger quantities of roots, especially those with medium and small diameter, on poorly drained sites than on well-drained sites. According to his results, the root systems were extremely long on poorly drained sites, so they had very abundant thinner roots. Kodrík (2002) analysed the frequency and thickness of root branches with diameter exceeding 1 cm in spruce trees growing on well-drained sites. He found out that the relative amount of roots with diameter not larger than 3 cm was 59.5%, in case of diameter 3.1–9.0 cm it was 28% and with diameter exceeding 10 cm it was only 12.5% of the total root numbers in wind thrown spruce trees. He, however, met different situation with standing spruce trees. In this case, the relative amount of roots with the diameter under 3 cm was 46.6%, with the diameter 3.1–9.0 cm it was 32.5% and with the diameter exceeding 10 cm it was 20.9%. After having excluded the first (only estimated) root-diameter class, we found out higher amounts of root branches in the second and the third root-diameter class (together 79.2% in these two root diameter classes) in spruce trees growing on well-drained sites in comparison to the results obtained by Kodrík (2002).

In general, we obtained a high frequency for root branches in the first three root-diameter classes and the values of average frequency of root branches slightly declining with increasing their diameters. Schmid and Kazda (2001) discovered that the total number of roots per square metre in case of diameter 2–5 mm was 406, in case of diameter 5–20 mm it was 63, and in case of diameter exceeding 20 mm, there were observed two roots in the spruce trees growing in well-drained monocultures. According to our results, 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 root branch diameter. Kodrík (2005) observed the highest values of mean root length in the first diameter class (≤ 0.5 cm) and the mean values of root length decreased gradually towards the higher root diameter classes in spruce trees growing on well-drained sites. Vyskot (1993) found the highest values of fresh weight of Norway spruce underground biomass for root thickness exceeding 10.0 cm, and these values gradually decreased towards the smaller root diameters. Kodrík (1992) observed the smallest weight of underground biomass in the first (<0.5 cm) and the highest weight of underground biomass in the highest (>10.0 cm) root-size class in Norway spruce growing on sites loaded with air pollution. Based on his results, the highest weight of underground biomass up to the 10.0 cm root diameter was found in the third root-size class (2.1–5.0 cm).

We obtained the lowest values of average length of root branches in the lower (thinner) root-diameter classes, but on the contrary, the average values of total root branch length were the highest namely 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 spruce trees growing on well-drained sites. After a re-calculation of his data, we have found out that the relative value of total length of root branches with diameter 1.0–3.0 cm was 57.8% from all root branches together. Similarly, re-calculation of our data resulted in finding that the relative value of total length of root branches with diameter 1.1–3.0 cm represented 65.0% of all root branches together (after having excluded the first root-diameter class) on waterlogged sites and it was 63.5% in spruce trees growing on well-drained sites. This difference is not big, therefore it seems that there are not substantial differences in total relative length of root branches in these root diameter classes between waterlogged and well-drained sites.

Konôpka (2005) made a detailed comparison of root system architecture between spruces growing in well-drained and poorly drained sites. He observed big differences in total length of roots between spruces growing in poorly drained and well-drained sites. He reports that the mean value of total root length was 58 m on waterlogged sites and 33 m on 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 a re-calculation it was 63.4% of the value obtained for all root-diameter classes together) in spruce trees growing on well-drained sites and 72.4 m (after a re-calculation it was 71.1% of the value for all root-diameter classes together) in spruces growing on waterlogged sites (selected trees with $D_{0.2}$ from 25.1 cm to 35.0 cm). Similarly, we found out that the mean value of total length of root branches was higher on waterlogged sites (by re-calculation we obtained 185 m for the all root-diameter classes together) in comparison to the well-drained sites (the re-calculation resulted at 134 m for all root-diameter classes together). However, after having excluded the first root-diameter class, we found out that the mean value of total length of root branches obtained for all root-diameter classes together was almost the same on waterlogged (75.6 m after re-calculation) and well-drained sites (76.3 m after re-calculation). Similarly, by re-calculation, we found out that the mean value of total length of root branches in the root-diameter classes 1.1–3.0 cm was 48.5 m (by re-calculation we obtained 63.5% for all root-diameter classes together) in spruce trees growing on well-drained sites and it was 49.3 m (by re-calculation obtained 65.0% for all root diameter classes together) on waterlogged sites.

Based on our results it seems that the total mean length of root branches (all root-diameter classes together) with diameter exceeding 1 cm is almost the same in spruce trees, growing both on waterlogged and well-drained sites. Rastin and Mintenig (1992) found out that the horizontal roots of Norway spruce at distance of 40 cm and especially 80 cm from the centre of the rootstocks were thicker on waterlogged soil types than on brown forest soil (well-drained). The spruce trees growing on brown forest soil also developed shorter and thinner horizontal roots than those growing on waterlogged soil types. Similarly, according to our results, spruce trees growing on well-drained sites form shorter root branches in case of thinner root-diameter classes, but the frequency of these root branches is higher in comparison with spruce trees growing on waterlogged sites. Therefore, there is practically no difference between total length of root branches (with diameter exceeding 1 cm) in spruce trees growing in waterlogged and well-drained sites. This contradiction to the results of Konôpka (2005) can be caused by different growth conditions in forests in that we carried out our research. Konôpka (2005) pursued his research in two localities with different water regime in the High Tatra Mts. Spruce trees analysed by this author, showed very similar aboveground parameters in both localities. The author reports that the mean values of stem diameter $D_{0.2}$ (measured at 20 cm from the ground level) of the analysed spruce trees showed no differences between the localities. The obtained values were 22.8 cm for well-drained and 21.7 cm for waterlogged sites. We studied spruce trees growing under different local growth conditions: waterlogged sites in the High Tatra Mts and well-drained sites in a locality richer in minerals, situated in Low Tatra Mts. Therefore, the aboveground parameters found for the analysed spruce trees showed differences between the two localities – the mean value of stem diameter $D_{0.2}$ of analysed spruce trees was 40.6 cm on waterlogged sites, but it was 62.5 cm on the well-drained sites. Therefore, the results of Konôpka (2005) seem to be more relevant in comparison with our results, our results, however, also provide a certain insight in the architecture of root branches of Norway spruce trees growing on sites with different water regimes.

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Štruktúra koreňových vetiev smreka obyčajného vzhľadom na zamokrenie pôdy

Súhrn

V lokalite Hnilá Blatá (Vysoké Tatry) (podmáčané stanovištia) a lokalite Zemská (Nízke Tatry) (nepodmáčané stanovištia) bola meraná štruktúra koreňových vetiev na vyvrátených smrekoch (*Picea abies* [L.] Karst.). Po vyčistení koreňových koláčov sme merali početnosť, hrúbku a dĺžku jednotlivých koreňových vetiev. Jednotlivé koreňové vetvy boli zatrieďované do dvanástich hrúbkových tried podľa ich hrúbky meranej v polovici dĺžky koreňovej vetvy. Priemerné hodnoty absolútnych početností koreňových vetiev v prvých ôsmich koreňovo-hrúbkových triedach (0,2–12,0 cm) boli vyššie pri smrekoch rastúcich na nepodmáčaných stanovištiach, pričom v prvých štyroch koreňovo-hrúbkových triedach boli tieto hodnoty až viac ako dvojnásobne vyššie (Tabuľka 4). V posledných štyroch koreňovo hrúbkových triedach (12,1–30,0 cm) sme naopak zistili menšie hodnoty priemerných početností koreňových vetiev pri smrekoch rastúcich na nepodmáčaných stanovištiach (Obrázok 3 a 4). Rozdiely v relatívnych početnostiach koreňových vetiev v jednotlivých koreňovo-hrúbkových triedach medzi týmito dvomi skupinami smrekov neboli až také výrazné. Zistili sme značne vyššie hodnoty priemerných dĺžok koreňových vetiev vo všetkých koreňovo-hrúbkových triedach pri smrekoch rastúcich na podmáčaných stanovištiach v porovnaní s nepodmáčanými stanovišťami. Priemerné hodnoty celkovej dĺžky koreňových vetiev boli dvojnásobne vyššie v prvej koreňovo-hrúbkovej triede a taktiež boli výrazne vyššie v posledných štyroch (12,1–30,0 cm) koreňovo-hrúbkových triedach pri smrekoch rastúcich na podmáčaných stanovištiach (Obrázok 5 a 6).

Na základe našich výsledkov sa zdá, že celková priemerná dĺžka koreňových vetiev (spolu všetky koreňovo-hrúbkové triedy) pri koreňoch s hrúbkou nad 1 cm je pri smrekoch rastúcich na podmáčaných a nepodmáčaných stanovištiach takmer rovnaká. Podľa našich výsledkov korene smrekov rastúcich na nepodmáčaných stanovištiach vytvárajú najmä v tenších koreňovo-hrúbkových triedach kratšie koreňové vetvy, ale ich početnosť je oproti podmáčaným stanovištiam vyššia. Tým sú celkové priemerné dĺžky koreňových vetiev (s hrúbkou nad 1 cm) medzi smrekmi rastúcimi na podmáčaných a nepodmáčaných stanovištiach takmer rovnaké.