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DISTRIBUTION AND MINERAL ELEMENT CONTENT OF FINE ROOTS IN THE NATURAL NORWAY SPRUCE FOREST STAND OF CHORNOGORA MOUNTAIN REGION (EASTERN CARPATHIANS, UKRAINE)

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The biomass and metal contents (Zn, Cd, Ni, Pb, Cu, Sr, Mn, Fe, K, Na, Ca, Mg, Al) of fine and coarse roots in the mature Norway spruce forest stand of Chornogora mountain region (Eastern Carpathians, Ukraine) were investigated. The result indicated that the root biomass decreased with increasing soil depth. The biomass and density of fine roots < 2 mm in diameter in litter layer accounted for 15% of the total amount in 40 cm soil profile. In litter and 0-40 cm of soil profile the roots biomass was approximately 2000 g/m^2 for a live roots, representing 90% of the total. The necromass does not exceed 10% of the total. Fine roots are more metal rich as compared to the coarse ones. The diameter classes were found to have a remarkable reduction in all elements, except Al, in coarse roots sizes (2–5 mm and 5–10 mm) as compared to fine roots (<2mm). Significant difference was found in Zn, Cd, K and Al, Pb, Fe concentrations between live and dead roots. Base cations/Al-balance in fine roots is much more then possible dangerous level 0.2 and does not pose a risk to forest health in the region.

Keywords: Norway spruce forest, fine roots, biomass, trace elements, nutrients.

Generally, fine roots are defined as roots less than 2 mm in diameter and very fine roots less than 0.5 mm in diameter (Gill & Jackson 2000). Thicker roots are called coarse roots. Fine roots play an important role in regulating the biogeochemical cycles of forest ecosystems. It has been estimated that more than half of annual total net primary production by forests allocated to fine roots [9] although fine root biomass contributes relatively little to total forest biomass [18] and the amount of carbon and nutrients returned to the soil from fine root turnover may equal or exceed that from leaf litter [15, 16]. Fine roots also have high levels of nutrient concentration, turnover and decomposition rates, which affect nutrient availability in soils. Therefore, data regarding fine roots are critical to the understanding of nutrient cycles of forest ecosystems [19].

Materials and methods

Site

R*esearch was conducted* in *The Carpathian National Nature Park located on the north-eastern slopes of the Ukrainian Carpathians.* A natural Norway spruce *(Picea abies*, (L.) H.Karst.) is monodominant mature forest with no human interference located on south-eastern slope, 50 m bellow of upper timberline *at elevation of 1,400 m* and nearby Pozhyzhevska weather station (lat. 49°08′39’’N; long. 24°31′25’’W) was selected as r*esearch* area. A representative stand with a slope of 15° in a 20 by 50-m plot with close up canopy 0.7, tree diameters at 30–40 cm and tree height at 30 m was randomly selected as the sample area. The average annual amount of precipitation is about 1,500 mm and the mean annual temperature is about 3°C.

Sampling and fine root processing

An excavation method was used to obtain soil samples. Three distances – 100, 150, and 200 cm from the base of the trunk were selected. Samples were taken at three duplicates at every distance. A 25 by 25-cm square sample hole was excavated at each spot at these 3 distances. Preliminary observations indicated that soil deeper than 40 cm contained a fairly small amount of fine roots. Therefore, the excavation process was stopped at 40 cm in depth. Soil excavated from these layers was stored in sealed plastic bags which were brought back to the laboratory for further categorization. In the laboratory these samples were placed in 1 mm sieves and washed with water. Fine roots were dried at room temperature and weighed. Each root sample was ground and mineralized using a dry combustion method (400–450°C). Ash was digested with HNO_3 and solution was analyzed for Zn, Cd, Ni, Pb, Cu, Fe, Mn with flame atomic absorption or flame atomic emission spectrometry for K, Na, Sr. The Aluminon method was used for Al [2]. Ca and Mg were determined with complexometric titration [1].

Results and discussions

Differences in the fine root biomass did not reach statistical significance among distances from the tree, so that we combined the results from different distances from the trunk and consider them as average values in forest stand. However, there were noticeable differences found in fine root biomass (Table 1) and densities (Table 2) among different soil layers. Both fine root density and biomass were the highest in the surface soil and decreased sharply towards deeper soil layers, as reported also by many other investigators [5, 11, 13]. Therefore, 90% of the biomass of fine roots was concentrated in soil of 0–20 cm in depth including litter above. The findings are within data published earlier by Finér et al. (2007) [6], where in boreal forests fine roots biomass achieves 80–90% of total fine roots located in the top 30 cm, or even top 20 cm. For fine roots of < 2 mm in diameter, the percentage of biomass at this depth was as high as 82%. Noteworthy the biomass and density of fine roots < 2 mm in diameter in litter layer accounted for 15% of the total. Fine root biomass (< 2 mm) in boreal forests generally ranges between 330 and 748 g/m^{-2} [6, 19]. The biomass for these size roots in Chornogora was within the same range. The necromass amounted to 100 g/m^2 was less than 10% of the total fine root content and compared with Majdi and Persson (1993) [12], Helmisaari and Hallbäcken (1998) [10], Carnol et al. (1999) [3] and Per H. Nygaard & Helene A. de Wit (2004) [14]. A small fraction of necromass may be an indicator of a highly vital root system.

Table 1

Fine root biomass (g/m^2) in the litter and upper 40 cm of soil in the natural Norway spruce monodominant forest of Chornogora mountain region (Eastern Carpathians, Ukraine) (mean±standard deviation, n=9), 08.2014

Soil layer, cm	Root diameter, mm					Sum
	0-2	2-5	5-10	10-20	20-50	
A_0, 3-0	61±48 (15)[3*] –	7±5 (2) 0.5±0.5(1)[4*]	–[2*]	–	–	68 (4)
A, 0-10	186±116 (46) –	118±49 (39) –	214±104 (51) –	465±288 (60) –	–	983 (50)
AB, 10-20	86±114 (21) -	94±93 (30) 4±3 (1)	168±89 (39) 10±7 (2)	255±40 (33) 61±20 (8)	38[1*] (100) –	714 (36)
AB, 20-40	71 (17) -	60 (20) 30±20 (9)	24 (6) 10±9(2)	–	–	195 (10)
Total	402	314	426	781	38	1960

Comments: [1]*roots were found in only one from total number of duplicates (the result was divided into 9);
[2]*roots were not found;
[3]*numbers in parentheses are percentages of the total;
[4]*data below the line are dead root biomass.

Table 2

Fine root density (kg/m^3) in the litter and upper 40 cm of soil in the natural Norway spruce monodominant forest of Chornogora mountain region (Eastern Carpathians, Ukraine) (mean±standard deviation, n=9), 08.2014

Soil layer, cm	Root diameter, mm				
	0-2	2-5	5-10	10-20	20-50
A_0, 3-0	20.3±16.0	2.3±1.7	–**	–	–
A, 0-10	18.6±11.6	11.8±4.9	21.4±10.4	46.5±28.8	–
AB, 10-20	8.6±11.4	9.4±9.3	16.8±8.9	25.5±4.0	3.8*
AB, 20-40	3.5	3.0	1.2	–	–

Comments: *roots were found in only one from total number of duplicates (the result was divided into 9); **roots were not found.

In general, fine roots are considered to be rich in nutrient concentration. The presented study also revealed that maximum nutrient concentrations were found in fine roots (<2 mm). The diameter classes were found to have a remarkable reduction in all elements, except Al, in coarse roots sizes (2–5 mm and 5–10 mm) as compared to fine roots (Table 3). In many cases there was no significant difference between the 2–5 and 5–10 mm sizes of coarse roots. Noteworthy the remarkable increasing of Al, Pb, Fe and decreasing of Zn, Cd, K concentrations in dead roots compared to living ones. In the first case that may be caused by passive transport in "soil solution–roots tissues" system and in the second – by retranslocation of elements from dead to living roots. No statistically significant difference in concentrations of other analyzed elements probably indicates that retranslocation might not be a factor for them. Very little information is available

Table 3

Nutrient concentrations (mean±standard deviation) of fine roots in the natural Norway spruce monodominant forest of Chornogora mountain region (Eastern Carpathians, Ukraine), n=9, 08.2014

Roots, mm	Zn	Cd	Ni	Pb	Cu	Sr	Mn	Fe	K	Na	Ca	Mg	Al
	mkg/g								mg/g				
							A_0, 3-0						
0–2	58±8	1.5±0.3	3.3±0.7	9±4	7±6	12±7	182±53	178±97	0.9±0.3	0.16±0.06	3.2±0.6	0.7±0.1	0.4±0.3
2–5	53±6	1.1±0.8	2.8±1.3	4±2	4±1	15±6	85±60	98±50	1.1±0.1	0.17±0.08	2.8±0.2	0.7±0.1	0.2±0.1
	35	0.8	1.1	16	5	9	166	205	0.6	0.36	3.1	1.2	0.2
							A, 0-10						
0–2	81±12	2.0±0.7	4.1±1.0	70±30	6±1	21±12	103±74	555±140	1.8±0.4	0.24±0.13	3.5±0.7	0.8±0.1	1.8±0.4
2–5	67±12	1.1±0.8	2.2±0.5	39±14	4±1	16±9	75±29	229±221	1.5±0.5	0.15±0.07	3.3±0.9	0.8±0.2	1.4±1.7
5–10	50±14	0.8±0.1	1.6±1.0	38±24	4±1	14±8	54±26	321±323	1.5±0.6	0.14±0.09	3.5±0.9	0.5±0.1	1.8±1.8
10–20	33±26	0.5±0.3	1.8±1.0	28±24	3±1	9±8	30±25	400±560	1.0±0.7	0.10±0.08	2.3±2.3	0.3±0.2	2.0±1.9
							AB, 10-20						
0–2	96±25	1.4±0.7	3.4±5.4	36±27	5±1	13±8	91±31	404±658	1.0±0.3	0.35±0.59	2.8±0.9	0.8±0.4	1.8±1.3
2–5	89±24	1.0±0.2	2.2±1.0	40±22	4±1	13±6	59±34	301±183	1.2±0.3	0.26±0.29	2.6±1.0	0.3±0.2	2.3±1.3
	15	0.3	4.6	49	8	7	14	828	0.39	0.57	0.7	0.1	10.2
5–10	57±20	0.7±0.3	1.5±1.1	24±13	3±1	12±6	43±28	272±189	1.3±0.7	0.14±0.11	2.4±1.2	0.5±0.2	2.6±2.1
	58	1.1	2.8	44	4	5	50	441	0.7	0.25	2.4	0.5	6.4
10–20	51±28	0.6±0.4	1.6±0.3	34±25	4±2	7±2	40±47	392±263	0.7±0.4	0.08±0.05	1.8±1.0	0.4±0.3	3.4±3.9
							AB, 20-40						
0–2	91±29	1.5±0.5	4.1±1.6	39±37	6±1	28±12	54±18	743±649	1.7±0.7	0.52±0.73	1.9±0.3	1.0±0.7	4.4±2.0
2–5	99±28	1.2±0.2	2.1±0.6	15±7	4±1	17±1	45±4	121±10	1.2±0.1	0.08±0.04	2.1±0.1	0.7±0.1	1.4±0.3
	42	0.3	1.3	20	4	15	25	541	0.7	0.5	1.6	0.5	4.3
5–10	115	0.5	1.4	11	3	21	44	107	1.0	0.09	2.6	0.6	0.6
	14	0.1	0.4	12	6	6	7	279	0.4	0.14	0.5	0.2	3.3

Comments: *data below the line are dead root element content (mixed sample was analyzed).

on the content of macronutrients and trace elements especially in fine roots of Norway spruce forests. So that we have no opportunity to compare our results to the values for other regions. However the K, Ca, Mg concentration in fine roots of Chornogora region is much less than average values for fine roots in general [8].

Base cations/Al-balance in soil water and fine roots has been suggested to be used as an indicator of aluminium toxicity. With a low Ca/Al ratio roots may be damaged due to antagonistic effects of Al on Mg and Ca uptake. Based on laboratory studies, Cronan and Grigal (1995) [4] conducted that there is a 50:50 risk on tree growth when the soil solution molar Ca/Al ratio is as low as 1.0 or fine roots tissue Ca/Al molar ratio is ≤ 0.2. Field experiments do not approve conclusion above [17]. No support was found for the proposed critical value of the Ca/Al ratio in root tissue of 0.2 as indicator of ecological stress. The lowest observed in field-based experiment Ca/Al ratio of fine roots was 0.15 and mortality was <10% of the total amount of fine roots. However, Mg/Al ratios of the roots when treating with Al decreased, which supports the hypothesis of the antagonistic effect of Al on uptake of Mg. Authors conducted that Mg/Al ratio in root tissue might be a possible indicator of nutritional stress [14]. In any event base cations/Al ratios in Chornogora were much larger than possible dangerous ones for fine roots functionality (Table 4).

Table 4

Base cations/Al balans in soil water and living fine roots in the natural Norway spruce monodominant forest of Chornogora mountain region (Eastern Carpathians, Ukraine), n=9,08.2014

Soil layer	Lysimetric water*		Roots < 2 mm		Roots 2-5 mm	
	Ca/Al	Mg/Al	Ca/Al	Mg/Al	Ca/Al	Mg/Al
	mol/mol					
O horizon	7.3	2.2	5.0	1.9	9.4	3.9
0–10 cm	2.3	1.9	1.3	0.5	1.6	0.6
10–20 cm	–	–	1.1	0.5	0.8	0.2
20–40 cm	10.0	3.9	0.3	0.3	1.0	0.5

Comments: *unpublished data (average for 2015 growing season).

CONCLUSIONS

The fine root biomass of Norway spruce forest stand of Chornogora mountain region falls within the same range as that in the corresponding vegetation zone in the other parts of the world. Root biomass was concentrated in the top 40 cm soil layer and demonstrate a sharp decrease with soil depth.

It is evident from the results that there is reduction in nutrient assimilation with the increase in diameter of the roots. Fine roots are more nutrient rich as compared to the coarse ones. Significant difference in Zn, Cd, K and Al, Pb, Fe concentrations between live and dead roots suggest that there is possible retranslocation from senescent roots in first case and passive transport from soil solution to the roots in the second.

Ca/Al molar ratio in the fine roots suggest that the potential aluminum toxicity is not the driving factor of the crown condition in Norway spruce and the Ca/Al ratio itself does not pose a risk to forest health in the region.

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РОЗПОДІЛ І ВМІСТ МІНЕРАЛЬНИХ ЕЛЕМЕНТІВ У ТОНКИХ КОРЕНЯХ КОРІННИХ СМЕРЕКОВИХ ДЕРЕВОСТАНІВ ГІРСЬКОГО МАСИВУ ЧОРНОГОРА (СХІДНІ КАРПАТИ, УКРАЇНА)

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Було досліджено біомасу та вміст мінеральних елементів (Zn, Cd, Ni, Pb, Cu, Sr, Mn, Fe, K, Na, Ca, Mg, Al) у тонких і грубих коренях корінного смерекового деревостану в Чорногірському масиві Українських Карпат. Встановлено, що маса коренів зменшується з глибиною. Біомаса і густина тонких коренів < 2 мм становить 15% від сумарних величин у 40 см шарі ґрунту. У підстилці й верхньому 0-40 см шарі ґрунту зосереджено до 2000 г/м^2 живих коренів, що становить до 90% від загальної кількості. Частка некромаси не перевищує 10%. Тонкі корені містять більше мінеральних елементів порівняно з грубими. Зі збільшенням товщини спостерігається помітне зменшення вмісту всіх елементів, за винятком Al. Виявлено значну різницю у рівнях накопичення Zn, Cd, K, Al, Pb, Fe живими коренями та відмерлими. Молярні співвідношення осно́вні катіони/Al у тонких коренях є значно більшими, ніж потенційно небезпечний для деревостанів рівень 0.2, і свідчать, що вміст Al не є можливою причиною всихання смерекових деревостанів у регіоні.

Ключові слова: смерекові ліси, тонкі корені, біомаса, мінеральні елементи.

РАСПРЕДЕЛЕНИЕ И СОДЕРЖАНИЕ МИНЕРАЛЬНЫХ ЭЛЕМЕНТОВ В ТОНКИХ КОРНЯХ КОРЕННЫХ ЕЛОВЫХ ДРЕВОСТОЕВ ГОРНОГО МАССИВА ЧЕРНОГОРА (ВОСТОЧНЫЕ КАРПАТЫ, УКРАИНА)

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Исследовали биомассу и содержание минеральных элементов (Zn, Cd, Ni, Pb, Cu, Sr, Mn, Fe, K, Na, Ca, Mg, Al) в тонких и толстых корнях коренного елового древостоя в Черногорском массиве Украинских Карпат. Установлено, что масса корней уменьшается с глубиной. Биомасса и плотность тонких корней < 2 мм составляет 15% от сосответствующих величин в 40 см слое почвы. В подстилке и верхнем 0–40 см слое почвы сосредоточено до 2000 г/м^2 живых корней, что составляет до 90% от общего количества. Доля некромассы не превышает 10%. Тонкие корни содержат больше минеральных элементов по сравнению с толстыми. С увеличением толщины содержание всех металлов, за исключением Al, заметно уменьшается. Обнаружена значительная разница в уровнях накопления Zn, Cd, K, Al, Pb, Fe живыми и отмершими корнями. Молярные соотношения осно́вные катионы/Al в тонких корнях значительно выше, чем потенциально опасный для древостоев уровень 0.2, и свидетельствуют, что содержание Al не является возможной причиной усыхания еловых древостоев в регионе.

Ключевые слова: еловые леса, тонкие корни, биомасса, минеральные элементы.