

Root biomass of *Fagus sylvatica* L. stands depending on the climatic conditions

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ABSTRACT

Fine root biomass of forest trees is a recognised indicator of environmental changes in the conditions of global climate change. The present study was carried out in six old-growth beech forests (112–140 years) located in different climatic conditions on the range border of *Fagus sylvatica* L. in Poland. The root biomass was investigated by soil coring method in the upper soil layers (0–5 cm, 5–15 cm and total layer 0–15 cm). The significantly greater total root biomass was found in the beech stands, which characterised by higher average precipitation and lower average annual temperatures in the period 2000–2005. The share of roots of diameter > 5 mm increased with increasing depth of top soils. Biomass of fine roots (diameter ≤ 2 mm) decreased with increasing depth of upper soil layers. The average biomass of fine roots ranged from 175.36 to 418.16 g m⁻² in the soil layer 0–15 cm. The significant differences of fine root biomass were found between studied stands in the soil layers 0–5 cm and 0–15 cm. Also, it was found significant positive correlation between fine root biomass in the soil layer 0–15 cm and precipitation during the growing season in 2006. Precipitation in the study period was connected with very high rainfall in August 2006, repeatedly exceeding the long-term monthly levels. Regional climatic conditions, in that extreme weather events in growing seasons can significantly to affect changes of fine root biomass of forest trees, consequently, changes of relationships between the growth of above- and below-ground of the old-growth forest stands.

KEY WORDS

root system, fine roots, fine root biomass, climate change, *Fagus sylvatica* L.

INTRODUCTION

Tree roots constitute about 20–40% of global forest biomass. In temperate forests of Europe, biomass of coarse roots is estimated on average 25%, while biomass of fine roots on average 1% of the biomass of trees (Godbold and Brunner 2007). The type of the root system, horizontal and vertical distribution of roots, is a feature species of forest trees modified by environmental con-

ditions (Jackson et al. 1996). Fine roots – their production, biomass and vitality – are recognised indicators of environmental change (Godbold and Brunner 2007; Finér et al. 2011). Most fine roots grow in the upper layers of soil. They are responsible for water and nutrient uptake and play a key role in the carbon cycle in forest ecosystems (Jackson et al. 1996; Le Goff and Ottorini 2001). The growth of fine roots of forest trees is dependent on the soil environment as well as climatic con-

ditions (Sanantonio and Grace 1987; Gill and Jackson 2000; Norby and Jackson 2000). The temperate forests are characterised by higher biomass than roots of small stands of the boreal zone. In the temperate zone, deciduous species distinguished by higher root biomass small compared with coniferous species (Vogt et al. 1986).

European beech is a species commonly found in European forests of the temperate zone. It creates both a single-species stands, as well as an important component of mixed stands. Climate change is observed on a global scale and can affect future changes in species composition of forests both in the boreal and temperate zones. The length of the growing season, temperature and soil moisture are the major factors that determine the natural range of many species of forest trees, including *F. sylvatica* (Stykes and Prentice 1995). Currently, the climatic conditions in the area of occurrence of beech are varied, but the annual precipitation of 500 mm is a limiting factor of the natural occurrence of this species (Jaworski 1995). Beech one of the species sensitive to water deficit in the soil. Its root system is characterised by intensive development of fine roots in the upper soil layers (Leuschner et al. 2004). The intensity of the fine roots growth is the result of climatic factors at the regional scale, as well as at the local scale (growing season). Biomass of fine roots is related also with features of trees such as age, dbh and features of stands e.g. tree density, species composition (Vogt et al. 1983; Le Goff and Ottorini 2001; Claus and George 2005; Finer et al. 2007; Yuan and Chen 2010).

The aim of the study was to compare the biomass of roots in the upper soil layers in the mature beech depending on the climatic conditions on the border of the occurrence of beech in Poland. The research verified the hypothesis: „Precipitation, especially in the growing season are the important factor of fine root growth in old-growth beech stands on the border of the natural occurrence of *Fagus sylvatica* L.”.

METHOD

The present study was carried out in six old-growth beech stands located near the border of the natural occurrence of *F. sylvatica* in Poland (Tab. 1, 2). The studied stands were 112–140 years old and represented the forest community *Melico-Fagetum*. The growth character-

istics of stands and soil conditions were prepared based on published data (Olszowska 2011; Dobrowolska 2015).

Table 1. Characteristics of studied stands

Study stand (Abbreviation)	Location	Site type	Age of stand (years)	Stand density* (trees ha ⁻¹)	Basal area* (m ² ha ⁻¹)
Łopuchówko (Ł)	52°38'N 17°07'E	FB	140	51	13.0
Góra Śląska (G)	51°31'N 16°48'E	FB	132	65	11.0
Jamy (J)	53°58'N 19°42'E	FB	112	83	17.5
Brzeziny (B)	51°50'N 19°40'E	FB	121	117	21.8
Mrażowo (M)	54°06'N 21°03'E	FB	125	120	21.4
Tomaszów Lubelski (T)	50°37'N 23°23'E	FBH	134	133	28.4

Site type: FB – fresh broadleaved forest, FBH – fresh broadleaved highlands forest.

* Data source: Dobrowolska 2015.

Table 2. Chemical properties of top soils in studied stands*

Study stand (Abbreviation)	Soil type	Layer (cm)	pH	%C	%N	S _{BC} (cmol (+)kg)
Łopuchówko (Ł)	Podzol Cambisol	0–5	3.43	2.96	0.136	1.82
		5–15	3.65	1.33	0.051	0.31
Góra Śląska (G)	Hyperdystric Cambisol	0–5	2.95	5.33	0.218	2.13
		5–15	3.34	1.75	0.074	0.42
Jamy (J)	Podzol	0–5	3.56	1.96	0.085	0.67
		5–15	3.76	1.23	0.055	0.27
Brzeziny (B)	Cambisol	0–5	4.02	1.95	0.086	1.07
		5–15	4.15	0.90	0.044	0.25
Mrażowo (M)	Podzol Cambisol	0–5	3.97	2.92	0.192	2.68
		5–15	3.85	1.46	0.085	0.73
Tomaszów Lubelski (T)	Cambisol	0–5	3.77	2.55	0.177	1.58
		5–15	3.75	1.27	0.077	0.33

S_{BC}- the soil bearing capacity.

* Data source: Olszowska 2011.

The climatic conditions of study area were characterised based on meteorological data for the period 2000–2005 and the growing season (April–September) 2006 from six IMGW stations: Poznań, Wrocław, Toruń, Łódź, Olsztyn, Lublin (Tab. 3). The field studies were conducted at the turn September/October 2006. Three beech trees were selected based on average growth parameters (dbh and height) in each study stand. Around each tree, at the distance not longer than 1.50 m from tree trunks, five soil samples with tree roots were collected using a soil corer (8 cm diameter), from top-soils: 0–5 cm and 5–15 cm (total 90 samples from each layer). Laboratory analyses were conducted consistent with the method described by Farfał (2011). Beech roots were sorted into four fractions depending on the root diameter: I fraction – $d < 2.0$ mm (fine roots), II fraction – $2.0 \leq d < 5.0$ mm, III fraction – $5.0 \leq d < 10.0$ mm, IV fraction – $d \geq 10.0$ mm. Total biomass of roots (g m^{-2}) and biomass according the size fraction of roots were determined in the upper layers of soil (0–5 cm, 5–15 cm) after the measurement of the dry mass of roots. The time and temperature of measurement were dependent on the root diameter (Böhm 1985). Also, the total biomass of roots and the biomass of each size fraction of roots were determined for the cumulative soil layer 0–15 cm.

Table 3. Climate characteristics of studied stands

Study stand (Abbreviation)	IMGW Station	Mean precipitation (mm)		Mean temperature (°C)	
		2000–2005	April/September 2006	2000–2005	April/September 2006
Łopuchówko (Ł)	Poznań	525	303	9.3	17.2
Góra Śląska (G)	Wrocław	533	407	9.5	16.4
Jamy (J)	Toruń	573	358	8.9	16.0
Brzeziny (B)	Łódź	596	281	8.7	16.1
Mrażowo (M)	Olsztyn	613	383	7.9	14.8
Tomaszów Lubelski (T)	Lublin	585	345	8.1	15.5

*Data source: Bulletin of the Institute of Meteorology and Water Management. 2000–2006. IMGW.

Statistical data analyses were carried out with *Statistica 10* (StatSoft Inc., Tulsa, OK, USA) Nonparametric ANOVA rang the Kruskal–Wallis test was used to assess the differentiation of root biomass between beech stands. Multiple comparisons average range test was used to assess the significance of differences between beech stands. The relationships between features of climate, stand, soil and biomass of roots were analysed using Spearman's rang correlation test.

RESULTS

Total root biomass

The average total root biomass of beech stands was within limits 634.47–1363.72 g m^{-2} in soil layer 0–15 cm (Fig. 1). The total biomass of roots increased with the depth of the upper soil layers (layer 0–5 cm: 126.66–408.24 g m^{-2} ; layer 5–15 cm: 284.44–955.48 g m^{-2}).

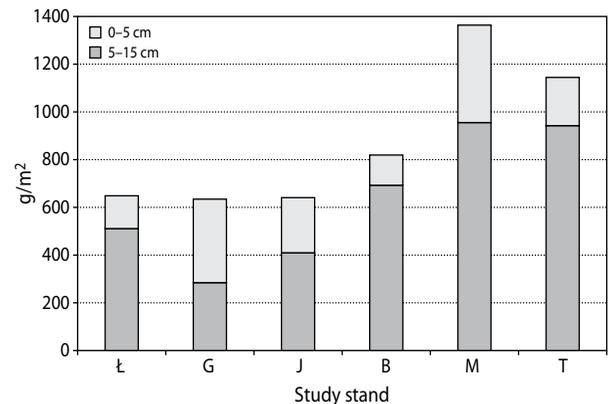


Figure 1. Total root biomass (g m^{-2}) in beech stands (soil layer 0–15 cm)

The beech stands 'M' and 'T' were distinguished the highest biomass of roots in the top soils, especially in soil layer 5–15 cm. A significant differentiation of the total biomass of roots was found between beech stands in the studied layers of soil (layer 0–5 cm: $H = 28.2701$ $p = 0.0000$; layer 5–15 cm: $H = 16.8186$ $p = 0.0049$; layer 0–15 cm: $H = 15.2843$ $p = 0.0092$). The results of multiple comparisons of average range test showed significant differences between the beech stands 'G' and 'B' ($p = 0.0007$), 'Ł' ($p = 0.0032$) and the stands 'M' and 'B' ($p = 0.0026$) and 'Ł' ($p = 0.0105$) in the soil layer 0–5 cm (Fig. 2).

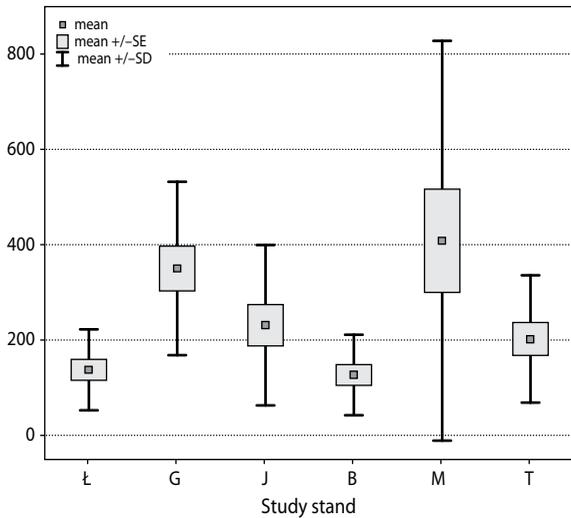


Figure 2. Total root biomass (g m^{-2}) in beech stands (soil layer 0–5 cm)

Size fractions of root

The fine root (I size fraction) growth was more intense in the soil layer 0–5 cm than 5–15 cm in the studied stands. The share of fine root biomass was within the limits of 65–83% in the soil layer 0–5 cm (except for the stand ‘M’ – 43%), and within 13–19% in the soil layer 5–15 cm. The stand ‘G’ was only distinguished by the high share of biomass fine roots in both soil layers (0–5 cm: 83% and 5–15 cm: 45%).

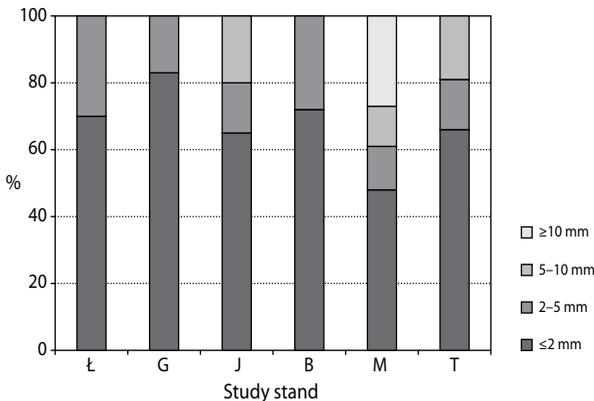


Figure 3. Percentage of the root biomass in size root fraction (soil layer 0–5 cm)

The beech stands characterised by similar share of biomass of roots of II size fraction in the soil layers 0–5 cm (13–30%) and 5–15 cm (12–29%). The roots of

III size fraction were found in the beech stand ‘J’, ‘M’ and ‘T’, and the roots of IV size fraction only in the stand ‘M’ in the soil layer 0–5 cm. The share of root biomass of III and IV size fraction increased with increasing depth of top soils. The stand ‘M’ characterised by the biggest share of the root biomass of III and IV size fraction in both soil layers (Fig. 3 and 4).

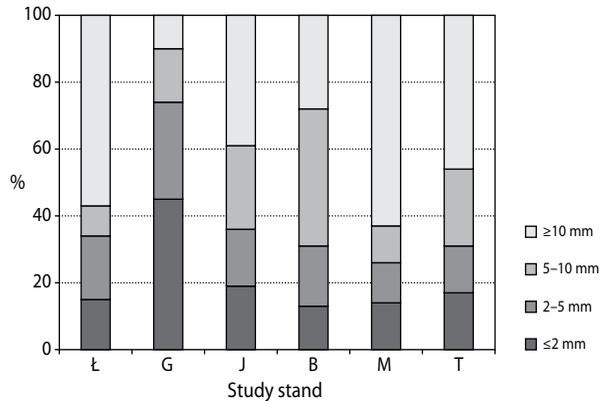


Figure 4. Percentage of the root biomass in size root fraction (soil layer 5–15 cm)

Fine root biomass

The average biomass of fine roots was in the range 175.36–418.16 g m^{-2} in the soil layer 0–15 cm (Fig. 5). Most of the fine roots grows (91.02–290.76 g m^{-2}) in the layer of 0–5 cm than in the layer 5–15 cm (76.99–156.18 g m^{-2}).

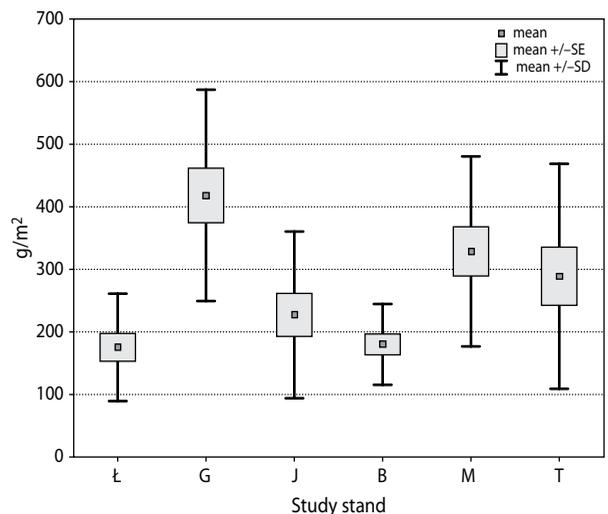


Figure 5. Fine root biomass (g m^{-2}) in beech stands (soil layer 0–15 mm)

The highest biomass of fine roots was found both in the soil layer 0–5 cm (290.77 g m^{-2}) and layer 0–15 cm (418.16 g m^{-2}) in the stand 'G' (Fig. 6). A significant differentiation of fine root biomass was found between forest stands in the soil layers 0–5 cm ($H = 29.008$; $p = 0.0000$) and 0–15 cm ($H = 28.4048$; $p = 0.0000$). The results of multiple comparison of average range test showed significant differences between beech stands 'G' and 'L' ($p = 0.002$), 'J' ($p = 0.036$), 'B' ($p = 0.000$), 'T' ($p = 0.028$) in the soil layer 0–5 cm and between stands 'G' and 'L' ($p = 0.0002$), 'J' ($p = 0.0114$), 'B' ($p = 0.0004$) in the soil layer 0–15 cm. No significant differences of the fine root biomass between beech stands were visible in the soil layer 5–15 ($H = 6.8293$; $p = 0.2337$).

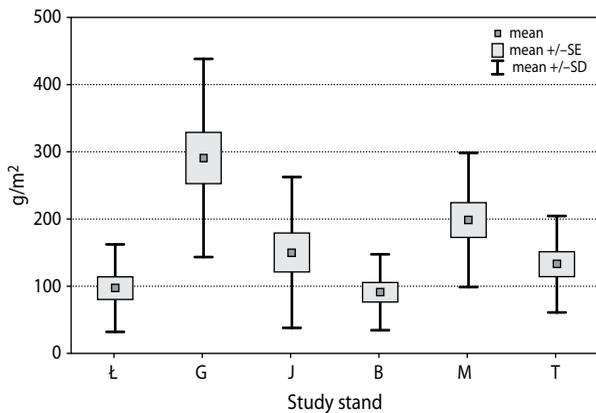


Figure 6. Fine root biomass (g m^{-2}) in beech stands (soil layer 0–5 mm)

The relationship between fine root biomass and climate, stand, soil

Correlation coefficients (R) between fine root biomass in top soils (0–15 cm, 0–5 cm, 5–15 cm) and the climatic, site and stand factors are shown in table 4. The significant correlation ($R = 0.8857$; $p = 0.018$) was shown between the fine root biomass of beech stands in soil layer 0–15 cm and the precipitation during the growing season (April–September) 2006 (Fig. 8). Beech stands 'L' and 'B', which showed the lowest biomass of fine roots in soil layer 0–15 cm (respectively: 175.36 g m^{-2} , 180.07 g m^{-2}), represented the areas with the precipitation (respectively: 281 mm, 303 mm), while the stands 'M' and 'G', which distinguished the largest biomass of

fine roots (respectively: 328.7 g m^{-2} , 418.16 g m^{-2}) represented areas with the highest precipitation (respectively: 383 mm, 407 mm) in the analysed growing season.

Table 4. Correlation coefficients (R Spearman) between fine root biomass (g m^{-2}) and the climatic, site and stand factors (* statistically significant correlations $p < 0.05$; $n = 6$)

Variable	R
Soil layer 0–15 cm	
Mean annual precipitation in 2000–2005 (mm)	0.257
Mean growing season precipitation 2006 (mm)	0.885*
Mean annual temperature in 2000–2005 ($^{\circ}\text{C}$)	-0.085
Mean growing season temperature 2006 ($^{\circ}\text{C}$)	-0.428
Stands density (trees ha^{-1})	0.314
Basal area ($\text{m}^2 \text{ ha}^{-1}$)	-0.142
Stand age (years)	-0.085
Soil layer 0–5 cm	
pH	-0.485
%C	0.695
%N	0.657
S_{BC} ($\text{cmol}(+)\text{kg}$)	0.542
Soil layer 5–15 cm	
pH	-0.028
%C	0.085
%N	0.714
S_{BC} ($\text{cmol}(+)\text{kg}$)	0.657

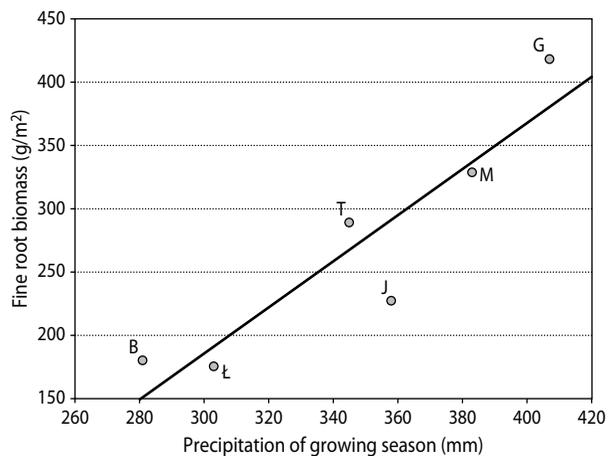


Figure 7. Correlation (R Spearman) between fine root biomass (g m^{-2}) and precipitation (mm) in growing season 2006 (soil layer 0–15 cm)

DISCUSSION

The results of the present study showed significant differences of the total root biomass in the upper soil layers of 0–15 cm between the beech stands. Beech stands aged 112–140 years old were located near the border of the natural occurrence of *Fagus sylvatica* L. in Poland and these were characterised by varied climatic conditions. The intensive root growth (1144.64–1363.72 g m⁻²) in the soil layer 0–15 cm was demonstrated in the stands, which were located in the areas with the highest average annual rainfall (585–613 mm yr⁻¹) and the lowest average annual temperatures (7.9–8.1°C) in 2000–2005. Whereas the biomass of roots almost twice less (634.47–648.61 g m⁻²) was observed in the areas with the lowest average annual rainfall (525–533 mm yr⁻¹) and the highest mean annual temperatures (9.3–9.5°C). In the studied stands the increase of the total biomass of roots with the increase of soil depth was also noted. With an increase in the depth of the soil, the increase of the share of biomass root >5 cm also took place. The opposite tendency was demonstrated in the case of fine roots. The share of fine root biomass in limits 65–83% in the soil layer 0–5 cm decreased (13–19%) with the increase of depth of soil (5–15 cm). Differentiation of fine roots biomass between forest stands was significant in the soil layer 0–5 cm and 0–15 cm. The average biomass of fine roots in soil layer 0–15 cm was within 175.36 g m⁻²–418.16 g m⁻². These results were similar to the published data for the species (Le Goff and Ottorini 2001; Leuschner et al. 2004; Bolte and Villanueva 2006; Finer et al. 2007; Jagodzinski et al. 2016) and for the temperate forests of Europe (Finér et al. 2011), despite the methodological differences related to the depth of the examined soil layers: 0–15 cm, 0–30 cm and 0–40 cm. According the data from the literature, more than 60% of the fine roots biomass from the soil layer 0–30 cm grows in the soil layer 0–15 to 20 cm (Jackson et al. 1996; Idol et al. 2000; Hertel and Leuschner 2002; Curt and Prevosto 2003; Bakker et al. 2008; Meinen et al. 2009; Jagodzinski et al. 2016).

The present study was carried out in the stands aged 112–140 years old, which represented the third phase of growth of biomass fine roots according to the model growth of fine root biomass along the life cycle of a forest stand (Claus and George 2005). The first phase of the model associated with the intensi-

ve growth of the fine roots biomass reaches a maximum around 20 years of age of the trees. The second phase takes place during maturation of stand and it is associated with a slow decrease in intensity of the biomass growth of fine roots. The third phase involves moderate and balanced growth of fine roots in the mature stands (steady-state). The relationship between the growth of fine roots and age stands were analysed taking into account a wide range of age stands, e.g. 4–100 years (Idol et al. 2000), 3–111 years (Claus and George 2005), 30–250 years (Finer et al. 2007), 9–146 years (Bakker et al. 2008).

Many studies have confirmed the decrease of the intensity of fine roots biomass growth with age stands. However, the biomass of fine roots in each phase of the growth of trees is a result of the impact of the many features stand, e.g. species composition, number, height and dbh of trees, as well as climatic and soil conditions (Jackson et al. 1996; Vogt et al. 1996; Idol et al. 2000; Hertel and Leuschner 2002; Curt and Prevosto 2003; Finer et al. 2007).

Leuschner et al. (2004) suggested that precipitation is the significant factor of the fine root growth in mature beech stands. The study was carried out in the stands at the age of 110–152 years old, representing areas with differing precipitation (520–1032 mm yr⁻¹). The lowest biomass of fine roots (<150 g m⁻²) in soil layer 0–40 cm was found in the driest stand with precipitation 520 mm yr⁻¹. Biomass of fine roots in the remaining beech stands was more than double.

In the present study, differentiation average precipitation in the years 2000–2005 (525–613 mm yr⁻¹) was lower than in the 2006 growing season (281–407 mm). According Idol et al. (2000), the weather conditions in individual months of the year have a significant impact on the seasonal dynamics of the fine root growth of forest trees, especially during the growing season. In the present study, a positive correlation between the fine root growth in soil layer 0–15 cm and the amount of rainfall in the growing season of 2006 was demonstrated. The size of precipitation in the analysed season decided very high rainfall in August 2006, especially in the areas represented by the beech stand 'G' (229 mm) and 'T' (203 mm). Forecasts of climate change for the Polish show an increase in the frequency and intensity of extreme weather events (Kundzewicz and Judah-Rezler 2010).

The relationships between climate and the intensity of the root growth, especially fine roots were repeatedly analysed both on the level of species, stand as well as at the global level, based on a synthesis of published data (Leuschner et al. 2001, 2004; Finér et al. 2007, 2011; Olesinski et al. 2011, 2012). The results of the analysis confirm the impact of changes in the forest environment, especially in the conditions of global climate change on the growth and vitality of fine roots of forest trees (Vogt et al. 1996; Gill and Jackson 2000; Norby and Jackson 2000; Finer et al. 2007; Yuan and Chen 2010). The results of the present study suggested that weather conditions during the growing season, including extreme weather events (precipitation in August 2006) can have significant impact on the fine root growth of forest stands even aged above 100 years. The intensive growth of fine roots was demonstrated mainly in the stand, which represented areas with a very low precipitation in the last 5 years. According to Leuschner and Hertel (2002), precipitation constitutes the main factor of the fine root growth of European beech – species very sensitive to water deficit. Temperature, age stand and soil pH are factors of secondary importance in the root growth of the beech stands.

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