Root biomass of beech as a factor influencing the wind tree stability

J. KODRÍK[1], M. KODRÍK[2]

[1]*Technical University, Faculty of Forestry, Zvolen, Slovak Republic*
[2]*Institute of Forest Ecology, Slovak Academy of Sciences, Zvolen, Slovak Republic*

ABSTRACT: Beech is, thanks to its root system, in general considered to be a wind-resistant woody plant species. Nevertheless, the research on beech root systems has revealed that it is not possible to mechanically divide the woody plants into deep rooted and shallow rooted, because their root systems are modified according to various stand conditions. The root system shape, growth and development are mostly influenced by soil conditions and groundwater level. In the case of a high groundwater level beech root systems do not form tap roots and the lateral roots are rather thin and weak. Important factor for the tree static stability is number of roots with diameter 3–10 cm. The most important for the tree stability are roots with diameter over 10 cm. Wood-destroying fungi have strong negative impact on tree static stability. There are differences between beech below-ground biomass growing in soils rich in nutrients and poor in nutrients. The total below-ground biomass of the beech stands poor in nutrients is higher.

Keywords: European beech; root systems; wind tree stability; belowground biomass

An enormous increase in frequency of windfalls in beech stands shows evidently that we must seek the cause of the damage rather in the root system than in the above-ground part of this species. Up to present knowledge about beech root system is only limited to a very general classification of this tree species as a wind-resistant wooden plant, namely due to a very well developed root system. Nevertheless, we cannot make general conclusions on the tree static stability without the detailed evaluation of the root system development, in connection also with soil and other environmental conditions. At last, but not at least we cannot neglect activation of wood damaging fungi, often due to an improper forest management activities.

Summarising the data obtained and published hitherto we can see that the classification of woody plants according their wind resistance needs to be put under discussion because tree root systems can considerably be modified, according to the different local conditions (SVOBODA 1952; BEZAČINSKÝ 1965). This hypothesis has also been supported by our observations on fir and oak (KODRÍK 1966, 1983, 1992). On the other hand, we could see that the problems connected with static stability of beech trees against wind have not been examined in details either in Slovakia or abroad. We have only met very short comments about the issue in several publications on silviculture or management and treatment. Beech roots data are known from early published writers: KRAUSS (1926), GRASER (1928), PASSARGE (1953), JÜTTNER (1954), KREUTZER (1961), GRIESCHE (1966), KÖSTLER et al. (1968). Authors mostly describe distribution of beech root systems in different soil types and horizons. VÁLEK (1977) characterised beech root system from viewpoint of water management and erosion control measures. There were also short notes on rot on beech roots.

EXPERIMENTAL PLOTS AND METHODS

We studied beech root ecosystems on the stands of forest type groups *Fagetum pauper* and *Fagetum typicum.* The research was focussed on the following localities: 1. Železná Breznica (belonging to the School Forest Enterprise of the Technical University in Zvolen), 2. Ostrôžky, 3. Poľana. In addition, control measurements were also performed in the areas adjacent to these experimental localities. At each locality we sampled 4–6 beech root systems. The excavated roots were evaluated according to their health state, way of anchorage and subjected to the measurements of length and width of their root systems, with regard also to the permeable physiological layer and soil type. The detailed measurements of roots as well as the measurements of the stem diameter ($d_{1.3}$) were accomplished on 170 wind-thrown trees. We also precisely evaluated the root number and width as well as their distribution in the soil horizon. The assessment of tree static needed only to include the roots with diameter more than 1 cm. The root diameter and length were measured in root middle, using a metal scale and a measuring tape. The investigation was held within 1995–2001. Data of uprooted trees were obtained within 10 days after uprooting.

The research on the total root biomass and its production required to measure all the roots obtained through destructive analysis of the sample trees in connection

Table 1. Number of investigated root systems on selected localities

Locality	Excavated root systems	Windfalls
SFE TU[1]	6	76
FE[2] Kriváň – Poľana (Hučava)	4	53
FE Kriváň – Ostrôžky	5	41
∑	15	170

[1]School Forestry Enterprise of Technical University
[2]Forestry Enterprise

with their sociological status in stand. For this purpose we excavated root systems using the archaeological method (KODRÍK 1994, 2002). The excavated biomass was immediately sorted in the following six diameter classes according to the root diameter: less than 0.5 cm; 0.6–2.0 cm; 2.1–5.0 cm; 5.1–7.0 cm; 7.1–10.0 cm and exceeding > 10.0 cm. A separate class was reserved for the stump. Immediately after the extraction, directly at the experimental locality, we took the fresh weight of each diameter fraction. The exception was only the first class with the length measured in laboratory. From each diameter class we took a sample for the processing in laboratory. In the laboratory the samples were dried in a drying oven at a temperature of 105°C to the dry weight. Obtained data was adjusted for the dry weight of the belowground biomass per one hectare. Due to the lack of data, the biomass of fine roots was examined with a special attention – including also the method of ingrove courses (PERSSON 1983). We evaluated also the soil type and horizon (soil pits) and mineral richness. The groundwater level was determined according to PENKA (1951 in ERDELSKÝ, FRIČ 1979). The criteria for the evaluation of tree health state were the presence of mycelium and the degree of rot attack. Information

Table 2. Depth and width range of beech trees in individual diameter classes according to localities

Locality	$d_{1.3}$ (cm)	Depth of root system (cm)	Width of root system (cm)
SFE TU	10–16	40–90	140–200
	17–21	70–100	130–300
	22–26	90–110	170–280
	27–31	50–100	220–430
	32–36	40–110	140–370
	37–41	50–120	300–450
	42–46	70–110	340–470
	47–51	100–110	430–500
Poľana Hučava	10–16	40–80	140–270
	17–21	90–100	220–270
	22–26	90–110	240–320
	27–31	50–110	350–380
	32–36	100–120	330–380
	37–41	80–130	340–480
	42–46	70–130	360–520
	47–51	100–110	480–550
FE Kriváň Ostrôžky	27–31	90	90
	32–36	50–70	200–230
	37–41	80–120	240–350
	42–46	60–120	130–420
	47–51	90–110	260–430
	52–56	110–120	320–350
	57–61	100–130	180–450
	62–66	90–120	300–490
	72–76	120	390–420

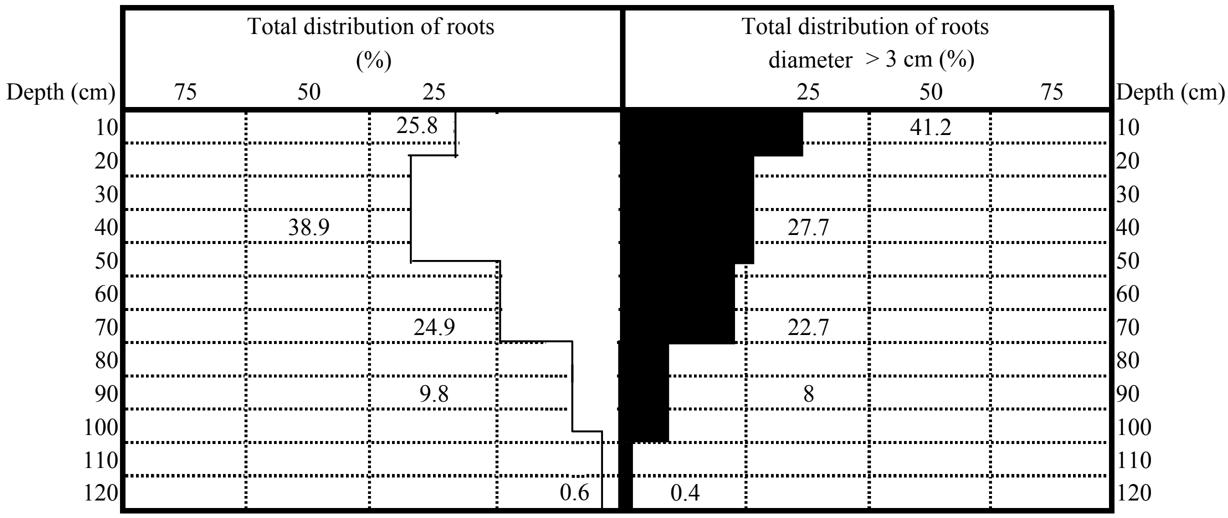

Fig. 1. Belowground biomass distribution uprooted trees of European beech (*Fagus sylvatica* L.) in different layers of soil substrate

about the numbers of root systems tested at the individual localities are shown in Table 1.

RESULTS

EVALUATION OF ROOT SYSTEMS AND THEIR DISTRIBUTIONS ACCORDING TO THE SOIL TYPES

Having obtained the results of soil analysis performed on samples from the studied localities taken with the aid of soil pits we could see that all the localities dominated cambisols with locally admixed rankers. This soil characteristic is proper for all the beech stands in Slovakia belonging to *Fagetum pauper* and *Fagetum typicum* forest type groups and growing in the 5th and 6th altitudinal vegetation zone where windfalls were observed. From the viewpoint of beech root system distribution an interesting limiting factor is the upper layer of horizon C_1, in general compact, representing also a physiological limit for the root growth. We have not observed this layer exceeding a thickness of 130 cm. The root system width did not exceed 550 cm. In rankers the width was lower – only 350 and the average value of depth was 80 cm. The values of range, maximum width and depth for the individual tree diameters $d_{1.3}$ and for the individual experimental plots are in Table 2.

A very important factor, often of the highest priority, was the groundwater level. The beech trees growing at sites with the high groundwater level never developed very thick roots. The opposite situation was in the case of low groundwater level. The root system was always

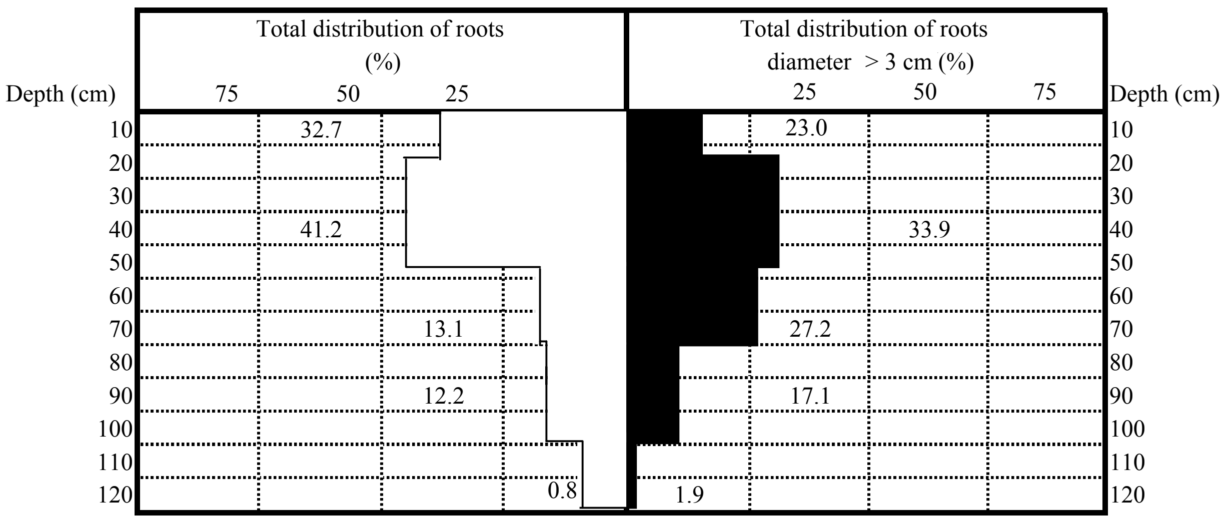

Fig. 2. Belowground biomass distribution of standing trees of European beech (*Fagus sylvatica* L.) in different layers of soil substrate

Table 3. Root biomass characteristics in particular diameter classes of uprooted beeches on School Forestry Enterprise Zvolen – Železná Breznica

	Number of roots in diameter degrees (cm)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Diameter class 10–16 cm															
Diameter	18.73	6.64	4.45	3.64	3.00	3.45	2.27	2.27	1.91	1.18	0.64	0.09			
Standard deviation	3.74	4.85	3.06	1.49	2.08	2.29	1.59	1.48	1.32	1.28	0.84	0.28			
Coefficient of variation (%)	19.99	73.12	68.81	40.90	69.39	66.18	69.78	64.99	69.14	108.24	132.61	302.77			
%	38.79	13.75	9.23	7.54	6.21	7.16	4.71	4.71	3.95	2.44	1.32	0.19			
Σ 11		61.77				34.28						3.95			
Diameter class 17–21 cm															
Diameter	21.14	8.00	6.43	3.86	3.71	5.00	2.57	3.43	3.00	2.43	0.00	0.86	0.43		
Standard deviation	3.68	4.72	5.50	2.95	2.91	3.78	3.02	1.99	1.20	1.92	1.16	0.83	0.73		
Coefficient of variation (%)	17.41	59.01	85.55	76.44	78.45	75.59	117.33	58.03	39.84	78.92	–	97.18	169.97		
%	34.74	13.15	10.56	6.34	6.10	8.22	4.23	5.63	4.93	3.99	0.00	1.41	0.70		
Σ 20		58.45				35.45						6.10			
Diameter class 22–26 cm															
Diameter	20.83	15.00	7.83	5.17	3.83	4.67	4.67	2.83	3.50	3.50	2.67	2.83	1.83	0.83	0.17
Standard deviation	6.44	7.23	5.81	3.39	2.73	1.89	2.56	1.57	1.12	1.89	1.49	3.80	1.46	1.21	0.37
Coefficient of variation (%)	30.91	48.23	74.22	65.56	71.31	40.41	54.87	55.49	31.94	54.08	55.90	134.27	79.77	145.60	223.61
%	25.99	18.71	9.77	6.45	4.78	5.82	5.82	3.53	4.37	4.37	3.33	3.53	2.29	1.04	0.21
Σ 11		54.47				30.77						14.76			
Diameter class 27–31 cm															
Diameter	17.50	17.17	12.33	4.67	8.00	8.60	1.83	2.00	4.50	3.50	2.00	1.67	0.17	1.17	
Standard deviation	2.93	3.85	7.16	2.36	2.16	2.42	2.27	2.24	3.50	1.50	1.53	1.49	0.37	1.67	
Coefficient of variation (%)	16.74	22.41	58.03	50.51	27.00	28.10	123.65	111.80	77.78	42.86	76.38	89.44	223.61	143.57	
%	20.56	20.17	14.49	5.48	9.40	10.11	2.15	2.35	5.29	4.11	2.35	1.96	0.20	1.37	
Σ 6		55.23				34.78						9.99			
Diameter class 32–36 cm															
Diameter	18.57	15.86	11.71	7.57	4.86	3.71	5.71	4.14	4.29	4.29	2.43	2.71	1.00	1.57	0.43
Standard deviation	2.50	6.03	4.10	3.89	3.87	2.55	2.86	3.18	1.75	1.16	0.90	1.48	1.20	1.92	0.73
Coefficient of variation (%)	13.46	38.05	34.96	51.33	79.68	68.59	50.12	76.80	40.82	27.08	37.20	54.70	119.52	121.97	169.97

Table 3 to be continued

	Number of roots in diameter degrees (cm)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
%	20.90	17.85	13.18	8.52	5.47	4.18	6.43	4.66	4.82	4.83	2.73	3.05	1.13	1.77	0.48
Σ 7		51.93				34.08						13.99			
Diameter class 37–41 cm															
Diameter	23.78	20.89	12.33	7.44	8.33	4.44	3.22	5.11	5.44	4.56	2.00	1.56	2.44	1.22	0.67
Standard deviation	4.59	6.64	3.65	3.02	3.13	3.17	1.87	2.51	2.06	3.10	0.94	1.57	1.83	1.03	0.94
Coefficient of variation (%)	19.30	31.79	29.61	40.60	37.52	71.24	58.11	49.19	37.85	67.94	47.14	101.02	74.97	84.31	141.42
%	22.99	20.19	11.92	7.20	8.06	4.30	3.11	4.94	5.26	4.41	1.93	1.51	2.36	1.18	0.64
Σ 9		55.10				32.87						12.03			
Diameter class 42–46 cm															
Diameter	26.40	20.70	15.30	9.60	7.10	4.90	4.50	5.40	4.00	6.20	4.20	3.20	1.60	2.90	1.30
Standard deviation	4.78	3.49	5.53	2.29	3.73	3.96	2.42	1.80	2.28	2.96	3.28	2.60	1.56	1.51	1.00
Coefficient of variation (%)	18.10	16.88	36.16	23.84	52.49	80.84	53.75	33.33	57.01	47.74	78.10	81.25	97.63	52.18	77.31
%	22.51	17.65	13.04	8.18	6.05	4.18	3.84	4.60	3.41	5.29	3.58	2.73	1.36	2.47	1.11
Σ 10		53.20				30.26						16.54			
Diameter class 47–51 cm															
Diameter	18.50	15.00	7.50	11.00	2.00	0.50	5.00	5.50	3.50	4.50	1.00	2.00	3.00	0.50	0.50
Standard deviation	0.50	3.00	2.50	1.00	1.00	0.50	3.00	0.50	1.50	2.50	1.00	0.00	0.00	0.50	0.50
Coefficient of variation (%)	2.70	20.00	33.33	9.09	50.00	100.00	60.00	9.09	42.86	55.56	100.00	0.00	0.00	100.00	100.00
%	23.13	18.75	9.38	13.75	2.50	0.62	6.25	6.87	4.38	5.63	1.25	2.50	3.75	0.62	0.62
Σ 2		51.26				34.37						14.37			

Table 4. Root biomass characteristics in particular diameter classes of uprooted beeches on Forestry Enterprise Kriváň – Poľana, locality Hučava

	Number of roots in diameter degrees (cm)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Diameter class 10–16 cm															
Diameter	25.75	11.75	17.00	9.75	3.50	4.75	1.75	1.75	2.50	2.25	0.75	0.75			
Standard deviation	3.27	3.42	3.08	3.56	2.87	4.55	2.05	1.79	1.66	0.43	0.83	0.83			
Coefficient of variation (%)	12.70	29.10	18.13	36.53	82.07	95.75	116.93	102.02	66.33	19.25	110.55	110.55			
%	31.31	14.29	20.67	11.85	4.26	5.78	2.13	2.13	3.04	2.74	0.91	0.91			
Σ 4		66.26				29.18						4.56			
Diameter class 17–21 cm															
Diameter	28.50	23.00	9.50	18.00	7.50	3.50	0.00	0.00	0.50	2.50	0.00	1.50	0.50		
Standard deviation	0.50	1.00	1.50	0.00	3.50	0.50	0.00	0.00	0.50	0.50	0.00	0.50	0.50		
Coefficient of variation (%)	1.754	4.35	15.79	0.00	46.67	14.29	–	–	100.00	20.00	–	33.33	100.00		
%	30.00	24.21	10.00	18.95	7.89	3.68	0.00	0.00	0.53	2.63	0.00	1.58	0.53		
Σ 2		64.21				31.05						4.74			
Diameter class 22–26 cm															
Diameter	27.80	17.80	11.60	22.60	8.00	4.80	1.80	1.60	3.60	1.60	0.60	2.80	0.20		
Standard deviation	2.99	4.66	1.85	5.43	4.34	2.93	2.40	2.06	2.65	2.06	1.20	0.98	0.40		
Coefficient of variation (%)	10.77	26.21	15.99	24.01	54.20	60.95	133.33	128.70	73.70	128.70	200.00	34.99	200.00		
%	26.53	16.98	11.07	21.56	7.63	4.58	1.72	1.53	3.44	1.53	0.57	2.67	0.19		
Σ 5		54.58				40.46						4.96			
Diameter class 27–31 cm															
Diameter	28.50	14.13	11.50	10.63	7.25	10.13	5.50	6.00	5.88	3.38	0.88	1.00	0.50		
Standard deviation	5.81	2.71	2.92	2.64	2.22	4.14	3.43	3.00	3.06	1.80	1.36	1.12	0.71		
Coefficient of variation (%)	20.38	19.21	25.35	24.87	30.65	40.85	62.32	50.00	52.07	53.29	155.84	111.80	141.42		
%	27.08	13.42	10.93	10.10	6.89	9.62	5.23	5.70	5.58	3.21	0.83	0.95	0.48		
Σ 8		51.43				43.11						5.46			
Diameter class 32–36 cm															
Diameter	32.57	14.29	12.71	14.71	9.86	7.57	4.86	3.43	6.00	3.29	4.14	1.14	0.86	0.29	
Standard deviation	3.42	3.53	2.19	3.95	3.40	2.56	3.56	2.56	3.85	3.45	3.04	1.73	1.73	0.70	
Coefficient of variation (%)	10.49	24.74	17.19	26.87	34.48	33.75	73.35	74.54	64.24	105.07	73.47	151.04	201.38	244.95	

Table 4 to be continued

	Number of roots in diameter degrees (cm)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
%	28.15	12.35	10.99	12.71	8.50	6.54	4.20	2.97	5.19	2.84	3.58	0.99	0.74	0.25	
Σ 7		51.49				40.11						8.40			
Diameter class 37–41 cm															
Diameter	32.00	18.44	12.33	14.89	10.11	12.22	5.67	4.44	6.56	9.11	5.33	4.89	3.56	2.67	0.44
Standard deviation	3.71	4.42	2.83	5.76	3.14	4.61	2.67	3.30	3.40	5.24	2.62	3.73	2.50	2.71	0.68
Coefficient of variation (%)	11.60	23.99	22.93	38.71	31.08	37.75	47.06	74.33	51.91	57.49	49.21	76.20	70.30	101.55	154.11
%	22.43	12.92	8.64	10.44	7.09	8.56	3.97	3.11	4.60	6.39	3.74	3.43	2.50	1.87	0.31
Σ 9		43.99				37.77						18.24			
Diameter class 42–46 cm															
Diameter	32.43	18.29	16.07	14.07	11.00	14.14	7.21	6.93	6.07	6.36	5.00	4.07	4.71	4.29	1.14
Standard deviation	4.47	4.83	4.85	4.27	4.63	4.73	2.93	2.28	2.46	4.12	4.42	3.10	1.75	1.53	1.41
Coefficient of variation (%)	13.78	26.42	30.16	30.33	42.08	33.47	40.64	32.94	40.57	64.75	88.48	76.25	37.11	35.75	123.11
%	21.37	12.05	10.59	9.27	7.25	9.32	4.75	4.56	4.00	4.19	3.29	2.68	3.10	2.83	0.75
Σ 14		44.01				39.15						16.84			
Diameter class 47–51 cm															
Diameter	32.75	21.25	18.50	16.00	15.00	8.50	9.50	11.75	7.75	8.75	11.25	8.75	5.75	2.25	2.00
Standard deviation	2.28	2.59	1.50	4.06	4.95	3.50	2.69	0.43	1.64	0.83	2.59	1.30	1.79	1.30	1.58
Coefficient of variation (%)	6.95	12.17	8.11	25.39	33.00	41.18	28.34	3.69	21.15	9.48	22.99	14.85	31.05	57.74	79.06
%	18.22	11.82	10.29	8.90	8.34	4.73	5.29	6.54	4.31	4.87	6.26	4.87	3.20	1.25	1.11
Σ 4		40.33				38.11						21.56			

Table 5. Root biomass characteristics in particular diameter classes of uprooted beeches on Forestry Enterprise Kriváň, locality Ostrôžky

	Number of roots in diameter degrees (cm)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Diameter class 27–31 cm															
Diameter	26.00	15.00	8.00	10.00	5.00	3.00	3.00	5.00	1.00	1.00	1.00	1.00			
Standard deviation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
Coefficient of variation (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
%	32.91	18.99	10.12	12.66	6.33	3.80	3.80	6.33	1.27	1.27	1.27	1.27			
Σ 1		62.02				34.18						3.80			
Diameter class 32–36 cm															
Diameter	37.50	22.00	21.00	16.00	2.50	7.00	3.50	5.00	1.00	4.00	1.50	2.50	2.50	1.50	2.50
Standard deviation	2.50	13.00	9.00	4.00	2.50	2.00	1.50	3.00	1.00	1.00	0.50	1.50	1.50	1.50	2.50
Coefficient of variation (%)	6.67	59.09	42.86	25.00	100.00	28.57	42.86	60.00	100.00	25.00	33.33	60.00	60.00	100.00	100.00
%	28.85	16.92	16.15	12.32	1.92	5.38	2.69	3.85	0.77	3.08	1.15	1.92	1.92	1.15	1.92
Σ 3		61.92				26.93						11.15			
Diameter class 37–41 cm															
Diameter	25.25	13.50	11.63	12.75	7.00	6.13	3.63	2.50	3.50	3.88	0.38	2.50	1.13	0.88	0.38
Standard deviation	5.76	3.61	5.41	5.47	3.46	3.41	3.20	2.40	1.80	1.69	0.70	2.00	1.17	1.17	0.70
Coefficient of variation (%)	22.82	26.71	46.51	42.91	49.49	55.63	88.25	95.92	51.51	43.64	185.59	80.00	103.64	133.25	185.59
%	26.58	14.21	12.24	13.42	7.36	6.45	3.82	2.63	3.68	4.08	0.39	2.63	1.18	0.92	0.39
Σ 8		53.03				37.36						9.61			
Diameter class 42–46 cm															
Diameter	28.18	17.91	13.09	14.27	8.00	6.18	2.18	2.55	3.36	2.82	1.82	1.82	1.73	0.91	0.27
Standard deviation	5.18	3.06	3.92	4.97	3.22	3.38	2.29	2.68	1.82	2.04	1.47	1.34	1.05	1.00	0.45
Coefficient of variation (%)	18.40	17.08	29.93	34.85	40.24	54.67	104.91	105.10	54.19	72.28	80.62	73.48	60.93	109.54	163.30
%	26.82	17.04	12.46	13.58	7.61	5.88	2.08	2.42	3.20	2.68	1.73	1.73	1.64	0.87	0.26
Σ 10		56.31				34.78						8.91			
Diameter class 47–51 cm															
Diameter	21.88	17.13	15.50	12.50	5.75	4.00	5.13	1.88	2.50	2.00	2.75	1.50	2.25	0.50	0.13
Standard deviation	5.23	3.98	4.95	5.63	4.52	3.16	3.44	1.54	1.50	0.87	2.63	1.00	1.20	0.71	0.33
Coefficient of variation (%)	23.91	23.25	31.93	45.08	78.62	79.06	67.20	81.92	60.00	43.30	95.78	66.67	53.29	141.42	264.58

Table 5 to be continued

	Number of roots in diameter degrees (cm)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
%	22.94	17.96	16.25	13.11	6.03	4.19	5.37	1.97	2.62	2.10	2.88	1.57	2.36	0.52	0.13
Σ 8		57.14				33.29						9.57			
Diameter class 52–56 cm															
Diameter	26.00	17.50	17.50	13.50	7.00	6.00	9.00	3.50	4.00	3.50	3.00	3.50	3.00	3.00	
Standard deviation	4.00	2.50	2.50	6.50	2.00	3.00	2.00	3.50	1.00	1.50	2.00	0.50	1.00	0.00	
Coefficient of variation (%)	15.38	14.29	14.29	48.15	28.57	50.00	22.22	100.00	25.00	42.86	66.67	14.29	33.33	0.00	
%	21.67	14.59	14.58	11.25	5.83	5.00	7.50	2.92	3.33	2.92	2.50	2.92	2.50	2.50	
Σ 2		50.84				35.83						13.33			
Diameter class 57–61 cm															
Diameter	30.67	21.33	20.33	12.67	6.33	5.67	2.00	5.67	6.33	6.33	7.67	4.67	1.67	4.67	2.00
Standard deviation	4.92	7.41	2.05	5.56	4.92	4.50	1.41	4.50	4.78	2.36	5.44	1.70	1.25	2.05	1.41
Coefficient of variation (%)	16.05	34.73	10.11	43.88	77.71	79.36	70.71	79.36	75.54	37.22	70.91	36.42	74.83	44.03	70.71
%	22.22	15.46	14.73	9.18	4.59	4.11	1.45	4.11	4.59	4.59	5.56	3.38	1.21	3.38	1.45
Σ 3		52.41				28.02						19.57			
Diameter class 62–66 cm															
Diameter	27.50	22.00	18.00	11.25	9.00	5.75	8.50	2.75	2.75	4.00		1.50	1.25	1.50	0.50
Standard deviation	4.33	6.96	5.20	3.42	2.55	3.70	1.12	1.64	1.64	1.41		1.66	0.83	1.66	0.50
Coefficient of variation (%)	15.75	31.66	28.87	30.39	28.33	64.34	13.15	59.61	59.61	35.36		110.55	66.33	110.55	100.00
%	23.66	18.92	15.48	9.68	7.74	4.95	7.31	2.37	2.37	3.44		1.29	1.08	1.29	0.43
Σ 4		58.06				34.41						7.53			
Diameter class 72–76 cm															
Diameter	29.00	24.00	19.50	10.00	13.00	4.50	7.00	1.50	1.50	6.50	0.50	1.50	2.00	1.00	1.50
Standard deviation	1.00	1.00	0.50	2.00	3.00	0.50	2.00	1.50	1.50	1.50	0.50	1.50	1.00	1.00	0.50
Coefficient of variation (%)	3.45	4.17	2.56	20.00	23.08	11.11	28.57	100.00	100.00	23.08	100.00	100.00	50.00	100.00	33.33
%	23.58	19.51	15.85	8.13	10.57	3.66	5.69	1.22	1.22	5.28	0.41	1.22	1.63	0.81	1.22
Σ 2		58.94				30.49						10.57			

Table 6. Characteristics of stems and roots biomass of standing beeches on particular research plots

Locality	$d_{1.3}$ (cm)	Depth (cm)	Width (cm)		Number of roots in centimetre diameter degrees																	
			left	right	1	2	3	(%)	4	5	6	7	8	9	(%)	10	11	12	13	14	15	(%)
TU SFE	30	100	150	160	22	8	8	42.22	3	5	5	7	5	8	36.67	5	6	5	3	0	0	21.11
	40	100	200	180	31	22	10	45.32	10	6	7	7	8	5	30.94	8	8	4	7	4	2	23.74
	42	100	220	210	35	20	20	44.12	10	8	8	6	6	8	27.06	9	8	14	8	6	4	28.82
Ostrôžky	30	100	220	180	30	20	21	45.81	18	10	8	8	5	2	32.90	7	9	9	4	4	0	21.29
	40	120	280	300	35	20	18	43.97	5	9	7	7	4	8	24.10	10	12	9	9	8	5	31.93
	42	120	300	300	32	18	18	38.20	12	10	8	9	10	7	31.46	12	10	11	8	8	5	30.34
Poľana	30	100	180	180	28	18	20	50.38	12	7	7	8	4	2	30.54	11	3	4	5	2	0	19.08
	40	120	280	260	35	18	22	49.02	7	5	5	6	8	3	22.22	13	10	10	5	3	3	28.76
	42	120	320	320	37	18	15	45.45	11	6	6	5	4	5	24.03	9	8	8	10	8	4	30.52

Legend: TU SFE = Technical University Zvolen – School Forestry Enterprise

robust, strong, with thick lateral roots ensuring the appropriate anchorage of the tree. The root systems observed in gleyed soils were atypical, whisk-shaped, with thinner roots.

At all the examined localities the skeleton content was under 60%. This fact was always reflected in the beech tree stability because more skeleton amount also implied higher stability. This was not true for the gleyed soils under impact of water-logging. On such localities we also observed more intense rotting of roots. The roots of beech trees growing on rankers – the soils characteristic with high skeleton content, low nutrient reserves and frequently fluctuating groundwater level were considerably branched, more flat-shaped, with a very low static resistance. This was true primarily for the forest type group of *Fageto Aceretum*. Also in this case we could observe an increased rot degree – due to *Armillaria.* No roots exceeding a depth of 130 cm were observed. This depth was also the limit of the physiological layer of the soil.

In presence of a high groundwater level the root systems never formed thick roots. We observed up to a 55% absence of roots with diameter over 4 cm. A different situation was with low situated groundwater level where we observed quite robust tap roots with strong and thick lateral roots. In the case of gleyed soils the root systems were whisk-shaped with prevailing thin roots exceeding up to 63% of the overall thickness.

THE ROOT SYSTEM COMPOSITION ACCORDING TO THE DIAMETER AND THEIR DISTRIBUTION

A very important factor for the tree static stability was the number of roots. This was true for both wind-thrown and standing trees (Tables 3, 4 and 5). The relative amounts of the measured roots as well as the results obtained after their analysis point to surprising uniformity in the individual stem diameter, primarily in the case of the wind-thrown beech trees. The relative amounts of roots with diameter under 3 cm ranged always between 41–66%. From the viewpoint of tree static stability these roots have only a little importance. More important are the roots with diameter 3–10 cm with the amount representing 26–43% of the total root number in root systems of wind-fallen trees. The most important for the tree stability were the roots with diameter over 10 cm representing only 3–22% of the total root numbers in fallen trees. Moreover, in the stands older than 60–80 years we could indicate rot processes on the roots belonging to this category. Comparing the excavated root systems we could detect evident differences. The thick roots were the determining factor for beech tree stability – it was primarily evident on standing trees. At all the localities the percentage of thick roots ranged between 19 and 21% of the total number of the roots in the case of young beech trees and between 24–30% in the case of older beech trees (Table 6). A more detailed analysis has resulted with conclusion that the tree static stability is key-dependent on the number of roots

Fig. 3. Uprooted beech trees in forest enterprise Kriváň, locality Hučava (15. 6. 2000)

in the depth 50–70 cm. If the roots thicker than 3 cm and several also than 10 cm are not sufficiently abundant in this horizon, the trees start very quickly to lose their stability.

The spatial distribution of beech roots according to their diameter shows that the majority (up to 48% of roots of a wind-fallen trees) of roots with diameter over 3 cm are from the soil surface to a 15 cm depth which results in a shallow root system. The relative numbers found between 16–48 cm and 71–92 cm were 27% and 8%, respectively. Summarising all the diameter categories, the most dense were roots in the depth 15–48 cm, namely up to 39%. Surprising was the distribution of roots from 0 to 15 cm where we detected only 26% of the total root number (Fig. 1).

A different situation is with the standing trees. In this case, the roots with diameter over than 3 cm were found in the depth 0–15 cm in an amount only 23% of the total and the highest number of the trees with this diameter was detected between 26–49 cm, representing 34% of the total.

As we can see an increase in occurrence of roots with the diameter larger than 3 cm could already be detected in the depth of 50–70 cm, and it represented 27% of the total. More remarkable was the difference detected in 70–100 cm, representing up to 17%. Also the overall root distribution involving all diameter categories was the highest between 25–50 cm, representing 41% of the total (Fig. 2).

The just performed analysis confirms that the highest percentage of roots of beech trees is situated from 25 to

Fig. 4. Partly rinsed root system of 43-years-old excavated beech in forest enterprise Kriváň, locality Hučava (28. 5. 2001)

Fig. 5. Totally washed out root system of 65-years-old beech before measuring in School Forest Enterprise of the Technical University in Zvolen, locality Kováčová (12. 7. 1999)

50 cm below the ground, and in such a way they are the decisive factors in the tree stability.

ROT ON BEECH ROOTS AND THE TREE STATIC STABILITY

Wood-destroying fungi have strong negative impact on tree static stability and, in addition, considerably influence physiological processes of the trees. On heavy soils we observed the occurrence of *Armillaria mellea* (Vahl: Fr.) Kummer, primarily on wind-fallen trees older than 50 years. The samples taken from the attacked trees confirmed considerable aggressiveness of the fungus at sites suffering in recent years due to moisture insufficiency. Both the samples taken from the experimental localities and from the adjacent area unambiguously confirmed the intense fungus destroying activities, increasing with the increasing immission load.

From the viewpoint of wind-stability of beech stands a very important was the finding that in the stands with *Armillaria* the rate of wood decay considerably increased immediately after the first cutting interventions. The shallower and more acid soils, the more abundant rhizomorphes (up to 40%) were observed. The soil type and soil mineral richness were found to be one of determining factors for the fungal decay activities. On mineral leaner soils with coarse structure where root systems were massive and well-developed the fungus attack was the weakest. Quite remarkable rot was observed on roots of wind-thrown trees growing on rankers. This can be caused by

Fig. 6. Typical root system of excavated 53-years-old beech in forest enterprise Kriváň, locality Poľana (17. 7. 2000)

Fig. 7. Washing out of beech root system School Forest Enterprise of the Technical University in Zvolen, locality Železná Breznica (20. 5. 1998)

frequent lack of water in these soils during summer and the following decrease in resistance of the stands against wood-destroying fungi.

Occurrence of wood-destroying fungi on roots and buttresses required us to re-evaluate the importance of fungus *Hypoxylon deustum* (Hoffm.: Fr.) Grev. that currently shows more frequent occurrence compared to the past. The root buttresses damaged during cutting and skidding provide very favourable conditions for this fungus. We performed detailed assessments in the stands of the School Forest Enterprise in Zvolen. Getting together the decay observations and the precise dates of the mechanical tree damage on standing trees we have concluded that the rate of decay process caused by this fungus in the observed stands was rather low. During the three study years after tree infection the fungus on injuries with volume larger than 5 cm^3 had not succeeded to penetrate in average more than 2.3 cm. The fungus frequency on the damaged beech stems was 44%. Much more evident were manifestations of the activities of *Armillaria* sp. From the other wood-destroying fungi we detected, specially on gleyed soils, *Ganoderama applanatum* (Pers.) Pat. This fungus occurred on mechanically damaged root buttresses, nevertheless without any remarkable economic impact. Important was the founding that already after the first cutting interventions there were several isolated wind-thrown trees. On 72% of these trees were detected rhizomorphes of *Armillaria*. The ends of tree roots were rotted and in 56% the rot was detected also in sapwood and heartwood (Table 2). The degrees of rot attack were very different depending on locality – which was reflected also on the beech stand static stability.

TOTAL BEECH BELOWGROUND BIOMASS

Table 7 illustrates the distribution of belowground biomass of European beech (*Fagus sylvatica* L.) according to the root diameter classes. The data was obtained analysing 15 sample trees. Our research on the belowground biomass was focussed on two types of localities: beech stands growing on soils rich in nutrients and beech stand growing on poor-in-nutrient soils. The total biomass of the beech stands on rich soils was 44.08 t/ha. On the poor soils this amount was higher – 47.59 t/ha. The weight differences were recorded in all the diameter fractions. In all the cases the belowground biomass amounts were higher on the nutrient-poor localities. The significant differences were detected only in the first and the second classes where the belowground biomass amounts on poor localities were twofold compared to the rich localities. Table 7 gives for

Table 7. Distribution of European beech (*Fagus sylvatica* L.) belowground biomass in term of dry weight on rich- and poor-in-nutrients forest stands (t/ha)

Stand (%)	Root diameter classes (cm)							Total
	≤ 0.5	0.6–2.0	2.1–5.0	5.1–7.0	7.1–10.0	> 10.0	Stump	
Rich	1.27	1.66	3.08	2.50	2.64	13.42	19.63	44.08
%	2.90	3.70	7.00	5.70	6.00	30.40	44.50	100.00
Poor	2.53	2.89	3.61	2.87	3.19	14.80	17.71	47.59
%	5.30	6.00	7.60	6.00	6.70	31.00	37.20	100.00

each fraction its percentage value from the total belowground biomass. Also in this case remarkable differences are only in the first and the second diameter classes. In the other classes the values are very similar. The only exception is the last root diameter class. In Table 7 we can see that the greatest weight percentage (68–74.9%) from the total belowground biomass is represented by roots with diameter more than 10 cm and by stumps. Interesting is also increase in stump weight on nutrient-rich localities. Here the difference is 7.3%.

DISCUSSION AND CONCLUSIONS

Beech is, thanks to its root system, in general considered to be a wind-resistant woody plant species. Nevertheless, the research on beech root systems has revealed that it is not possible to mechanically divide the woody plants into deep rooted and shallow rooted, because their root systems are modified according to various stand conditions. On this point we agree with SVOBODA (1952) and BEZAČINSKÝ (1965). The root system shape, growth and development are mostly influenced by soil conditions and groundwater level. In the case of a high groundwater level beech root systems do not form tap roots and the lateral roots are rather thin and weak. In the case of low groundwater level and physiologically favourable soils the situation is different – beech trees form quite massive tap roots with dense lateral roots. Very different – whisk formed – are beech root systems in gleyed soils.

This is in accordance with GRASSER (1928) who recorded maximum depth of beech roots 1 m, also in good and deep soils. Similarly we agree with WAGENKNECHT (1960) who investigated in depth 1 m 70% of fine roots. HOFFMANN's (1960) results of belowground investigation in gleyed soils where depth of roots was only 30 cm are in accordance of our ones. A very convincing seems to be the opinion of JAKUCS (1984) that during dry periods, when the tree water demands increase, the roots cannot penetrate into deeper soil layers. Transpiration requirement increases, tree vitality decreases, and *Armillaria* becomes to be very aggressive. Similar observations we can find in PAPP and PAPP (1984).

Our observations have revealed that environmental changes, at the first place frequently repeated extreme dry periods, give favourable conditions for increasing occurrence and destroying activities of *Armillaria* sp. Very dangerous seems to be also wood-destroying fungus *Hypoxylon deustum* (Hoffm.: Fr.) Grev., in Slovakia currently evaluated as economically less important from the viewpoint of forest economy. Our research results show that it is necessary to re-evaluate the significance of *Hypoxylon* fungus. If the wounds on roots are larger than 5 cm^2 – due to neglectful cutting and skidding, there can be infected, though the infection proceeds into the buttresses slower compared to *Armillaria*. According to our observations, a wood-destroying fungus attacks only a part of root system, most frequently the main root, and here the rot progress is very slow. In this situation the lateral roots are sufficient to ensure the tree static stability. However, when the rot had penetrated into the butt the tree static stability is impaired and the tree falls down. In the case of *Armillaria* the attack is the most dangerous if dry periods occur at the beginning of the vegetation period. This is in accordance with PŘÍHODA (1959) and STOLINA (1953) who recorded massive occurrence of the fungus in eastern Slovakia and in Ľuboreč after an exceptionally dry year 1947 where the dry spring was also followed by dry summer. The rot caused by *Armillaria* was the most abundant on rankers and in presence of low groundwater level.

We have not found relation on belowground biomass of beech stand according to different mineral richness of soil substrate. OSZLÁNYI (1986) investigated belowground biomass of European beech in conditions of Slovakia. He found in 75-year old beech forest stand 43.9 t/ha. NIHLGÅRD (1972) found out the quantity of belowground biomass of beech forest stand in conditions of South Sweden 49 t/ha. All that results was made without relationship with mineral richness of soil.

Summarising the observations on beech windfalls we can make a preliminary conclusion that the root systems of trees from natural regeneration are better anchored in the soil substrate. The verification of this hypothesis requires the testing on larger sample sets.

Our partial results seem to confirm the opinion of VLAD (1973), by whom the "selection cutting" must be accomplished before the full-developed stand canopy, i.e. before the competition has taken place in the stand. It is necessary to note here that up to present these questions have been examined only marginally.

Nevertheless, we cannot agree with SEREDA (1983) who means that namely fine roots with diameter only of several mm form a reinforced matrix; and that they are important for tree static stability. Our research results show evident that a significant role for tree stability must be accounted to roots with diameter larger than 3 cm, primarily to the roots with diameter more than 10 cm.

Very important is also the fact that after an age of 90 years the tree growth stops, which was confirmed by the method of ingrove courses placed into the soil. Evaluating the growth dynamics at localities under smoke impact we observed that if a beech crown has been more than 25% dead, the roots stop growing and there are attacked by rot, most frequently caused by *Armillaria* sp.

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Koreňová biomasa buka z hľadiska statickej stability voči vetru

J. KODRÍK[1]**, M. KODRÍK**[2]

[1]*Technická univerzita, Lesnícka fakulta, Zvolen, Slovenská republika*

[2]*Ústav ekológie lesa, Slovenská akadémia vied, Zvolen, Slovenská republika*

ABSTRAKT: Buk je drevina, ktorá vzhľadom na koreňový systém je všeobecne považovaná za vetru odolnú. Výskum koreňových sústav buka však poukázal na to, že triedenie drevín na hlbokokorenné a plytkokorenné nemožno z hľadiska statickej stability stromov zovšeobecňovať, pretože koreňová sústava sa modifikuje podľa rôznych podmienok. Na koreňovú sústavu buka, jej rast a formovanie najviac vplývajú pôdne podmienky a podzemná voda. Pri vysokej hladine podzemnej vody koreňová sústava buka nevytvára kolový koreň a aj bočné korene sú tenšie a slabšie. Dôležitým faktorom statickej stability je početnosť koreňov s priemerom 3–10 cm. Z aspektu statickej stability sú najdôležitejšími korene s priemerom nad 10 cm. Drevokazné huby značne znižujú statickú stabilitu stromov. Zistené boli rozdielnosti v podzemnej biomase bukov rastúcich na rôznych stanovištiach z aspektu minerálnej sily pôdneho substrátu. Podzemná biomasa bukových porastov na minerálne chudobnejších stanovištiach bola vyššia.

Kľúčové slová: buk obyčajný; koreňové systémy; stabilita voči vetru; podzemná biomasa

Výskum koreňovej sústavy buka bol sústredený v porastoch skupín lesných typov *Fagetum pauper* a *Fagetum typicum* na troch rôznych stanovištiach stredného Slovenska. Na každej lokalite sme archeologickou metódou vykopali 4–6 koreňových systémov buka, zistili ich zdravotný stav, spôsob zakotvenia, merali sme šírku a dĺžku koreňovej sústavy so zreteľom na vyhodnotenú priepustnú fyziologickú vrstvu a druh pôdy. Ďalšie merania sme vykonali na 170 vetrom vyvrátených kmeňoch buka, pričom sme zistili aj hrúbku kmeňov v $d_{1,3}$. Objektom výskumu bol počet a hrúbka koreňov ako aj ich rozloženie v pôdnom horizonte. Pri výskume celkovej biomasy a jej produkcie sme stanovili hmotnosť všetkých koreňov, získaných deštrukčnou analýzou vzorníkov, vzhľadom na ich biosociologické postavenie v poraste.

Z hľadiska rozloženia koreňového systému buka je zaujímavá vrchná vrstva horizontu C_1, ktorá je obyčajne uľahnutá a je aj fyziologickou hranicou pre rast koreňov. Vo všetkých oblastiach hĺbka nikde neprekročila 130 cm. Šírka koreňovej sústavy nikde nepresiahla maximum 550 cm. Na rankrových pôdach šírka dosahovala nižšie hodnoty, a to len 350 cm s priemernou hĺbkou 80 cm.

Dôležitým faktorom často prioritným bola hladina podzemnej vody. Pri vysokej hladine buk nikde nevytváral hrubšie korene. Opačná situácia bola pri hlbšej hladine podzemnej vody, kde sa vyskytoval vždy mohutnejší, silnejší koreňový systém s hrubšími bočnými koreňmi, ktoré dobre zakotvovali buky. Na oglejených pôdach koreňová sústava mala charakter atypický, metlovitý, s pomerne tenkými koreňmi.

Dôležitým faktorom statickej stability bola početnosť koreňov buka tak pri vyvrátených, ako i stojacích kmeňoch buka. Početnosť a vyhodnotenie meraných koreňov poukazuje na prekvapivo veľkú vyrovnanosť v jednotlivých hrúbkach, a to hlavne na vyvrátených bukoch. Početnosť koreňov do 3cm hrúbky sa všade pohybovala od 41 do 66 % zo všetkých koreňov. Z hľadiska statickej stability sú málo významné. Významnejšie sú korene rozložené v hrúbkach 3–10 cm, ktorých na vývratoch bolo 26–43 %. Najvýznamnejšie boli korene hrubšie ako 10 cm, ktorých pri vývratoch bolo len 3–22 % z celkového počtu koreňov, ktoré naviac v starších porastoch od 60–80-ročných javili aj znaky hnilobnosti. Rozbor ukázal, že z hľadiska statickej stability je rozhodujúci počet koreňov v hĺbke 50–70 cm. Ak je v tomto horizonte malý počet koreňov hrubších ako 3 cm ako i koreňov nad 10 cm, stávajú sa veľmi labilné.

Uvedený rozbor potvrdzuje, že najväčšie percento koreňov buka je v hĺbke 25–50 cm, kde sa vlastne rozhoduje o statickej stabilite.

Drevokazné huby značne znižujú statickú stabilitu stromov a okrem toho výrazne ovplyvňujú aj fyziologické procesy. Na ťažších pôdach sa na všetkých lokalitách vyskytovala podpňovka *Armillaria mellea* (Vahl: Fr.) Kummer, a to prevažne na vývratoch bukov starších ako 50 rokov.

Z hľadiska stability bučín voči vetru bolo dôležité zistenie, že pri výskyte podpňovky intenzita rozkladu v porastoch značne narástla už po prvých ťažobných zásahoch. Čím bola pôda plytkejšia a kyslejšia, objavovali sa rizomorfy vo väčšej miere (až v 40 % prípadov). Podľa druhu pôd, resp. ich minerálnej sily sa dalo zistiť, že na minerálne slabších pôdach s hrubšou štruktúrou, kde bola koreňová sústava mohutnejšia a dobre vyvinutá, bolo napadnutie koreňov podpňovkou najmenšie.

Za dôležité považujeme zistenie, že už po prvých ťažobných zásahoch sa v bukových porastoch začali objavovať ojedinelé vývraty, na ktorých sa už v 72 % prípadov vyskytli rizomorfy podpňovky, pričom konce koreňov boli zahnité a hniloba v 56 % prípadov prechádzala aj do bele a jadra. Zahnívanie koreňov na rôznych lokalitách bolo veľmi rozdielne, čo sa prejavilo aj v rozdielnej statickej stabilite bučín.

Výskum podzemnej biomasy bol orientovaný na dva typy stanovíšť – na bučiny rastúce na pôdach bohatých na živiny a na bučiny rastúce na pôdach na živiny chudobné. Celková biomasa bukového porastu na stanovištiach bohatých na živiny bola 44,08 t/ha. Na chudobných stanovištiach bola celková podzemná biomasa bukového porastu vyššia – 47,59 t/ha. Rozdiely v hmotnosti boli zaznamenané vo všetkých hrúbkových frakciách v prospech podzemnej biomasy bučín na chudobných stanovištiach. Významné rozdielnosti boli zaznamenané len v prvých dvoch hrúbkových triedach (korene do priemeru 2 cm).

Corresponding author:

Doc. Ing. MILAN KODRÍK, CSc., Ústav ekológie lesa, Slovenská akadémia vied, Štúrova 2, 960 53 Zvolen, Slovenská republika
tel.: + 421 45 533 09 14, fax: + 421 45 547 94 85, e-mail: kodrik@sav.savzv.sk