JOURNAL OF FOREST SCIENCE, *53*, 2007 (12): 561–566

Root systems of forest tree species and their soil-conservation functions on the Krušné hory Mts. slopes disturbed by mining

P. Čermák[1], F. Fér[2]

[1]*Research Institute for Soil and Water Conservation, Prague, Czech Republic*
[2]*Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic*

ABSTRACT: The paper describes the root system architecture of the forest tree species *Fagus sylvatica* L., *Quercus robur* L., *Pinus sylvestris* L., *Carpinus betulus* L., *Acer platanoides* L., and *Alnus glutinosa* (L.) Gaertn. at the age of 80–220 years growing on the slopes of the Krušné hory Mts. at the altitude of 330 to 480 m above sea level. These species were influenced by open-pit mining of brown coal as well as by power engineeting. The investigation also involves the determination of soil properties of Ranker Cambisols.

Keywords: root system; architecture; soil properties; Ranker Cambisols; mining; landslides

The investigated territory at the elevation from 330 to 480 m above sea level is situated between the boundaries of the Krušné hory Mts. slopes disturbed by open-pit mining of brown coal and landslides. It occupies the non-representative zone of thermophytes and mesophytes, and its boundary is demarcated by the Most region in the southeast and by the Krušné hory Mts. bioregion in the northwest. The width of the slopes disturbed by mining is 100–170 m and the length is more than 5 km. The central part of these slopes more than 1 km long is located downwards the Jezerka National Nature Preserve, the lower boundary of which passes approximately below the contour line 350 m a.s.l. This is the boundary to which the denuded slopes of the ČSA Mine are stretching; and no future plan was proposed for the inner dumping of mines above the elevation 280 m a.s.l. According to Quitt the lower slopes of the Krušné hory Mts. are in the mild warm area, exceptionally in the warm area. As for precipitation, this territory belongs to the arid area (Chomutov 497 mm, Ervěnice 464 mm, except for Horní Litvínov with 653 mm). Mainly acidophilous oak stands (*Genistogermanicae-Quercion*), sporadically also cow-wheat oak-hornbeam stands (*Melampyro-nemorosi-Carpinetum*), grow in the lower parts of the slopes continuing by herb-rich beech forests (*Violo reichenbachianae-Fagetum*) at the higher altitudes. Of the natural soil types mainly Ranker Cambisols are markedly represented. The contemporary vegetation state of the investigated bioregion is a result of extensive mining of this landscape since the Middle Ages as well as of power engineering and developing chemical industry since the mid-20th century. All these factors caused the gradual devastation of forest tree species composition on the slopes and large-scale dying of spruce stands on the Krušné hory Mts. plateau.

MATERIAL AND METHOD

Reclamations of the evaluated territory. At present, the width of denuded slopes of the Krušné hory Mts. is 100–170 m and their length is more than 5 km. The central part of the side slopes more than 1 km in length is situated approximately below

Supported by the Ministry of Agriculture of the Czech Republic, Project No. MZe 0002704901.

the Jezerka National Nature Preserve. The lower boundary of this preserve is below the contour line 350 m above sea level. Denuded slopes of the ČSA Mine are reaching as far as this boundary, and it is not assumed that they would be filled with the inner dump of the ČSA Mine above the elevation 280 m above sea level. Remediation and reclamation of these side slopes are proposed to be carried out after the mining operations have been terminated on these lands, i.e. after 2016.

The character of Anthroposols (Němeček 2001) is influenced quite significantly by the properties of geogenic substrates, methods of their overlaying (mixing) including the reclamation technologies used for the improvement of their soil properties. In the course of reclamation of the lowest slope parts of the Krušné hory Mts. pelitic Anthroposols (with the content of soil particles < 0.01 mm higher than 45%) will be formed most frequently while their soil-forming substrate will be composed of illitic-kaolinitic gray clays with chemical and physical soil properties favourable for forestry production; overlaid Anthroposols will also be formed that will consist of various proportions of rocks of the coal seam, gray clays including substrates of the original natural soils (sand, gravel, boulders). Reclamations at the highest locations will be finished by terraced Anthroposols – erosion-control measures will be taken on the slopes using only substrates of original natural soils (Cambisols).

Rhizological findings from the investigation carried out in the disturbed space of the Krušné hory Mts. slopes should contribute to the optimisation of the created species composition on Anthroposols of steeper gradient, influenced by substrates of original natural soils to a significant extent.

Investigations performed. As a major part of root biomass is concentrated in the active or "physiological soil profile", taking into account the position of the windthrow (the total area of the denuded root system) great attention was paid to the characterisation of the formation of skeletal roots that comprise horizontal and vertical roots – taproot, heart-shaped roots, vertical and oblique anchor roots that determine the overall morphogenesis of the root system at a site; its state can also be defined by so called "robustness of the root system" (the ratio of its depth to its width) as well as by roots of lower orders and terminal roots if possible – root hairs that were not damaged by the windthrow. The walls of landslides – cross profiles of denuded roots of some tree species were used for these purposes (Fig. 1). The rhizological structure of the forest tree species root system denuded due to landslides and windfalls was assessed

Fig. 1. Root system of *Quercus robur* L.

for 210 individuals lying on the relatively broken topography with slope inclination 0–40° and with stand density of 0.7–0.9 m. The age of *Fagus sylvatica* L. was 80–170 years, *Quercus robur* L. 70–220 years, *Carpinus betulus* L. 70–130 years, *Acer platanoides* L. 70–110 years, *Pinus sylvestris* L. 70–130 years and *Alnus glutinosa* (L). Gaertn. 110–140 years. Determination of soil properties of the represented soil type (Cambisol) was a part of research work. Impaired soil samples were taken in 3 replications from typical soil horizons (Cambisol, soil-forming substrate) and analysed in central laboratories of the Research Institute for Soil and Water Conservation in Prague. Soil texture, soil reactions, cation exchange capacity, content of total nitrogen, carbonates and available nutrients (P, K, Mg, Ca according to Mehlich III) of Cambisol horizon and pedogenic substrate were included in this evaluation.

RESULTS AND DISCUSSION

Soil characteristic of investigated territory

The Quaternary character in the investigated region is predetermined by the geological formation and morphological conditions of the Krušné hory Mts. The slopes of the Krušné hory Mts. are mostly covered by stony to boulder debris up to 2 m in thickness; diluvial sand-stony debris dominates in quite a great deal of the lower slope parts in which loamy fractions are found more frequently towards the basin and the thickness of pedogenic substrate increases up to several metres. Fluvial sediments are less frequent in the lower slope parts where mostly sandy loam and loamy gravel with changeable proportions of gneiss fractions occur.

Of the soils types Ranker Cambisols (Němeček 2001) are represented most frequently in the territory that developed on skeleton slopes formed of acid metamorphic rocks. Cambisols, the most

Table 1. Chemical and other soil properties

Soil profile (cm)	pH KCl	CEC (cmol +/kg)	V (%)	N_t (%)	C_{ox} (%)	Available nutrients (mg/kg)			
						P	K	Mg	Ca
0–30	3.7	18.7	< 30	0.11	2.82	116	86	17	83
40–300	4.1	5.3	72	< 0.05	< 0.12	30	50	92	268

Table 2. Grain composition

Soil profile (cm)	Content of particle-size category (%)				
	< 0.001 mm	< 0.01 mm	0.01–0.05 mm	0.05–0.25 mm	0.25–2.0 mm
0–30	10.0	20.7	17.7	16.8	44.8
40–300	7.6	14.6	9.8	15.6	60.0

widely distributed soil type in this country, occur mainly in more humid, mildly warm climate – the most frequently in highlands and uplands. Intensive soil weathering is the main pedogenic process during which Fe_2O_3 hydrates are released and cover soil particles causing the characteristic colouring of the soil horizon (Bv) from brown to rusty matt brown. The soil horizon is maximally 0.3–0.35 m in thickness in this investigated territory, is characterised by the strongly acid soil reaction, extreme sorption non-saturation, without carbonates, humus content is high, nutrient content of phosphorus and potassium is favourable and contents of magnesium and calcium are very low. The pedogenic substrate differs from the Cambisol horizon in a slight increase in soil alkalinity, fast drop of the content of mineral substances, increase in adsorption saturation, reduction in the supply of phosphorus and potassium and increased content of magnesium and calcium. As for texture, the soil in the whole profile can be defined (according to Novák) as loamy soil to sandy loam with increasing content of medium sand fraction and skeletonisation (gravel, stone, boulders) downwards the soil profile.

The investigated soil properties of Ranker Cambisols are presented in Tables 1 and 2.

Rhizological structure of the root system of investigated tree species

In the description of the root system of evaluated tree species taxa we also present the rhizological characterisation according to Jeník (1957, 1960, 1974; Köstler et al. 1968; Válek 1977; Meyer 1982; Ehlers 1986; Balder 1998; Fér 2003).

***Fagus sylvatica* L.** 102 individuals were evaluated with dbh ($d_{1.3}$) 40–95 cm. The root system is characterised by a huge set of 16 strong horizontal skeletal roots uniformly distributed with huge buttresses and many root graftings (in older individuals the slab-like character with very hardly separable soil among roots) that are further branching and at the end mildly bending geotropically into the depth. Numerous slant and classical anchor-shaped roots grow from these skeletal roots, taproot occurs in 40% of individuals markedly narrowing at the depth of 0.9–1.3 m (is branching, bending to sides). The oval shape of roots at the distance of 0.6–0.8 m from the stem is sharp; its shorter side measures 20–35 cm and is in horizontal position and its side in vertical position in length is 1.5 times longer than the shorter side. Total rooting depth of soil profile reaches 1.5 to 2.3 m and rooting diameter of soil profile under the stem axis is 5.0–10.5 m. Fig. 2 shows *Fagus sylvatica* L. at a site with increased groundwater level. The tree species is characterised by a robust system of horizontal roots with numerous oblique and vertical anchor roots while the taproot is missing, the depth of root penetration into the soil is 0.7 m and total

Fig. 2. Root system of *Fagus sylvatica* L.

Fig. 3. Root system of *Quercus robur* L.

Fig. 4. Root system of *Carpinus betulus* L.

root width is 8.4 m. In most cases, the tree species is attributed the heart-shaped root system except in clay and calcareous soils.

***Quercus robur* L.** 66 individuals were evaluated with dbh ($d_{1.3}$) 40–105 cm. The root system is characterised by a huge set of 12 strong horizontal skeletal roots uniformly distributed that are further branching and at the end arch-shaping into the depth. The oval section of roots at the distance of 0.6–0.8 m from the stem perimeter is sharp; its shorter wall measures 13–20 cm and is in horizontal position and its wall in vertical position in length is twice longer than the shorter wall. Numerous slant and classical anchor-shaped roots grow from these skeletal roots, taproot, being 2.1 m long, is developed in 90% of investigated individuals and like in European beech markedly narrows to the diameter ca 1.0 m (is branching, bending to sides). Total rooting depth of soil profile reaches 1.5–3.0 m and rooting diameter under the stem axis is 4.6–8.7 m. Rhizological characterisation of *Quercus robur* L. of the breast-height diameter ($d_{1.3}$) 75 cm is shown in Fig. 3. It belongs to the tree species with long roots (more than 6 m), deep-rooting (more than 1 m), which can penetrate through clay layers (gley horizons), with a good capacity of reinforcing the banks of watercourses and soils against landslides. At younger age the tree species is characterised by the taproot root system that is functionally replaced by the heart-shaped root system at old age.

***Carpinus betulus* L.** 19 individuals were evaluated with dbh ($d_{1.3}$) 30–52 cm. The root system is characterised by a huge set of 12 strong horizontal skeletal roots uniformly distributed (with huge root buttresses in the older individuals) further branching and at the end arch-shaping into the depth. Numerous slant anchor-shaped roots grow from

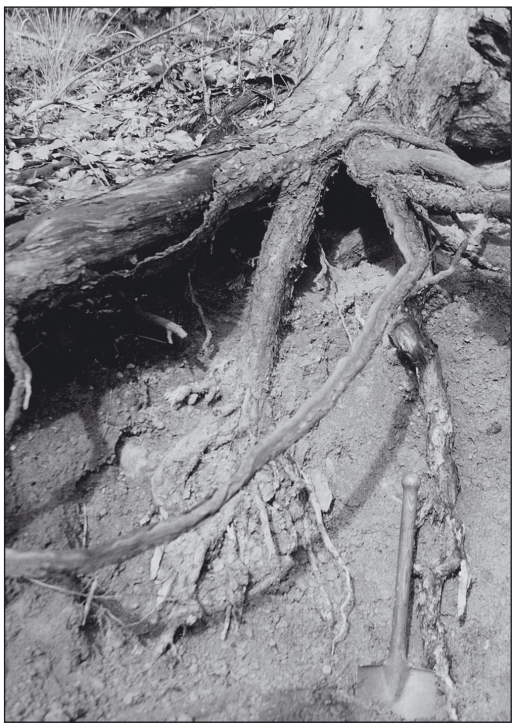

Fig. 5. Root system of *Pinus sylvestris* L.

these skeletal roots. The oval section of roots at the distance of 0.6–0.8 m from the stem perimeter is sharp; its shorter wall measures 10–14 cm and is in horizontal position and its wall in vertical position in length is 1.5 times longer than the shorter wall. The root system is often completed by one storey of horizontal roots at the depth of 0.35 m, taproot is developed in 40 % of individuals and reaches the maximal length of 0.7 m. Total rooting depth of soil profile ranges between 1.3 and 1.6 m and rooting diameter under the stem axis is 4.5 to 5.7 m. Rhizological characterisation of *Carpinus betulus* L. of the breast-height diameter ($d_{1.3}$) 45 cm is shown in Fig. 4. It belongs to the tree species with roots of medium length (max. 6 m), penetrating into a medium depth (1 m), with lower branching density (max. 100 m/ m^2). At younger age it forms a shorter taproot that is functionally replaced by the heart-shaped root system at old age.

***Acer platanoides* L.** 23 individuals were evaluated with dbh ($d_{1.3}$) 35–58 cm. The root system is characterised by a huge set of 14 strong horizontal skeletal roots uniformly distributed, further branching and at the end arch-shaping into the depth. Numerous slant anchor roots and classical anchors grow from these skeletal roots. The root diameter at the distance of 0.6–0.8 m from the stem perimeter reaches 20 to 25 cm and its section is rather circular. Taproot (very often also with twin taproots) is developed in 90% of individuals and reaches the maximal length of 1.2 m when it is narrowing (diameter 1.0 cm, is branching and bending to sides). Total rooting depth of soil profile reaches 1.5–1.9 m and rooting diameter under the stem axis is 4.4–6.2 m. It is a tree species with roots of medium length (maximally 6 m), reaching into a medium depth (to 1 m), of smaller branching density (less than 100 m/m^2). This tree species has a heart-shaped and anchor root system.

***Pinus sylvestris* L.** 8 individuals were evaluated with dbh ($d_{1.3}$) 40–55 cm. The root system is characterised by a huge set of 8 strong horizontal skeletal roots uniformly distributed, branching at the half of their length in the majority of individuals, one branch arches into the depth and overgrows the taproot at the reached depth in the older individuals and the other branch continues in horizontal growth. The root diameter at the distance of 0.6–0.8 m from the stem perimeter reaches 22–25 cm and its section is rather circular. Taproot was found in all the investigated individuals with the maximal length of 1.4 m (further narrowing to a diameter of 1.0 cm). Total rooting depth of soil profile reaches 1.3–1.7 m and rooting diameter under the stem axis is 6.1–8.3 m. Rhizological characterisation of *Pinus sylvestris* L. of the breast-height diameter ($d_{1.3}$) 48 cm is shown in Fig. 5. In deep soils the tree species forms a taproot with strong horizontal roots (also at two storeys), it is not afflicted by windthrows, and it reinforces well the soil against landslides.

Fig. 6. Root system of *Alnus glutinosa* (L.) Gaertn.

***Alnus glutinosa* (L.) Gaertn.** The state of root system was observed in 2 individuals with dbh ($d_{1.3}$) 47–60 cm in a terrain depression in front of the stream mouth into the reinforced stream bed. The root system is characterised by a huge set of 14 strong horizontal roots uniformly distributed with strong root buttresses, at the end arching into the depth, completed by some more roots of diameter 3–5 cm, growing mostly vertically into the depth of soil profile and filling very densely the central part of horizontal skeletal roots. The oval section of roots at the distance of 0.6 to 0.8 m from the stem perimeter is sharp; its shorter wall measures 6–10 cm and is in horizontal position and its wall in vertical position in length is 12 times longer than the shorter wall. Total rooting depth of soil profile is up to 2.0 m and rooting diameter under the stem axis is up to 6.0 m. Rhizological characterisation of *Alnus glutinosa* (L.) Gaertn. of the breast-height diameter ($d_{1.3}$) 48 cm is shown in Fig. 6. It belongs to the trees species with short roots (max. 3 m), penetrating into medium depths (max. 1 m), with sparse branching of roots (max. 100 m/m^2). The tree species forms a heart-shaped root system (the shape of bell) when stronger, longer-reaching roots are missing.

According to the available rhizological knowledge from spoil banks of the North Bohemian Brown Coal

Basin (Čermák 2005) we can consider particularly *Quercus robur* L., *Fraxinus excelsior* L. and *Alnus glutinosa* (L.) Gaertn. as very important tree species from the aspect of reclamation (erosion control) with the initial formation of very sizeable systems of skeletal roots (horizontal and vertical ones) on all types – subtypes of formed Anthroposols at the age of 15 years.

CONCLUSION

Very high density of root penetration into the surface soil horizon (0–0.3 m), accompanied by copious root grafting in the central part of the root system, is typical at the evaluated age of tree species mainly of *Fagus sylvatica* L., *Carpinus betulus* L. and *Acer platanoides* L., and in the density of terminal radicles in *Quercus robur* L. (these traits are compared only with *Fagus sylvatica* L. below in the text). All evaluated tree species (*Fagus sylvatica* L., *Quercus robur* L., *Carpinus betulus* L., *Acer platanoides* L., *Pinus sylvestris* L., *Alnus glutinosa* [L.] Gaertn.) are characterised rhizologically by the sizeable system of horizontal roots, heart-shaped and anchor roots while the greatest width of root penetration into the soil profile was observed in *Fagus sylvatica* L. The taproot (prop roots) was observed almost in all individuals of *Quercus robur* L., *Acer platanoides* L., and *Pinus sylvestris* L., a lower frequency (less than 40%) was determined in *Fagus sylvatica* L. and *Carpinus betulus* L. In relation to the tree species age the taproot (prop roots) markedly narrows down at a depth of 1.4–1.7 m, branches and deflects laterally whereas the longest taproot was measured in *Quercus robur* L., *Acer platanoides* L., *Pinus sylvestris* L. The highest volume of root biomass is in the soil horizon of 0–0.3 m.

References

BALDER H., 1988. Die Wurzeln der Stadtbäume. Berlin, Parey Buchverlag: 180.

ČERMÁK P., 2005. Hodnocení používaných rekultivačních postupů při zalesňování antropozemí. [Výstup z řešení výzkumného záměru MZe 0002704901.] Praha, VÚMOP: 26.

EHLERS M., 1986. Baum und Strauch in der Gestaltung und Pflege der Landschaft. Berlin und Hamburg, Verlag Paul Parey: 257.

FÉR F., 2003. Stanovištně-rizologické charakteristiky vodohospodářsky významných dřevin. [Dílčí závěrečná zpráva výzkumného úkolu FLE.] Praha, ČZU: 20.

JENÍK J., 1957. Kořenový systém dubu letního a zimního (*Quercus robur* L. et *Q. petraea* Liebl.). In: Rozpravy ČSAV, řada Matematicko-přírodní vědy. Praha, *67*: 8.

JENÍK J., 1960. Kořenový system dřevin. In: Zprávy Dendrologické sekce ČSBS Praha: 9.

JENÍK J., 1974. Adventní kořeny u nahosemenných a dvouděložních dřevin. In: Acta Musei Silesiae, Series Dendrologica, Opava, *XXIII*: 153–163.

KÖSTLER J.N., BRÜCKNER E., BIBELRIETHER H., 1968. Die Wurzeln der Waldbäume. Hamburg und Berlin, Verlag Paul Parey: 284.

MEYER F.H., 1982. Bäume in der Stadt. Stuttgart, Verlag Ulmer: 380.

NĚMEČEK J., 2001. Taxonomický klasifikační systém půd České republiky. Praha, ČZU: 79.

VÁLEK Z., 1977. Lesní dřeviny jako vodohospodářský a protierozní činitel. Praha, SZN: 203.

Received for publication February 20, 2007
Accepted after corrections August 2, 2007

Kořenové systémy lesních dřevin a jejich protierozní funkce v prostoru báňským provozem narušených svahů Krušných hor

ABSTRAKT: Je popsána architektura kořenového systému lesních dřevin – *Fagus sylvatica* L., *Quercus robur* L., *Pinus sylvestris* L., *Carpinus betulus* L., *Acer platanoides* L., *Alnus glutinosa* (L.) Gaertn. – ve věku 80–220 let v prostoru svahových partií Krušných hor s nadmořskou výškou 330 až 480 m, ovlivněných prováděnou povrchovou těžbou hnědého uhlí a energetickou činností. Součástí provedených prací bylo i stanovení půdních vlastností kambizemě rankerové.

Klíčová slova: kořenový systém; architektura; půdní vlastnosti; kambizem rankerová; báňská činnost; půdní sesuvy

Corresponding author:

Ing. Petr Čermák, CSc., Výzkumný ústav meliorací a ochrany půdy, v.v.i., Žabovřeská 250,
156 27 Praha 5-Zbraslav, Česká republika
tel.: + 420 257 921 640, fax: + 420 257 921 246, e-mail: cermak@vumop.cz