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The impact of juvenile tree species canopy on properties of new forest floor

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ABSTRACT: To keep forest soils fertile, forest practitioners plant mixed stands that are composed of both economically efficient trees such as conifers and soil-improving broadleaves. This is a mandated practice in the Czech Republic. As the new forest grows, it creates a dense canopy. The canopy is a principal source of organic matter to the forest soil. The formation of new forest humus is particularly important in first-generation forests on the former agricultural soil. Former meadow is a suitable site for forest floor and soil investigation since forest-floor humus covering the surface of the soil is a completely new layer. Both pure evergreen conifer and mixed treatments were planted in 2001. The experimental plot was established in order to investigate performance of tree species and restoration of forest-site conditions. We sampled dead-plant material and 0–10 cm topsoil to investigate their properties under the 10-year-old stands. We compared the treatments by descriptive statistics using both univariate and multivariate techniques. Dry mass (medians of weight) varied among the treatments from 11 to 19 Mg·ha^{-1}. The forest floor nutrient concentrations appeared to be dependent on the presence of admixed deciduous tree species (sycamore maple, small-leaved linden and European larch) as these forest floors (EL1, EL2, NS3, SM) were higher in base cations and phosphorus compared to pure spruce (NS1, NS2) and pure Douglas fir (DF) treatments. The first axis of PCA ordination plot revealed 45% of total variability and showed a clear distinction between evergreen coniferous and mixed species treatments. Young plantations produced forest floors of different quality; however it was not reflected in the topsoil properties.

Keywords: afforestation; agricultural land; forest floor; topsoil; nutrients

Forest soils are covered with dead-plant tissues fallen off the vegetation. These layers accumulate on the soil surface as the plant biomass of a new forest stand increases (Briggs 2004). They are the principal source of soil humus. All matter covering the forest soil is referred to as forest floor. Unlike the long-term forest soil, the afforested agricultural soil does not contain the humus that is partly inherited from previous forest crops; forest-floor humus covering the surface of the soil is a completely new layer. Reviews (Binkley 1995, Prescott 2002) and studies dealing with nutrient cycling and relationships between forest floor and topsoil properties of the tree species have been published. Some of these observations were focused on a comparison of pure tree species (Vesterdal, Raulund-Rasmussen 1998; Augusto et al. 2002; Ritter et al. 2003; Hagen-Thorn et al. 2004; Reich et al. 2005; Zhiyanski et al. 2008; Mareschal et al. 2010) and some also compared the effect of mixed plantations (Binkley, Valentine 1991; Prescott et al. 2000; Wang QingKui et al. 2007; Laganière et al. 2010). The results from mixed forests seem to vary greatly. Laganière et al. (2009) concluded that coarse-scale tree species mixing may have a different effect on soil biodiversity and soil processes than fine-scale mixing. Binkley and Giardina (1998) noted that most forests were not comprised

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of a single tree species, and that mixtures of species complicated the attempts to determine simple effects of the species. These authors also mentioned the opportunities being indicated in first-generation studies, for instance afforested agricultural land. For the purpose of our study we also used a former meadow as a suitable site to conduct the investigation of forest floor and soil properties. The study is focused on mixed-species stands because there is a need to establish productive, vigorous and sustainable forests. To be truly sustainable, forestry must be ecologically oriented and economically returnable. To plant commercially efficient tree species such as Norway spruce and Scots pine along with a portion of ameliorative species is a mandated practice in the Czech Republic. Such mixed forests are expected to produce enough wood and are also expected to keep the forest soil fertile. These requirements ought to be met particularly when managing new forests that produce the new forest floor. The study addresses the following research question: How do forest floor and soil properties reflect an intimate mixture of species in the overstorey compared to pure evergreen conifers?

MATERIAL AND METHODS

Study site and treatments

The site is a former meadow having GPS coordinates 50°19'40.838''N, 16°14'58.403''E. The meadow was afforested in 2001. Mixtures of tree species were investigated there; deciduous tree species such as larch (*Larix decidua* Mill.), sycamore maple (*Acer pseudoplatanus* L.) and small-leaved linden (*Tilia cordata* Mill.) were mixed (row mixture) with evergreen conifers such as Norway spruce (*Picea abies* [L.] Karsten) and Douglas fir (*Pseudotsuga menziesii* [Mirbel] Franco). Norway spruce and Douglas fir were also planted as pure treatments. In addition to the aforementioned species, silver fir (*Abies alba* Mill.) and mountain ash (*Sorbus aucuparia* L.) constituted a very low percentage of the overstorey (Table 1); we assumed that their effect on forest floor and soil properties was negligible. The soil is derived from the metabasite and phyllite bedrock (Opletal, Domečka 1983). The treatments were designed as square plots (145 m^2 each). The plots constituted seven different treatments according to the dominating species (Table 1).

Sampling

Both forest-floor humus and topsoil samples were collected on a site with 10-year-old plantation. Humus sampling was conducted using a metal frame (25 × 25 cm = 625 cm^2). Topsoil sampling was done using a soil corer (6 cm in diameter). Four samples per plot were taken.

Chemical analyses

The forest-floor samples were dried under open-air conditions. The dry samples were analysed for the following characteristics: humus content (%) by the Springel-Klee method, nitrogen content (%) by the Kjeldahl method, pH in both water and KCl, base saturation (BS in %) by the Kappen method, and concentration (mg·kg^{-1}) of plant-available nutrients (P, K, Ca, Mg) by the Mehlich III method (Mehlich 1984; Zbíral 1995).

Table 1. Tree species share in treatment plots

Treatment plot	Douglas fir	Silver fir	Mountain ash	Small-leaved linden	European larch	Norway spruce	Sycamore maple	Basal area (m^2·ha^{-1})
	(%)							
SM	24	2		14	10	10	40	13.6
EL1	26	1		8	35	7	25	13.2
EL2				11	45	24	21	14.3
NS3	6	2	1		28	59	4	19.5
NS1						100		16.4
NS2						100		12.5
DF	100							14.3

treatments' abbreviations are based on species composition: mixed plots with important species (SM – sycamore maple, EL1 and EL2 – European larch, NS3 – Norway spruce), pure evergreen conifer plots (NS1 and NS2 – Norway spruce, DF – Douglas-fir)

Statistics

The experimental design did not meet the requirements for using ANOVA for appropriate evaluation of treatment effects because of the lack of treatment replications. Thus, we compared the treatments only by descriptive statistics using both univariate and multivariate techniques. Since the number of pits per plot was quite small and we could not assume the normality (or at least symmetric distribution) of data, we used the median as appropriate parameter of the central tendency of data. We displayed data by strip charts because of small sample sizes. We also performed principal component analysis (PCA) and constructed ordination plots, because of their ability to reveal relationships between mutually correlated variables. For the purpose of multivariate analysis, the individual variables were logarithmically transformed and also centred and standardized. Arrows in the ordination plots show directions in which the value of the given variable is increasing, the angle between the respective arrows represents correlations between the variables. Because the analyses did not allow us to separate differences between the plots due to treatment effect and due to the other uncontrolled influences, caution must be used when inferring conclusions.

RESULTS

Amount and properties of forest floor

Dry mass (medians of weight) varied among the treatments from 11 to 19 t·ha^{-1}. Although the highest dry mass amount was observed in DF treatment, the other evergreen coniferous treatments (plots NS1, NS2) did not show any substantial differences from mixed species treatments (Fig. 1). Nutrient concentrations (P, K, Ca, and Mg) were generally lower in evergreen coniferous treatments compared to mixed species treatments (Fig. 2). The DF treatment also showed the highest values of pH and C/N ratio (Fig. 3). Base saturation varied from 57 to 63%, and these differences can be considered negligible. The first axis of PCA ordination plot revealed 45% of total variability and showed a clear distinction between evergreen coniferous and mixed species treatments (Fig. 4). Interpretation of the second canonical axis, which revealed 26% of total variability, is not clear. The ordination plot displayed strong correlations between Ca, Mg and K, very strong correlation between dry mass and C/N and also between pH/H_2O and pH/KCl.

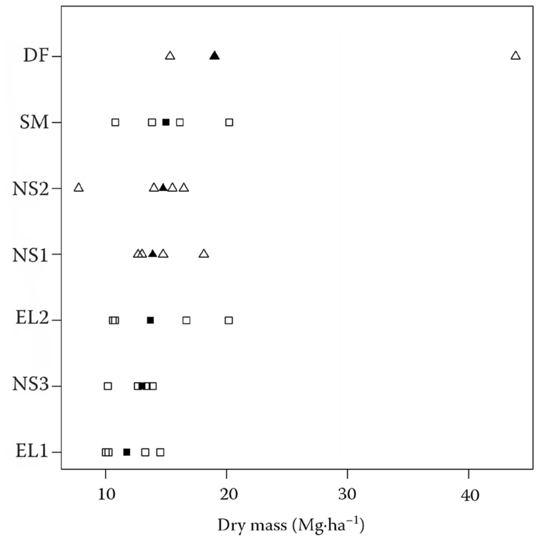

Fig. 1. Dry mass of forest floor samples

squares – mixed species treatments, triangles – pure evergreen conifers, closed squares and triangles show median values; treatments' abbreviations are based on the species composition: mixed plots with important species (SM – sycamore maple, EL1 and EL2 – European larch, NS3 – Norway spruce), pure evergreen conifer plots (NS1 and NS2 – Norway spruce, DF – Douglas-fir)

Properties of topsoil

The DF treatment showed the highest values of pH/KCl and C/N, but values in NS1 and NS2 did not confirm any substantial differences between evergreen coniferous and mixed species treatments. Similarly, nutrient contents and base saturation did not show a clear distinction between the soils of evergreen coniferous and mixed species treatments (Figs 5 and 6). Base saturation between plots varied substantially from 22 to 49%. The first two axes of the ordination plot revealed 64% of total variability, but we cannot claim a distinction pattern between evergreen coniferous and mixed species treatments (Fig. 7). The ordination plot displayed very strong correlations between base saturation and pH/KCl, and also between Ca and Mg. Young plantations produced forest floors of different quality; however it was not reflected in the topsoil properties.

DISCUSSION

Unlike agricultural soils, forest soils are naturally fertilized by litterfall from plants; the greatest amounts of nutrients are sequestered in woody species. Binkley (1986) stated that more than a half of the annual nutrient uptake of a forest is returned

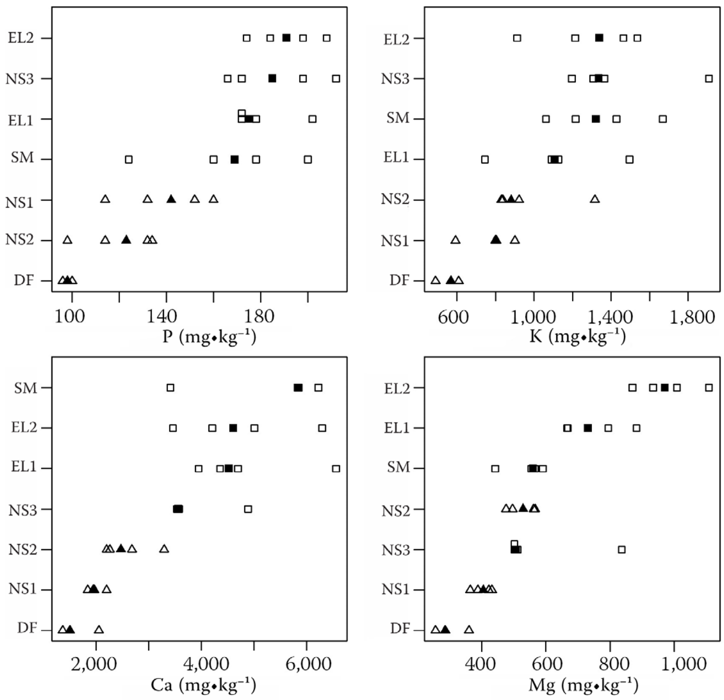

Fig. 2. Nutrient concentrations in forest floor samples

squares – mixed species treatments, triangles – pure evergreen conifers, closed squares and triangles show median values; treatments' abbreviations are based on the species composition: mixed plots with important species (SM – sycamore maple, EL1 and EL2 – European larch, NS3 – Norway spruce); pure evergreen conifer plots (NS1 and NS2 – Norway spruce, DF – Douglas-fir)

to the soil (litterfall and fine-root turnover). This recycling forms a major pool of available nutrients. The process of forest floor formation is an important component of forest environment restoration, particularly when the former agricultural land is being afforested. Unlike long-term forest soils with humus layers partly inherited from previous generations of the forest, the forest floor developing after afforestation is com-

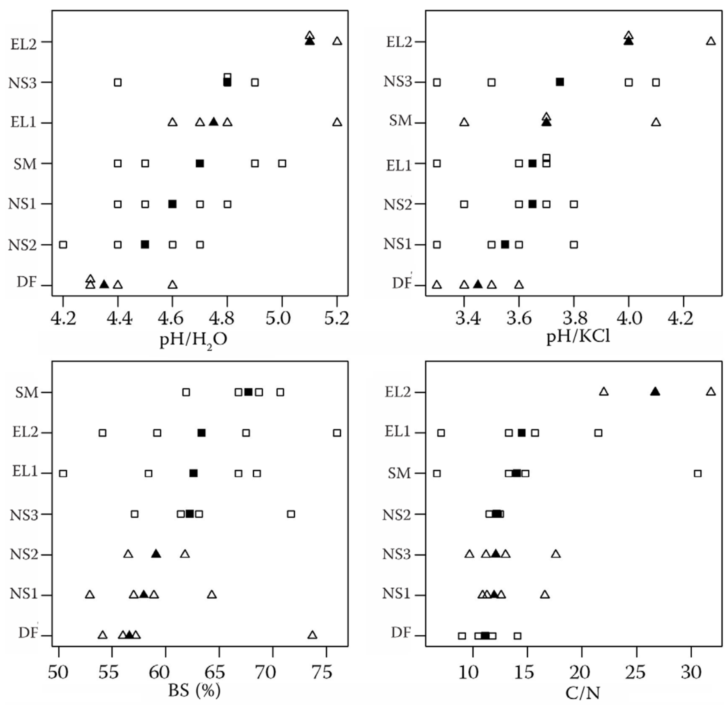

Fig. 3. Values of pH, base saturation (BS) and C/N ratio of forest floor samples

squares – mixed species treatments, triangles – pure evergreen conifers, closed squares and triangles show median values; treatments' abbreviations are based on the species composition: mixed plots with important species (SM – sycamore maple, EL1 and EL2 – European larch, NS3 – Norway spruce); pure evergreen conifer plots (NS1 and NS2 – Norway spruce, DF – Douglas-fir)

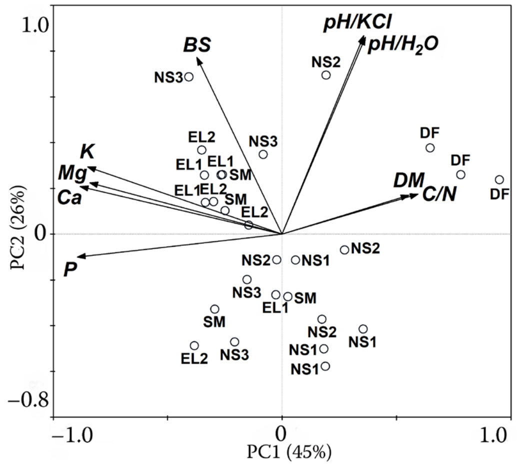

Fig. 4. PCA ordination plots for forest floor samples

BS – base saturation, DM – dry mass, treatments' abbreviations are based on the species composition: mixed plots with important species (SM – sycamore maple, EL1 and EL2 – European larch, NS3 – Norway spruce); pure evergreen conifer plots (NS1 and NS2 – Norway spruce, DF – Douglas-fir)

pletely new. However, these soils may still retain a legacy of former cultivation practices such as higher pH and higher extractable nutrients of the soil (Wall, Hytönen 2005; Oheimb et al. 2008). This legacy can be a great advantage for a new forest as the soils have medium to high forest site productivity (Wall, Westman 2006). This increased fertility plays an important role in the formation of a forest floor rich in nutrients. However, poor-quality litter and humus are also related to local climates. Singer and Munns (1996) wrote: "Acid soils are most common where high rainfall and free drainage favour leaching and the biological production of acids". As for Czech conditions, heavily acidified soils occur at higher altitudes (> 800 m) where high annual precipitation and low air temperature contribute to the formation of a thick layer of forest-floor organic matter. The study site is situated in more favourable conditions at the altitude of 520 m. The soils were found to be also acidic. However, pure NS1, NS2 and DF are not situated on more acidic soils and do not produce more acidic forest floors compared to mixed treatments. The soil under a mixture dominated by Norway spruce and European larch (NS3) had lower calcium and magnesium contents. The lower concentration might indicate an intensive uptake of both nutrients by trees since this treatment had also the highest basal area (Table 1). It might be in accordance with Binkley (1986), who reported a relationship between the accumulation of biomass and net movement of nutrients from the soil into the vegetation. NS3 produced forest floor high in nutrients. As for forest floor properties, we found higher P and base nutrient concentrations in the forest floor of mixed treatment origin. This was attributed to the positive effect of deciduous species (both broadleaves

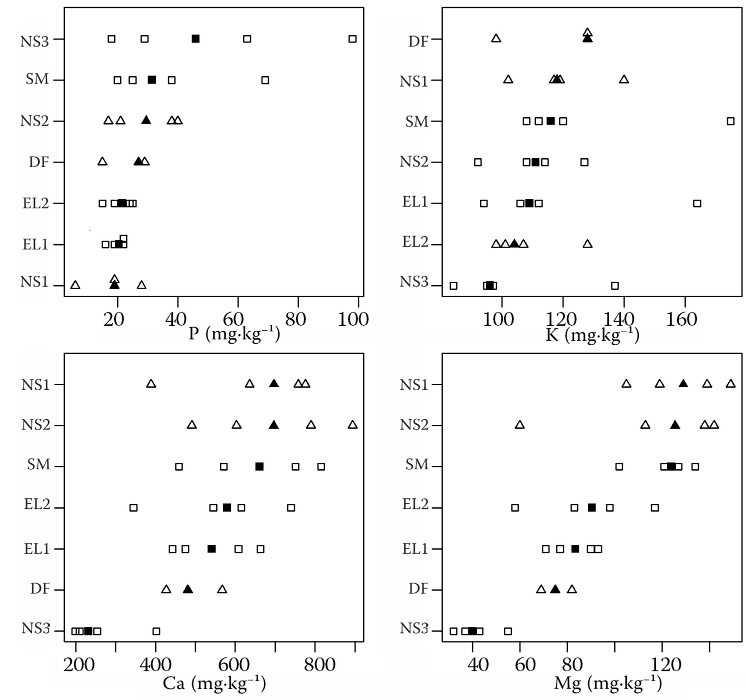

Fig. 5. Nutrient concentration in topsoil samples

squares – mixed species treatments, triangles – pure evergreen conifers, closed squares and triangles show median values; treatments' abbreviations are based on the species composition: mixed plots with important species (SM – sycamore maple, EL1 and EL2 – European larch, NS3 – Norway spruce), pure evergreen conifer plots (NS1 and NS2 – Norway spruce, DF – Douglas-fir)

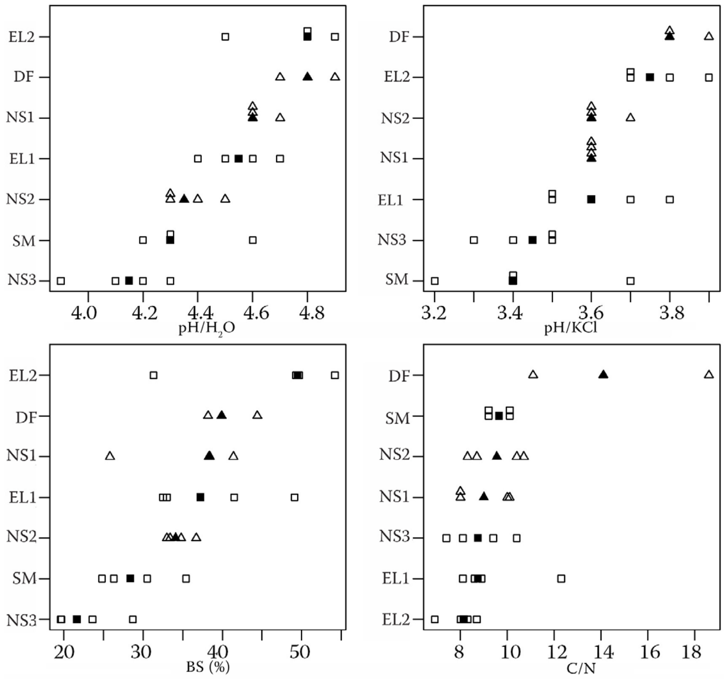

Fig. 6. Values of pH, base saturation (BS) and C/N ratio of topsoil samples

squares – mixed species treatments, triangles – pure evergreen conifers, closed squares and triangles show median values; treatments' abbreviations are based on the species composition: mixed plots with important species (SM – sycamore maple, EL1 and EL2 – European larch, NS3 – Norway spruce), pure evergreen conifer plots (NS1 and NS2 – Norway spruce, DF – Douglas-fir)

and larch) compared to pure evergreen conifers. It corresponds with the studies which were done in broadleaved and coniferous stands (Prescott et al. 2000; Albers et al. 2004; Borken, Beese 2005; Pernar et al. 2008) and generally indicated faster litter decomposition in broadleaved or mixedwood forests compared to coniferous forests.

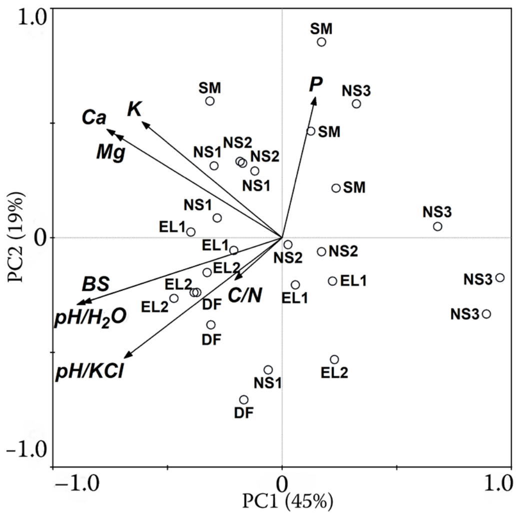

Fig. 7. PCA ordination plots for topsoil samples

BS – base saturation, DM – dry mass, treatments' abbreviations are based on the species composition: mixed plots with important species (SM – sycamore maple, EL1 and EL2 – European larch, NS3 – Norway spruce), pure evergreen conifer plots (NS1 and NS2 – Norway spruce, DF – Douglas-fir)

However, this effect is not simply due to the mixing of litters or to differences in leaf litter quality. Properties of sites seem to affect nutrient cycling as Prescott (2002) found greater differences in forest floor net N mineralization rates among four sites than among four conifer species.

As for the investigated evergreen conifers, Podrázský and Remeš (2008) found higher plant-available calcium, magnesium and potassium concentrations under Douglas-fir than under Norway spruce. Their study, however, brought preliminary results. Podrázský et al. (2009) found Douglas fir humus and soil slightly more favourable compared to spruce; the difference was not significant. We observed no substantial difference between Douglas fir and Norway spruce either, though Douglas fir forest floor was slightly lower in plant-available nutrients. Augusto et al. (2002) reported Douglas fir to be the intermediate soil-affecting tree in terms of saturation index for exchangeable earth-alkaline cations compared to lower evergreen conifers (Scots pine, Norway spruce) and higher broadleaves. Raulund-Rasmussen and Vejre (1995) reported more acidic forest floors under both species compared to broadleaves. This applied also to broadleaves and eastern hemlock in the study by Finzi et al. (1998). These studies suggest the importance of tree species which shed all foliage every year and results of our study show similar patterns. Hagen-Thorn et al. (2004) found linden trees to be the best ameliorative species increasing pH and calcium concentration in soil. Linden is also present in three mixed treatments (SM, EL1 and EL2) in our study. However, we cannot conclusively relate the increased calcium concentration with this species. The topsoil layers do not differ in nutrient concentrations and higher amounts of calcium were not found only under mixtures with linden. Moreover, the linden may not always have an effect on an increase in pH and base nutrient saturation as reported by Holzwarth et al. (2011). This is likely to apply to the differences among species and sites (see Prescott 2002). We also found the forest floor base nutrients to be higher under the mixture (NS3) dominated by spruce and larch where linden was missing and the share of sycamore maple was low. This treatment is likely to have a high production potential due to the presence of spruce and larch. Confirmation of the capability to produce more biomass while having forest floor high in plant-available nutrients will require further investigations.

CONCLUSIONS

The forest floor nutrient concentrations appeared to be dependent on the presence of admixed deciduous tree species as these treatments were higher in base cations and phosphorus compared to pure spruce and pure Douglas fir treatments.

The mixed treatments being able to form the nutrient-rich forest floors would meet requirements for sustainable nutrient cycling between the formerly agricultural soil and the new forest and would also have the important production function.

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References

Albers D., Migge S., Schaefer M., Scheu S. (2004): Decomposition of beech leaves (*Fagus sylvatica*) and spruce needles (*Picea abies*) in pure and mixed stands of beech and spruce. Soil Biology and Biochemistry, ***36***: 155–164.

Augusto L., Ranger J., Binkley D., Rothe A. (2002): Impact of several common tree species of European temperate forests on soil fertility. Annales of Forest Science, ***59***: 233–253.

Binkley D. (1986): Forest Nutrition Management. New York, John Wiley & Sons: 290.

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. 28. February–2. March 1994. Canterbury, Lincoln University Press: 1–33.

Binkley D., Valentine D. (1991): Fifty-year biogeochemical effects of green ash, white pine, and Norway spruce in a replicated experiment. Forest Ecology and Management, ***40***: 13–25.

Binkley D., Giardina Ch. (1998): Why do trees affect soils? The warp and woof of tree-soil interactions. Biogeochemistry, ***42***: 89–106.

Borken W., Beese F. (2005): Soil respiration in pure and mixed stands of European beech and Norway spruce following removal of organic horizons. Canadian Journal of Forest Research, ***35***: 2756–2764.

Briggs R.D. (2004): The Forest Floor. In: Burley J., Evans J., Youngquist J.A. (eds): Encyclopedia of Forest Sciences. Oxford, Elsevier: 1223–1227.

Finzi A.C., Canham Ch.D., van Breemen N. (1998): Canopy tree-soil interactions within temperate forests: species effects on pH and cations. Ecological Applications, ***8***: 447–454.

Hagen-Thorn A., Callesen I., Armolaitis K., Nihlgård B. (2004): The impact of six European tree species on the chemistry of mineral topsoil in forest plantations on former agricultural land. Forest Ecology and Management, ***195***: 373–384.

Holzwarth F. M., Daenner M., Flessa H. (2011): Effects of beech and ash on small-scale variation of soil acidity and nutrient stocks in a mixed deciduous forest. Journal of Plant Nutrition and Soil Science, ***174***: 799–808.

Laganière J., Paré D., Bradley R.L. (2009): Linking the abundance of aspen with soil faunal communities and rates of belowground processes within single stands of mixed aspen-black spruce. Applied Soil Ecology, ***41***: 19–28.

Laganière J., Paré D., Bradley R.L. (2010): How does a tree species influence litter decomposition? Separating the relative contribution of litter quality, litter mixing, and forest floor conditions. Canadian Journal of Forest Research, ***40***: 465–475.

Mareschal L., Bonnaud P., Turpault M.P., Ranger J. (2010): Impact of common European tree species on the physicochemical properties of fine earth: an unusual pattern. European Journal of Soil Science, ***61***: 14–23.

Mehlich A. (1984): Mehlich 3 soil test extractant: a modification of Mehlich 2 extractant. Communications in Soil Science and Plant Analysis, ***15***: 1409–1416.

Oheimb G. von, Härdtle W., Naumann P., Westphal Ch., Assmann T., Meyer H. (2008): Long-term effects of historical heathland farming on soil properties of forest ecosystems. Forest Ecology and Management, ***255***: 1984–1993.

Opletal M., Domečka K. (1983): Synoptic Geological Map of the Orlické hory Mts. Praha, Ústřední ústav geologický, Geological Survey & Geodetic and Cartographic Enterprise.

Pernar N., Matić S., Bakšić D., Klimo E. (2008): The accumulation and properties of surface humus layer in mixed selection forests of fir on different substrates. Ekologia (Bratislava), ***27***: 41–53.

Podrázský V., Remeš J. (2008): Půdotvorná role významných introdukovaných jehličnanů – douglasky tisolisté, jedle obrovské a borovice vejmutovky. [Soil-forming role of important introduced conifers – Douglas fir, Grand fir and Eastern white pine.] Zprávy lesnického výzkumu, ***53***: 29–36.

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.

Prescott C.E., Zabek L.M., Staley C.L., Kabzems R. (2000): Decomposition of broadleaf and needle litter in forests of British Columbia: influences of litter type, forest type, and litter mixtures. Canadian Journal of Forest Research, ***30***: 1742–1750.

Prescott C.E. (2002): The influence of the forest canopy on nutrient cycling. Tree Physiology, ***22***: 1193–1200.

Raulund-Rasmussen K., Vejre H. (1995): Effect of tree species and soil properties on nutrient immobilization in the forest floor. Plant and Soil, ***168–169***: 345–352.

Reich P.B., Oleksyn J., Modrzynski J., Mrozinski P., Hobbie S.E., Eissenstat D.M., Chorover J., Chadwick O.A., Hale C.M., Tjoelker M.G. (2005): Linking litter calcium, earthworms and soil properties: a common garden test with 14 tree species. Ecology Letters, ***8***: 811–818.

Ritter E., Vesterdal L., Gundersen P. (2003): Changes in soil properties after afforestation of former intensively managed soils with oak and Norway spruce. Plant and Soil, ***249***: 319–330.

Singer J.S., Munns D.N. (1996): Soils. An Introduction. New Jersey, Prentice Hall: 480

Vesterdal L., Raulund-Rasmussen K. (1998): Forest floor chemistry under seven tree species along a soil fertility gradient. Canadian Journal of Forest Research, ***28***: 1636–1647.

Wall A., Hytönen J. (2005): Soil fertility of afforested arable land compared to continuously forested sites. Plant and Soil, ***275***: 247–260.

Wall A., Westman C.J. (2006): Site classification of afforested arable land based on soil properties for forest production. Canadian Journal of Forest Research, ***36***: 1451–1460.

Wang Q., Wang S., Fan B., Yu X. (2007): Litter production, leaf litter decomposition and nutrient return in Cunninghamia lanceolata plantations in south China: effect of planting conifers with broadleaved species. Plant and Soil, ***297***: 201–211.

Zbíral J. (1995): Analýza půd I. [Soil Analysis I.] Brno, Státní kontrolní a zkušební ústav zemědělský: 177.

Zhiyanski M., Kolev K., Sokolovska M. (2008): Tree species effect on soils in Central Stara Planina Mountains. Nauka za Gorata – Forest Science, ***4***: 65–82.

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