# Soil-forming effect of Douglas fir at lower altitudes – a case study

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**ABSTRACT**: Forest ecosystem and in particular forest soil biodiversity and stability could be jeopardised by the impropriate tree species composition. Douglas fir is a species which has a high potential in Europe both from economic and biodiversity aspects of forest management. A more detailed analysis of Douglas fir effects on the humus forms and forest soil under different conditions is needed to evaluate the future use of this species in central European forests. The study plots cover acid sites with natural hardwood, spruce monoculture and Douglas fir stands. The soil analysis proved favourable effects of this species on soil chemistry, organic matter as well as nutrient dynamics. When compared with domestic coniferous species, Douglas fir proved to have lower acidifying effects on upper soil layers and contributes to better humus forms, recycling nutrients more effectively and producing litter which could be easily decomposed.

**Keywords**: tree species composition; forest soil changes; Norway spruce; nutrient cycle

The productivity increase of European forests due to the altered tree species composition has represented until now one of the leading ideas for Central-European forestry. The mixed and broadleaved forest stands were replaced by coniferous monocultures on large areas. Besides the lower stability of these highly productive forests, this trend causes changes of forest ecosystem biodiversity, which is supposed to represent the main European forestry concern (Máliš et al. 2010). The effects of Norway spruce increase with the time of cultivation (Hadač, Sofron 1980), and it was documented in many studies from the Czech-Slovak region (Ambros 1990; Poleno 2001; Šomšák, Balkovič 2002; Šomšák 2003), they follow differences between natural spruce and beech forests to some extent (Vacek, Matějka 2010). Large introduction of Norway spruce is considered also as one cause of broad acidification of the forest environment (Borůvka et al. 2005; Oulehle, Hruška 2005). Instead of Norway spruce (*Picea abies* [L.] Karsten), Douglas fir (*Pseudotsuga menziesii* [Mirb] Franco) is becoming a species with an increasing economic potential in Europe (Ferron, Douglas 2010; Larson 2010) for its fast growth and technical characteristics of very valuable timber. Also in the Czech conditions, it was recognized as the most productive species (Kantor et al. 2001a, b; Martiník 2003; Martiník, Kantor 2007; Kantor 2008; Kantor, Mareš 2009; Podrázský et al. 2009; Remeš et al. 2010) with relatively favourable effects on the forest soil – at least comparing to native conifers (Podrázský et al. 2002, 2009; Podrázský, Remeš 2008; Menšík et al. 2009; Podrázský, Kupka 2011).

The appropriate considering of soil effects of this species needs a higher number of particular studies, as well as the synthesis. The aim of the present paper is to document a case study on the effects of Douglas fir on the humus form quantity and their soil chemical characteristics compared

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to Norway spruce and site corresponding broadleaved species. The main target is a comparison of Norway spruce and Douglas fir effects.

## MATERIAL AND METHODS

The study plot represents the change from site-natural hardwoods (61 years) to the monocultures of Norway spruce (61 years) and Douglas fir (45 years, age all in 2008). The site is relatively acid, characterized by an altitude of 420 m a.s.l., mean annual temperature of 8.5°C and precipitation 550 to 650 $mm \cdot yr^{-1}$, the soil is described as Luvisol. The standing volume was 266 $m^3 \cdot ha^{-1}$ for hardwoods, 507 $m^3 \cdot ha^{-1}$ for spruce and 579 $m^3 \cdot ha^{-1}$ for Douglas fir. Average annual increment was calculated as 4.43 $m^3 \cdot ha^{-1} \cdot a^{-1}$ for hardwoods, 8.45 $m^3 \cdot ha^{-1} \cdot a^{-1}$ for spruce and 12.87 $m^3 \cdot ha^{-1} \cdot a^{-1}$ for Douglas fir.

Soils, i.e. holorganic layers, organomineral A horizon and uppermost mineral part of B horizon were sampled in mid-November 2008. Sampling was performed in each stand of ca 0.5 ha at 5 places randomly distributed in the stand and analysed individually. The sampling of holorganic layers took place using the iron frame 25 × 25 cm in size, the mineral soil horizons were not sampled quantitatively by the core sampler. The analyses of individual samples were performed by standard analytical methods in the certified Tomáš Laboratory (Zbíral 2002).

These characteristics were determined:

– amount of dry matter (D.M.) of the holorganic horizons at 105°C and calculation per 1-ha area,
– total carbon content (humus content) using the Springer-Klee method, total nitrogen content using the Kjeldahl method,
– soil reaction (pH) in water and 1N KCl, potentiometrically,
– characteristics of the soil adsorption complex by the Kappen method: S – base content, T-S (H) – hydrolytical acidity, T – cation exchange capacity, V – base saturation,
– plant available nutrients using Mehlich III solution. The P-content was determined photometrically as complex P and Mo salt, the other nutrients (Ca, Mg, K) by AAS,
– characteristics of exchangeable acidity in the KCl solution,
– total nutrient content in the holorganic horizons, after mineralization by the mixture of sulphuric acid and selenium. Two methods for total nitrogen analysis seem to be redundant, but enable to compare different methods for N content determination.

The statistical evaluation was performed using the STATISTICA 9.1 (SPSS, Tulsa, USA) by the analysis of variance methods (factorial ANOVA). The results were evaluated by Tukey's HSD tests by multiple comparisons on the 95% significance level. Both tree species and horizons were taken as categorical predictors.

## RESULTS AND DISCUSSION

The tree species composition is one of the important factors determining the soil development, especially humus form development, while its role has been discussed basically in the last period and it has been considered less important than other factors such as climate, bedrock, and forest management (Augusto et al. 2003). On the other side, in the presented case the species composition is the only differentiating factor among stands, assuming the initial soil state was similar (mixed hardwoods). This factor increases the significance of results (Binkley 1995). The humus form is the ecosystem soil compartment with the most intense and rapid dynamics (Green et al. 1993). In the studied locality, the tree species composition showed a distinct effect on the surface soil characteristics, including the holorganic layer accumulation and total element contents (Table 1).

The lowest surface humus accumulation occurred in the mixed hardwood stand being of moder – mullmoder character (Green et al. 1993; Němeček 2001), similarly in the Douglas fir stand, on the other side the Norway spruce showing significantly higher accumulation in the H-layer and having clear moder characteristics. Very similar results were documented in a comparison of Douglas fir and Norway spruce from Czech conditions also by other authors (Menšík et al. 2009) indicating more rapid decomposition and transformation of Douglas fir litter on both acid and mesotrophic sites compared to Norway spruce. Also older results from the studied region documented higher accumulation of the surface humus in the stands of Douglas fir compared to stands composed of native and site corresponding broadleaved species, but significantly more intense turnover of litter in comparison with other conifers, especially Norway spruce and Scots pine at lower and middle altitudes (Podrázský, Remeš 2008; Podrázský et al. 2009).

The total nitrogen content did not show any statistically significant differences; but the holorganic layers of the Douglas fir stand had higher $N_{tot}$

Table 1. Surface humus accumulation and total element content in the holorganic horizons of studied stands

| Species | Horizons | Dry matter (g) | Dry matter ($t \cdot ha^{-1}$) | $N\text{-}H_2SO_4$ | $P\text{-} H_2SO_4$ | $K\text{-}H_2SO_4$ | $Ca\text{-}H_2SO_4$ | $Mg\text{-}H_2SO_4$ |
|---|---|---|---|---|---|---|---|---|
| | | | | | | (%) | | |
| Spruce | L+F1 | 44.70[a] | 7.2 | 1.26[a] | 0.048[a] | 0.140[a] | 1.192[a] | 0.0576[a] |
| | F2+H | 316.29[c] | 50.1 | 1.42[a] | 0.046[a] | 0.220[a] | 0.128[b] | 0.0400[a] |
| | | | 57.3 | | | | | |
| Douglas fir | L+F1 | 50.66[a] | 8.1 | 1.55[a] | 0.063[a] | 0.164[a] | 1.732[a] | 0.0888[a] |
| | F2+H | 197.95[b] | 31.7 | 1.49[a] | 0.052[a] | 0.312[b] | 0.156[b] | 0.0747[a] |
| | | | 39.8 | | | | | |
| Oak | L+F1 | 20.70[a] | 3.3 | 1.45[a] | 0.061[a] | 0.360[c] | 1.868[a] | 0.2008[b] |
| | F2+H | 129.19[b] | 20.7 | 1.36[a] | 0.066[a] | 0.408[c] | 0.536[b] | 0.1168[a] |
| | | | 24.0 | | | | | |

[a–c]the same letters – not significant at α = 0.05

contents. A tendency of low total N content in the litter of broadleaved stand was not consistent with the $N_{Kjel}$ tendency (Table 3) and can be assumed as random. The total phosphorus content did not show any significantly different results, except the lowest values registered in the Norway spruce stand. On the contrary, the broadleaved litter had a significantly higher content of potassium (also deeper in the upper soil profile) and magnesium, non-significant differences were documented for calcium (Table 1). Content of bases was so the highest in the humus form of broadleaved stand, Douglas fir having a medium position. This is in accordance both with Czech as well as foreign knowledge (Augusto et al. 2003; Podrázský, Remeš 2008; Menšík et al. 2009; Podrázský et al. 2009).

Statistically significant differences in the active soil reaction were documented only in the horizon $F_2$+H, i.e. in the more transformed surface humus layer, in all cases (Table 2). Douglas fir acidified also other horizons of the studied soil profile until B horizon, but Norway spruce did so even more. A similar trend was described for the potential pH and base content (S-value). The significant increase of pH, base content and base saturation (V-value) in the more transformed holorganic layer of the broadleaved stand was documented

Table 2. Soil reaction and soil adsorption complex characteristics in the soil of particular studied stands

| Species | Horizons | $pH/H_2O$ | pH/KCl | S | T-S | T | V (%) |
|---|---|---|---|---|---|---|---|
| | | | | | ($mval \cdot 100g^{-1}$) | | |
| Spruce | L+F1 | 4.51[a] | 3.98[a] | 25.18[a] | 14.90[a] | 40.07[a] | 63.32[a] |
| | F2+H | 3.72[b] | 3.01[b] | 26.86[a] | 50.78[b] | 77.63[b] | 34.82[b] |
| | Ah | 4.45[a] | 3.47[b] | 5.11[b] | 12.97[a] | 18.08[c] | 30.17[b] |
| | B | 4.25[a] | 3.25[b] | 1.55[b] | 8.48[a] | 10.03[c] | 16.55[b] |
| Douglas fir | L+F1 | 4.80[a] | 4.23[ac] | 38.27[c] | 19.05[a] | 57.32[d] | 67.13[a] |
| | F2+H | 4.06[a] | 3.44[b] | 33.92[ac] | 41.67[b] | 75.58[b] | 45.04[ab] |
| | Ah | 4.52[a] | 3.56[b] | 13.58[b] | 18.26[ac] | 31.84[a] | 42.32[b] |
| | B | 4.35[a] | 3.12[b] | 3.12[b] | 7.92[a] | 11.04[c] | 27.55[b] |
| Oak | L+F1 | 4.56[a] | 4.05[a] | 46.86[cd] | 28.26[c] | 75.12[b] | 62.23[a] |
| | F2+H | 5.15[c] | 4.54[c] | 49.44[d] | 15.70[a] | 65.14[bd] | 75.93[a] |
| | Ah | 4.73[a] | 4.06[a] | 11.29[b] | 8.73[a] | 20.02[c] | 54.54[a] |
| | B | 4.88[a] | 3.92[a] | 3.82[b] | 6.21[a] | 10.04[c] | 37.84[b] |

[a–d]the same letters – not significant at α = 0.05, S – base content, T-S – hydrological acidity, T – cation exchange capacity, V – base saturation − all by Kappen as relative enrichment of the surface organic matter during its transformation, like in other cases (Tietema 1992; van Wesemael 1992). In coniferous stands, this tendency was not obvious due to slower litter decomposition. The hydrolytical acidity (T-S value) exhibited an opposite tendency. For the soil adsorption complex characteristics, Douglas fir occupied a position between Norway spruce and broadleaved stand in general again. Similar results were documented also by Menšík et al. (2009).

The position of Douglas fir in the soil acidification process is documented also by the results of the exchangeable acidity analysis and its components, exchangeable H and Al (Table 3). In the litter layer, exchangeable acidity is significantly the highest in the broadleaved stand, corresponding to the most profound transformation ($H^+_{ex}$ content). On the contrary, the exchangeable content of Al was the lowest here. Smaller, significant differences document the visible acidification under spruce, much less under Douglas fir, based dominantly on the $Al_{ex}$ differences.

A higher degree of transformation in the F2+H layer and in the Ah horizon of the mixed hardwood stand was detected on the basis of significant total humus ($C_{ox}$ respectively) decrease in the F2+H horizon. The more favourable status of humic substances was reflected in lower $Al_{ex}$ mobilisation.

The holorganic layers of the Douglas fir stand exhibited the insignificantly highest $N_{Kjel}$ contents, reflecting higher N turnover in soils influenced by this species, which was documented also by Binkley (1995).

The humus forms in the Douglas fir stand showed a significantly lower C/N ratio compared to other species in the holorganic layers (with the exception of F2+H layer in the mixed hardwood stand), lower, significant differences were less frequent, the values being lower in the broadleaved stand (Table 3).

Together with the other soil chemical characteristics it indicates higher transformation and mineralisation of the Douglas fir litter, these trends are consistent with other relevant literature sources (Menšík et al. 2009). Nevertheless, the C/N values with the exception of spruce litter do not fall below the limit value 24, indicating worse conditions for humus transformation (Emmet et al. 1998), but describing the good quality of the site in general.

The tendency of faster nitrogen turnover dynamics in the stands of the tree species in focus is indicated also by the more diverse and nitrophilous ground vegetation in its stands throughout the older stands of the Czech Republic, compared with both coniferous and broadleaved forests (Podrázský et al. 2011), as well as in other European countries (Augusto et al. 2003).

Differences in the content of plant available phosphorus were significantly the highest under broadleaved stand, followed by Douglas fir and Norway spruce (Table 4). In the mineral horizons, P content was several times higher under Douglas fir, documenting bigger mobility of this nutri-

Table 3. Exchangeable acidity, total humus, carbon and nitrogen contents in the soil of particular studied stands

| Species | Horizons | $Acid_{ex}$ | $H^+_{ex}$ | $Al^{3+}_{ex}$ | Humus | $C_{ox}$ | $N_{Kjel}$ | C/N |
|---|---|---|---|---|---|---|---|---|
| | | (mval·100 g$^{-1}$) | | | (%) | | | |
| Spruce | L+F1 | 20.72[c] | 6.44[b] | 14.28[c] | 67.65[a] | 39.24[a] | 1.26[a] | 31.1[a] |
| | F2+H | 36.32[d] | 7.70[b] | 28.92[b] | 60.85[a] | 35.30[a] | 1.46[a] | 24.2[a] |
| | Ah | 53.99[a] | 0.03[c] | 53.97[a] | 11.52[b] | 6.68[b,c] | 0.39[b,c] | 17.1[b] |
| | B | 60.23[a] | 0.24[c] | 59.99[a] | 2.91[c] | 1.69[c] | 0.13[c] | 13.0[c] |
| Douglas fir | L+F1 | 18.32[c] | 8.26[b] | 10.06[c] | 62.05[a] | 35.99[a] | 1.61[a] | 22.4[b] |
| | F2+H | 25.96[b] | 7.30[b] | 18.66[b] | 52.40[a,d] | 30.39[a] | 1.54[a] | 19.7[b] |
| | Ah | 58.4[a] | 1.48[c] | 56.92[a] | 18.99[b] | 11.02[b] | 0.58[b] | 19.0[b] |
| | B | 29.27[b] | 0.03[c] | 29.25[b] | 3.50[c] | 2.03[c] | 0.15[c] | 13.5[b,c] |
| Oak | L+F1 | 35.26[d] | 27.58[a] | 7.68[c] | 62.67[a] | 36.35[a] | 1.43[a] | 25.4[a] |
| | F2+H | 21.02[b,c] | 12.80[b] | 8.22[c] | 45.50[d] | 26.39[d] | 1.42[a] | 18.6[b] |
| | Ah | 34.87[d] | 0.32[c] | 34.56[b] | 7.61[b] | 4.41[b,c] | 0.42[b,c] | 10.5[c] |
| | B | 17.29[c] | 0.03[c] | 17.27[b] | 3.04[c] | 1.76[c] | 0.18[c] | 9.8[c] |

[a–d]the same letters – not significant at α = 0.05

Table 4. Plant available nutrient content in the soil of particular studied stands

| Species | Horizons | P | K | Ca | Mg |
|---|---|---|---|---|---|
| | | (mg·kg$^{-1}$) | | | |
| Spruce | L+F1 | 39.20[a] | 618.4[a] | 2044.4[a] | 176.4[a] |
| | F2+H | 26.80[a,b] | 370.4[a] | 2696.0[a,c] | 198.0[a] |
| | Ah | 16.40[b] | 94.0[b] | 503.8[b] | 48.8[b] |
| | B | 2.40[c] | 59.8[b] | 288.8[b] | 33.2[b] |
| Douglas fir | L+F1 | 55.20[d] | 785.6[a] | 3129.6[c] | 237.2[a] |
| | F2+H | 39.20[a,b] | 335.8[a] | 3628.0[c] | 200.0[a] |
| | Ah | 57.60[d] | 146.0[b] | 1385.8[a] | 90.4[a] |
| | B | 16.80[b] | 86.40[b] | 411.6[b] | 41.4[b] |
| Oak | L+F1 | 96.00[e] | 2104.0[c] | 3423.6[c] | 882.4[c] |
| | F2+H | 87.20[e] | 1390.4[d] | 4522.4[d] | 739.6[d] |
| | Ah | 16.00[b,c] | 235.6[a] | 967.4[a] | 119.0[a] |
| | B | 4.40[c] | 101.0[b] | 397.6[b] | 43.8[b] |

[a–d]the same letters – not significant at $\alpha = 0.05$

ent here, which is not fully in agreement with the total P. This element has to be studied in greater detail relating to Douglas fir stands, together with the nitrogen dynamics. The potassium availability was more pronounced under broadleaved species, followed again by Douglas fir and finally by Norway spruce, this is in general agreement with other sources (Augusto et al. 2003). The same, partly significant tendency was documented for plant available calcium and magnesium. More data concerning this form of nutrients is missing, available literature supposes a similar tendency of the medium position of Douglas fir related to broadleaves and domestic conifers as for availability of bases (Podrázský, Remeš 2008; Menšík et al. 2009; Podrázský et al. 2009).

Douglas fir can exhibit a very favourable soil-forming role compared with prevailing domestic coniferous species, especially in mixtures with broadleaved tree species, which is recommended also for the good growth of forest stands (Hofman 1964; Kenk, Ehring 1995; Beran, Šindelář 1996; Burgbacher, Greve 1996; Huss 1996). Replacing partly the Norway spruce at lower altitudes, it can contribute not only to improvement and revitalisation of forest soils but also to the higher static stability of forest stands (Mauer, Palátová 2012) and to better use of shortening soil water resources. Douglas fir so represents a promising tree species among other introduced taxa, replacing site non-corresponding Norway spruce in these conditions partly, supposing to select responding provenances.

## CONCLUSIONS

Douglas fir represents a very promising introduced tree species for the Czech Republic, as well as for the whole Central Europe. Our results document its favourable effects on soil chemistry and on organic matter and nutrient dynamics. Compared to other domestic coniferous tree species, Douglas fir acidifies the upper soil layers to a lesser extent and contributes to the origin of better humus forms. It recycles nutrients more effectively and produces litter which is easily decomposed and transformed. It could be considered as an appropriate partial substitution for Norway spruce in corresponding site conditions.

## References


Ambros Z. (1990): Bylinná synusia jako indikátor změn abiotické části smrkových monokultur. [Herbaceous synusia as an indicator of changes in the abiotic environment of spruce monoculture.] Preslia, ***62***: 205–214.

Augusto L., Dupouey J.L., Ranger J. (2003): Effects of tree species on understory vegetation and environmental conditions in temperate forests. Annals of Forest Science, ***60***: 823–831.

Beran F., Šindelář J. (1996): Perspektivy vybraných cizokrajných dřevin v lesním hospodářství ČR. [Some exotic species prospectives in Czech forestry.] Lesnictví–Forestry, ***42***: 337–355.

Binkley D. (1995): The influence of tree species on forest soils: processes and patterns. In: Mead D.J., Cornforth

I.S. (eds): Proceedings of the Trees and Soil Workshop. Canterbury, 28. February–2. March 1994. Canterbury, Lincoln University Press: 21–33.

Bořůvka L., Podrázský V., Mládková L. (2005): Some approaches to the research of forest soils affected by acidification in the Czech Republic. Soil Science and Plant Nutrition, ***51***: 745 – 749

Burgbacher H., Greve P. (1996): 100 Jahre Douglasienanbau im Stadwald Freiburg. Allgemeine Forstzeitschrift, ***51***: 1109–1111.

Emmet B.A., Boxman D., Bredemeier M., Gundersen P., Kjonaas O.J., Moldan F., Schleppi P., Tietema A., Wright R.F. (1998): Predicting the effects of atmospheric nitrogen deposition in conifer stands. Evidence from the NITREX ecosystem scale experiments. Ecosystem, ***1***: 352 – 360.

Ferron J.L., Douglas F. (2010): Douglas-fir in France: history, recent economic development, overviews for the future. In: Opportunities and risks for Douglas fir in a changing climate. Freiburg, 18.–20. October 2010. Freiburg, Albert-Ludwigs-Universität Freiburg: 11–13.

Green R.N., Trowbridge R.L., Klinka K. (1993): Towards a taxonomic classification of humus forms. Forest Science, ***39****:*1– 49

Hadač E., Sofron J. (1980): Notes on syntaxonomy of cultural forest communities. Folia Geobotanica et Phytotaxonomica, ***15***: 245–258.

Hofman J. (1964): Pěstování douglasky. [Silviculture of Douglas fir.] Praha, SZN: 253.

Huss, J. (1996): Die Douglasie als Mischbaumart. Allgemeine Forstzeitschrift, ***51***: 1108–1112.

Kantor P., Knott R., Martiník A. (2001a): Production capacity of Douglas fir (*Pseudotsuga menziesii* /Mirb./ Franco) in a mixed stand. Ekológia (Bratislava), ***20***: 5–14.

Kantor P., Knott R., Martiník A. (2001b): Production potential and ecological stability of mixed forest stands in uplands – III. A single tree mixed stand with Douglas fir on a eutrophic site of the Křtiny Training Forest Enterprise. Journal of Forest Science, ***47***: 45–59.

Kantor P. (2008): Production potential of Douglas fir at mesotrophic sites of Křtiny Training Forest Enterprise. Journal of Forest Science, ***54***: 321–332.

Kantor P., Mareš R. (2009): Production potential of Douglas fir in acid sites of Hůrky Training Forest District, Secondary Forestry School in Písek. Journal of Forest Science, ***55***: 312–322.

Kenk G., Ehring A. (1995): Tanne-Fichte-Buche oder Douglasie? Allgemeine Forstzeitschrift, ***50***: 567–569.

Larson B. (2010): The dynamics of Douglas-fir stands. In: Opportunities and risks for Douglas fir in a changing climate. Freiburg, 18.–20. October 2010. Freiburg, Albert-Ludwigs-Universität Freiburg: 9–10.

Mális F., Vladovič J., Čaboun V., Vodálová A. (2010): The influence of *Picea abies* in forest plant communities of the Veporské vrchy Mts. Journal of Forest Science, ***56***: 58–67.

Martiník A. (2003): Possibilities of growing Douglas fir (*Pseudotsuga menziesii* /Mirb./ Franco) in the conception of sustainable forest management. Ekológia (Bratislava), ***22***: 136–146.

Martiník A., Kantor P. (2007): Branches and the assimilatory apparatus of full–grown trees of Douglas fir (*Pseudotsuga menziesii* /Mirb./ Franco) of a different coenotic position. Ekológia (Bratislava), ***26****:* 223–239.

Mauer O., Palátová E. (2012). Root system development in Douglas fir (*Pseudotsuga menziesii* /Mirb./ Franco) on fertile sites. Journal of Forest Science, ***58***: 400–409.

Menšík L., Kulhavý J., Kantor P., Remeš M. (2009). Humus conditions of stands with the different proportion of Douglas fir in training forest district Hůrky and the Křtiny Forest Training Enterprise. Journal of Forest Sciences, ***55***: 345–356.

Němeček J. (2001): Taxonomický klasifikační systém půd české republiky. [Taxonomic Classification Soil System in the Czech Republic.] Praha, ČZU, VÚMOP: 78.

Oulehle F., Hruška J. (2005): Tree species (*Picea abies* and *Fagus sylvatica*) effects on soil water acidification and aluminium chemistry at sites subjected to long–term acidification in the Ore Mts., Czech Republic. Journal of Inorganic Biochemistry, ***99***: 1822–1829.

Podrázský V., Remeš J., Liao Ch.Y. (2002): Vliv douglasky tisolisté *(Pseudotsuga menziesii* /Mirb./ Franco) na stav humusových forem lesních půd – srovnání se smrkem ztepilým. [Douglas fir influence on humus forms of forest soils – a comparison with Norway spruce.] Zprávy lesnického výzkumu, ***46***: 86–89.

Podrázský V., Kupka I. (2011): Vliv douglasky tisolisté (*Pseudotsuga menziesii* /Mirb./ Franco) na základní pedofyzikální charakteristiky lesních půd. [Douglas fir influence on basic physical properties of foret soils.] Zprávy lesnického výzkumu, ***56****:* 1–5.

Podrázský V., Remeš J. (2008). Půdotvorná role významných introdukovaných jehličnanů – douglasky tisolisté, jedle obrovské a borovice vejmutovky. [Soil forming role of introduced species – Douglas fir, Grand fir and White pine.] Zprávy lesnického výzkumu, ***53***: 27–33.

Podrázský V., Remeš J., Hart V., Moser W.K. (2009): Production and humus form development in forest stands established on agricultural lands – Kostelec nad Černými lesy region. Journal of Forest Science, ***55***: 299–305.

Podrázský V., Viewegh J., Matějka K. (2011): Vliv douglasky na rostlinná společenstva lesů ve srovnání s jinými dřevinami. [Douglas fir influence on plant society in comparison with other tree species.] Zprávy lesnického výzkumu, ***56***: 44–51.

Poleno Z. (2001): Vliv přeměn smrkových monokultur na stav a vývoj lesních půd a rostlinných společenstev. [Influence of transformation of spruce monocultures on state and development of forest soil and herbal vegetation.] Zprávy lesnického výzkumu, ***46***: 6–15

Remeš J., Pulkrab K., Tauchman P. (2010): Production and economical potential of Douglas fir on selected locality of the School Training Forest Kostelec nad Černými lesy. In: Podrázský V. (ed.): News in silviculture of introduced tree species. Kostelec nad Černými lesy, 21.10. 2010. Prague, Czech University of Life Sciences Prague: 68–69.

Šomšák L. (2003): Effect of secondary spruce forests on phytoenvironment in the Slovenské Rudohorie Mountains. Folia Oecologica, ***30***: 41–59.

Šomšák L., Balkovič J. (2002): Cyclic succession and plant biodiversity within the secondary spruce forests in the Hnilec river watershed. Phytopedon, ***1***: 45–51.

Tietema A. (1992): Nitrogen Cycling and Soil Acidification in Forest Ecosystems in the Netherlands. [Ph.D. Thesis.] Amsterdam, University of Amsterdam: 140.

Vacek S., Matějka K. (2010): State and development of phytocenoses on research plots in the Krkonoše Mts. forest stands. Journal of Forest Science, ***56***: 505–517.

van Wesemael B. (1992): Soil Organic Matter in Mediterranean Forests and its Implications for Nutrient Cycling and Weathering of Acid, Low-grade Metamorphic Rocks. [Ph.D. Thesis.] Amsterdam, University of Amsterdam: 140.

Zbíral J. (2002). Analýza půd I. Jednotné pracovní postupy. [Soil analysis. Standard analysis methods.] Brno, Ústřední kontrolní a zkušební ústav zemědělský: 197.

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