Relationships between parameters of aboveground parts and parameters of root plates in spruce trees growing in poorly drained sites

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Abstract

Štofko, P., Kodrík, M. 2008. Relationships between parameters of aboveground parts and parameters of root plates in spruce trees growing in poorly drained sites. *Folia oecol.*, 35: 67–73.

In the locality Hnile Blatá (the High Tatras Mts) we measured the aboveground parts (tree height, stem diameter, length and width of crowns) of windthrown spruces (*Picea abies* (L.) Karst.). The width and thickness of root plates were measured on the belowground parts. The methods of linear regression and correlation analysis were used to evaluate the relationships between the aboveground and the belowground parts. Extreme wide and shallow root plates were found out in spruces growing in poorly drained sites. The higher degree of statistically significant correlation was found out between the individual stem diameters and the root plate parameters. The medium values of multiple correlation coefficients were found out among the root plate parameters and the tree height, width and length of crown. The low degree of correlation was found out between the crown proportion index and the belowground parameters of root plates. The partial correlation coefficients point out that the correlation only exists between the average width of root plate (AWrp) and the individual aboveground parameters. No correlation was found out between the thickness of root plates (Trp) and the individual aboveground parameters.

Key words

root plate, Norway spruce, poorly drained sites

Introduction

The morphology and size of tree root system is predetermined by the genetic properties of particular tree species, as manifested through interspecies differences. However, the environment (especially soil conditions) can influence root system features considerably (Coutts, 1987).

Research on tree root system is less frequent than studies on the aboveground parts because of a variety of reasons. Root systems are not directly visible to the unaided eye and they are of less economic importance than the aboveground biomass. Tree root system research is also very laborious and its methods are not as well developed as procedures for the aboveground biomass inventory. The belowground biomass inventory methods have been comprehensively described by Köstler et al. (1968), Kolesnikov (1972), Böhm (1979) and recently by Smit et al. (2000).

In Slovakia, extensive research of tree root system has been done by Kodrík (2002) who investigated the root systems of main forest trees in term of static stability. Konôpka (2001, 2002) compared root systems

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of trees with respect to soil drainage. Kodrík (2005) analysed the root biomass of forest woody plants in view of productive ecology.

The root system is usually in contact with several parts of the soil profile which differ in water, air and nutrient content, texture, bulk density, organic material and pH, whereas the soil profile is generally considered to consist of layers, and the conditions in each layer are treated separately (Smit et al., 2000). The depth of penetration of a root system is mainly influenced by soil properties and humidity. However, rooting is influenced by many other factors little investigated by now because it is not easy to follow a root system growth.

In undisturbed development, spruce forms typical shallow root system. The rootedness gets shallower with worsening soil aeration (Köstler et al., 1968). Maximum depth of root penetration can also be reduced by a high groundwater table.

The purpose of this paper is to evaluate the relationships between parameters of the main aboveground parts and root plates in spruces growing in poorly drained sites.

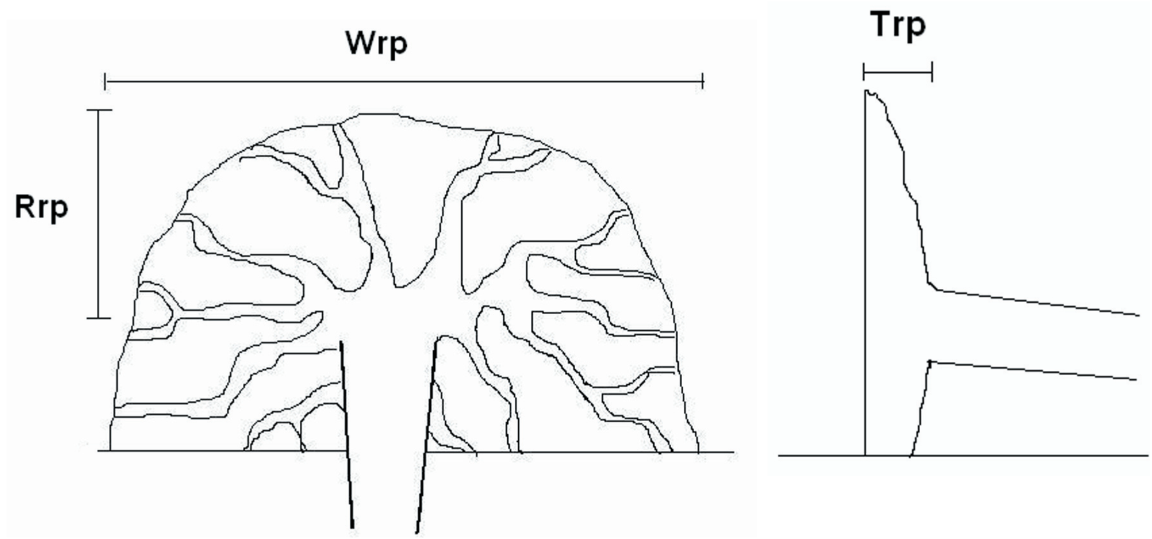
Material and methods

The aboveground parts and root systems were measured on Norway spruces (*Picea abies* (L.) Karst.) uprooted by wind in the locality Hnilé Blatá (the High Tatras Mts). This site is uneven-aged, with the over storey 90 years old, south aspect, 5–10% slope, altitude is about 950 m asl. Management set of forest type is waterlogged fir-spruce. The site consists of the forest types: peaty fir-spruce (50%) that belongs to the vegetation unit Abieto-Piceetum, birch-alder on a fluvio-glacial substrate (40%) that belongs to the vegetation unit Betuleto-Alnetum and bilberry-spruce with fir (10%) that belongs to the vegetation unit Piceetum abietinum higher stage (Križová, 1995). Spruce is the dominant woody plant at the site, but the birch and alder are also quite abundant. The soil is rather waterlogged, with low incidence of peats.

Altogether, 77 windthrown spruce trees were measured. For the aboveground biomass the following parameters were measured: stem diameter on the ground level ($D_{0.0}$), stem diameter 20 cm from the ground level ($D_{0.2}$), diameter at breast height (DBH), ie 130 cm from the ground level, tree height (H), crown length (L) and crown width (Wc). Crown proportion index Cpi = L/H × 100 values were calculated.

For the belowground biomass, the following parameters were measured: horizontal width of root plate (Wrp), vertical radius of root plate (Rrp), and thickness of root plate (Trp) (See Figs 1 and 2). The average width of root plate (AWrp) was calculated according to the formula: AWrp = (Wrp + 2Rrp)/2. The mean values of all aboveground and belowground biomass characteristics were calculated.

The relationships between the root plate thickness as well as average root plate width and the aboveground biomass parameters were analyzed statistically, using multiple linear correlation and regression analysis. Values of multiple correlation coefficients were calculated. These multiple correlation coefficients indicated the degree of correlation among the individual aboveground parameters (dependent variable) and the average width (AWrp) and thickness (Trp) of root plates (independent variables). The values of partial correlation coefficients were calculated too. These partial correlation coefficients indicated the degree



Figs 1 and 2. Measurement of the root plate parameters: root plate width (Wrp), distance from the stem centre to the windward edge – vertical radius of root plate (Rrp) and root plate thickness (Trp) across the plate of correlation between the individual aboveground parameters and the average width of root plates (AWrp) and between the individual aboveground parameters and the thickness of root plates (Trp). The parameters of regression equation were calculated. These parameters were calculated in order to estimate the individual aboveground parameters (dependent variable) on the basis of the root plate parameters (independent variables).

Results

Mean values of the aboveground biomass characteristics of Norway spruce are shown in Table 1. Mean value for DBH was 32 cm, for $D_{0.2}$ it was 41 cm and for $D_{0.0}$ it was 49 cm. Mean value of tree heigth was 22.5 m. Mean value of crown width was 5.04 m. Relatively high mean value (16.4 m) of crown length was found out in this locality. Mean value for crown proportion index was 72%, thus the statical stability of spruces growing in this locality should be rather favourable.

Mean values of the root plate parameters are shown in Table 2. Mean values for belowground biomass are the following: for horizontal width it was 5.04 m, for vertical radius it was 1.56 m and for thickness of root plates it was 30.5 cm. Mean value of calculated average width of root plates was 4.08 m. These data indicate rather wide and shallow root plates of spruces growing in poorly drained sites.

Values of multiple correlation coefficients of linear dependence among the individual aboveground parameters and the average width and the thickness of root plates are shown in the upper part of Table 3. Values of partial correlation coefficients of linear dependence between the individual aboveground parameters and the average width of root plates and between the individual aboveground parameters and the thickness of root plates are shown in the last two lines at the bottom of Table 3. The higher degree of correlation was found out between the individual stem diameters and the average width of root plates. The highest degree of correlation ($r = 0.62$) was found out between the $D_{0.0}$ and the average width of root plates. Medium degree of correlation was found out between the tree heights, width and length of crowns and the average width of root plates. Low degree of correlation was found out between the crown proportion index and the average width of root plates. In this case, the value of correlation coefficient was only 0.22 and it was

Table 1. Mean values of the aboveground parameters of Norway spruce (± standard deviation)

Number of measured trees	Stem diameter			Tree height	Crown		Crown proportion index
	DBH	$D_{0.2}$	$D_{0.0}$	H	Width (Wc)	Length (L)	Cpi = (L/H) × 100
	[cm]	[cm]	[cm]	[m]	[m]	[m]	[%]
77	32.05±7.61	40.91±10.33	49.19±13.27	22.59±2.65	5.04±1.36	16.41±2.92	72.65±9.70

Table 2. Root plate parameters of Norway spruce (arithmetic mean ± standard deviation)

Number of measured trees	Horizontal width of root plate (Wrp)	Vertical radius of root plate (Rrp)	Average width of root plate (AWrp)	Thickness of root plate (Trp)
	[m]	[m]	[m]	[cm]
77	5.04±1.32	1.56±0.70	4.08±1.15	30.51±5.13

Table 3. Values of correlation coefficients of linear dependence among individual aboveground parameters and root plate width (AWrp) and root plate thickness (Trp) in Norway spruce

Statistics	Stem diameter			Tree height	Crown		Crown proportion index
	DBH	$D_{0.2}$	$D_{0.0}$	H	Width (Wc)	Length (L)	Cpi = (L/H) × 100
Multiple R	0.60*	0.60*	0.62*	0.51*	0.51*	0.46*	0.22^{n}
AWrp	0.58*	0.60*	0.61*	0.50*	0.51*	0.46*	0.16^{n}
Trp	0.08^{n}	0.03^{n}	0.03^{n}	0.08^{n}	-0.07^{n}	-0.06^{n}	-0.16^{n}

*statistically significant correlation coefficient, $p < 0.05$, ^{n}statistically insignificant correlation coefficient statistically insignificant. No correlation was found out between the individual aboveground parameters and the thickness of root plates. In these cases, the values of correlation coefficients were close to zero.

The graphical representations of 3-dimensional linear correlation among the individual aboveground parameters and the average width and thickness of root plate are shown in the Figs 3–9. After insertion of linear plane into the graphs it is apparent that the values of individual aboveground parameters increase with increasing values of average width of root plates. The values of thickness of root plates increase only with the increasing values of DBH, $D_{0.2}$, $D_{0.0}$ and tree height. On the linear plane, the values of thickness of root plates are almost straightened with the values of width and length of crowns. The values of crown proportion index increase with decreasing values of thickness of root plates.

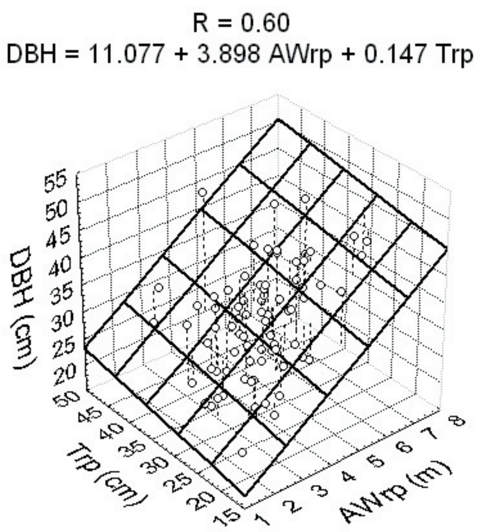


Fig 3. Presentation of 3-D linear correlation among DBH values and calculated average width (AWrp) and thickness (Trp) of root plates

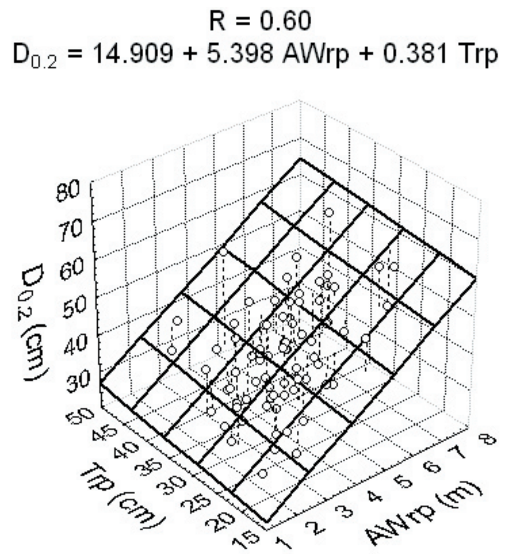


Fig 4. Presentation of 3-D linear correlation among $D_{0,2}$ and calculated average width (AWrp) and thickness (Trp) of root plates

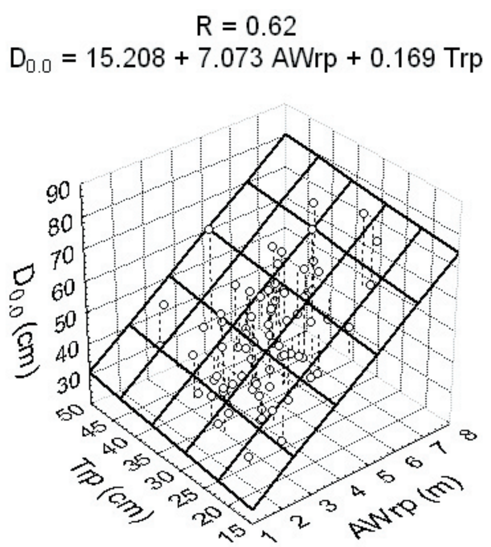


Fig 5. Presentation of 3-D linear correlation among $D_{0.0}$ and calculated average width (AWrp) and thickness (Trp) of root plates

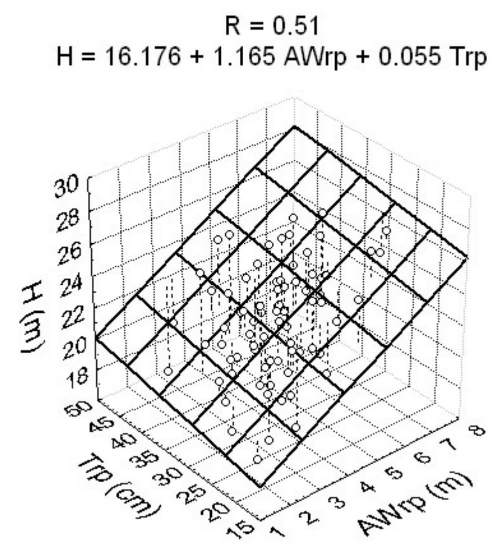


Fig 6. Presentation of 3-D linear correlation among tree height (H) and calculated average width (AWrp) and thickness (Trp) of root plates

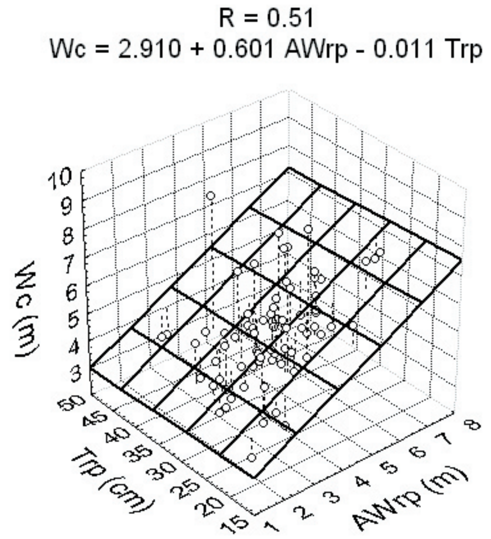


Fig 7. Presentation of 3-D linear correlation among tree crown width (Wc) and calculated average width (AWrp) and thickness (Trp) of root plates

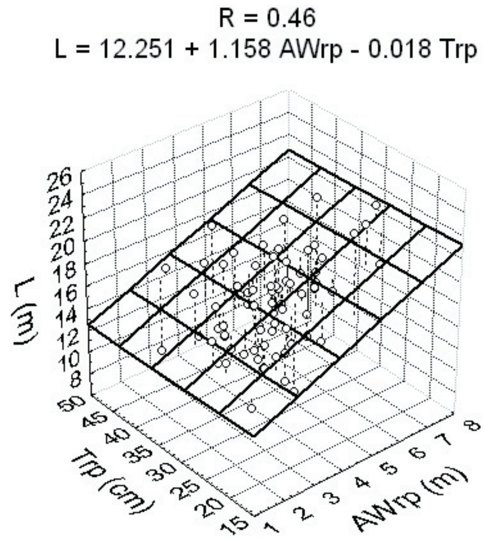


Fig 8. Presentation of 3-D linear correlation among tree crown length (L) and calculated average width (AWrp) and thickness (Trp) of root plates

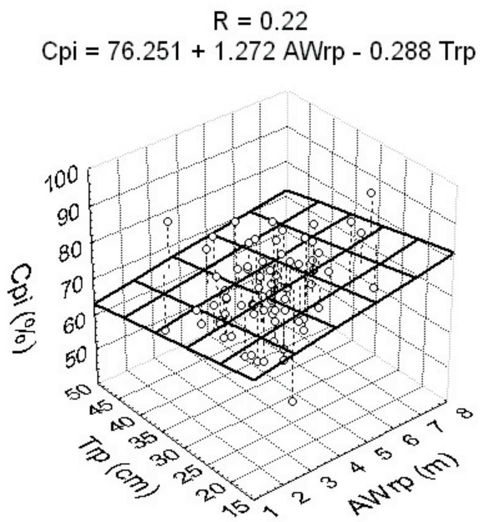


Fig 9. Presentation of 3-D linear correlation among crown proportion index (Cpi) and calculated width (AWrp) and thickness (Trp) of root plates

Discussion

High mean value of crown length may refer to favourable aboveground parameters of static stability of spruce trees growing in this locality. Similarly, Konôpka (2000) found out higher values of crown length of spruce trees growing in poorly drained sites. Cucchi et al. (2003) found out that trees of *Pinus pinaster* growing on wet land have significantly a greater relative crown length than those growing on dry land.

Our results point out the fact that root systems of spruce trees growing in poorly drained sites are extreme wide and shallow. Similarly, Konôpka (2001, 2002) found out wide and shallow root systems of Norway spruces growing in poorly drained sites in the High Tatras Mts. Interestingly, the mean value of crown width (Wc) is the same as the mean value of root plate width (Wrp), which was measured in the same horizontal direction. Kodrík (1983) found out that the root system of Norway spruce exceeded the circumference of crown. This author found out that the width of spruce root system in the locality Hronec was wider by 94 cm than the width of crown. On the other hand, Konôpka (2002) found out lower values (more or less half-values) of root system widths than the values of crown widths of spruce trees growing in well-drained sites. Contrariwise, this author found out that the values of root plate widths were higher than the values of crown widths of spruce trees growing in poorly drained sites. For example, Kodrík and Kodrík (1996) found out that the values of crown widths were higher than the values of root system widths in fir trees growing in well-drained sites. Konôpka (2002) found out that the root systems of spruce trees growing in poorly drained sites were broader by one-third units than those in well-drained sites.

The mean value of root plate thickness was only 30 cm. This type of shallow root system, even though broad, is unstable and reduces the positive effect of high value of crown length on spruce stability. Konôpka (2002) found out that the root systems were two times shallower in poorly drained sites than in well-drained sites. Similar results were obtained by Rottmann (1986), who claimed that permanently waterlogged sites did not allow tree roots to penetrate the deeper horizons due to insufficient oxidation. Štofko (2006) points at an increase in root plate width corresponding to an increase in DBH, but he found out that the average values of root plate depth were in all stem diameter classes almost identical (around 30 cm). Nicoll and Ray (1996) found out that the spread of the root system of *Picea sitchensis* trees and the ratio of root mass to shoot mass (root/shoot ratio) were both negatively related to soil-root plate depth.

Our results point out that the correlation exists only between the individual aboveground parameters and the width of root plates. We found out no correlation between the individual aboveground parameters and the thickness of root plates. Gruber and Lee (2005) found out narrow correlation ($r^2 = 0.96$) between DBH and coarse root dry mass for spruce trees growing in well-drained sites. Similarly, we found out the highest correlation between the stem diameters and the root plate widths. Konôpka (2001) evaluated the root system depth and width of spruce, fir, beech, larch and pine and compared interspecific differences in root system measurements. This author found out higher degree of correlation between the width of root plates and the DBH than between the depth of root plates and the DBH. Konôpka (2002) found out statistically significant correlation between the DBH, $D_{0.2}$, crown width, slenderness ratio and the width and the depth of root plates. Interestingly, this author found out statistically significant correlation between the aboveground parameters and the depth of spruce root plates growing in poorly drained sites. These results do not correspond to our results, because we found out no correlation between the aboveground parameters and the thickness of root plates. This phenomenon may reflect deeper (mean value 45 cm) and narrower (mean value 315 cm) root plates found out by Konôpka (2002). This author found out statistically insignificant correlation between the crown proportion index and the depth of root plates, and it agrees with our results. However, he observed that correlation between the crown proportion index and the width of root plate was statistically significant in the locality Kežmarské Žľaby, but it was statistically insignificant in the locality Rosengard (both localities in poorly drained sites).

For example, Nicoll et al. (2006) found out positive linear correlation between coarse root volume and stem volume for *Picea sitchensis*. Similarly, Di Iorio et al. (2005) analyzed root system architecture in *Quercus pubescens.* They found out that the diameter at breast height was the best predictor of root volume, however lacking correlation with root length and number. Schmid and Kazda (2001) found out no correlation either between root diameter and soil depth for monospecific stand of spruce.

Conclusions

The vertical distribution of roots hangs on soil aeration, compression, and moisture-holding capacity of the particular soil horizons. In general, relatively shallow and little spread root systems are found at fertile and moist sites where trees have sufficient water and nutrients supply in the upper soil layer. Our research also confirmed that spruce trees had considerably wide and shallow roots at the poorly drained sites. Our partial results document that the growth and distribution of roots are influenced by conditions in available underground water. It seems that this factor has mainly impact on the root system's depth.

Acknowledgement

The study was supported by the Grant Agency of Science VEGA, grant No. 1/4397/07: Disturbance processes cause on ecological stability of forest ecosystems and landscape.

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Vzťahy medzi parametrami nadzemných častí a parametrami koreňových koláčov na smrekoch rastúcich na podmáčaných stanovištiach

Súhrn

V lokalite Hnilé Blatá (Vysoké Tatry) sme zmerali nadzemné a podzemné časti smrekov vyvrátených vetrom. Z nadzemných častí sa kvantifikovala: hrúbka kmeňa v prsnej výške $d_{1,3}$ (DBH), hrúbka kmeňa vo výške 20 cm od úrovne pôdy ($D_{0,2}$), hrúbka kmeňa na úrovni pôdy ($D_{0,0}$), výška stromu (H), dĺžka (L) a šírka koruny (Wc). Vypočítané boli hodnoty korunovosti podľa vzťahu Cpi = L/H × 100. Z podzemných parametrov sme meraním zistili:

Horizontálnu šírku (Wrp), vertikálny polomer (Rrp) a hrúbku (Trp) koreňových balov podľa obrázkov 1 a 2. Vypočítali sme priemernú šírku koreňových koláčov (AWrp) podľa vzťahu: AWrp = (Wrp + 2Rrp)/2. Vypočítali sme priemerné hodnoty uvedených parametrov (Tabuľka 1 a 2). Na vyhodnotenie vzťahov medzi nadzemnými a podzemnými časťami smrekov sme použili metódy lineárnej regresnej a korelačnej analýzy.

Výsledky práce poukazujú na extrémne široké a plytké koreňové baly smrekov rastúcich na podmáčaných stanovištiach. Vyšší stupeň štatisticky významnej korelácie sme zistili medzi jednotlivými hrúbkami kmeňa a rozmermi koreňových balov. Stredné hodnoty mnohonásobných korelačných koeficientov sme zistili medzi rozmermi koreňových balov a výškou stromu, šírkou a dĺžkou koruny. Nízka a štatisticky nevýznamná korelácia existuje medzi korunovosťou a podzemnými parametrami koreňových koláčov. Pri hodnotení parciálnych korelačných koeficientov sme zistili vyššie a štatisticky významné hodnoty korelačných koeficientov iba medzi šírkou (AWrp) koreňových balov a jednotlivými nadzemnými parametrami. Medzi hrúbkou (Trp) koreňových koláčov a jednotlivými nadzemnými parametrami smrekov neexistuje takmer nijaká závislosť (Tabuľka 3).

Received November 5, 2007
Accepted January 16, 2008