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Changes of agricultural land characteristics as a result of afforestation using introduced tree species

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ABSTRACT: The paper documents the mid-term changes of the soil characteristics and upper soil dynamics in the stands of introduced tree species, grand fir and Douglas-fir, on the former agricultural lands. These species were compared with Norway spruce stand and original grassland in the same site conditions at the Hrubá Skála locality (Eastern Bohemia). The plot was established in 1980 on Luvisol type of soil, sandy clay. Altitude ranges between 350 and 360 m a.s.l., mean annual temperature was 7.8°C, mean annual precipitation 703 mm. Results confirmed the starting process of the development of humus forms typical for forest ecosystems, despite the initial stage was dominant. The amount of surface humus (holorganic horizons) did not differ between the tree species stands and the agricultural land, but the grassland humus layer contained much more mineral particles. The grand fir was confirmed as a species favourably affecting the site, Douglas-fir affecting it less favourably in the given conditions compared with Norway spruce. Different dynamics was documented for soil reaction, characteristics of soil adsorption complex, soil acidity and nutrient dynamics.

Keywords: agricultural land afforestation; soil characteristics; grand fir; Douglas-fir

Agricultural land afforestation, both spontaneous and intentional, has been going on for centuries, and its intensity varies with landscape exploitation and its history and development. In particular, the 1950s and the 1960s represent an era of significant changes in land use in the Czech Republic characterized by extensive afforestation of land that lost any further agricultural prospect (Špulák 2006; Hatlapatková, Podrázský 2011; Špulák, Kacálek 2011). Since then, afforestation has been going on to utilize marginal agricultural land, using also government subsidies, as well as to improve retention properties of landscape (Holubík et al. 2014; Vopravil et al. 2015). It is crucial to evaluate the condition and development of forest stands on the afforested land for their future management. The extremely high production of coniferous tree species, outstanding as it may be, contrasts with the timber quality affected by frequent rot. Soil quality is of high importance as it can be influenced by various tree species to a certain extent. Restoration of humus layers and matter cycle typical of forest soils come into focus in this context (Kacálek et al. 2006, 2007; Podrázský et al. 2010; Slodičák et al. 2011). It is also interesting to discover how tree species – individually as well as in mixed groups – exploit available soil nutrients and at the same time enrich the soil with organic matter, and thus restore its forest-soil characteristics.

In this context, forests represent the most important sink of carbon as well as ecosystems with typical carbon fluxes on a global scale (Brown,

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Lugo 1990; Ellert, Bettany 1995; Merganičová, Merganič 2010; Marková et al. 2011). A land use change has an important influence on soil characteristics and stabilization (Tisdall, Oades 1982; Barcena et al. 2014). Kaiser et al. (2002) determined that forest subsoil contains about 45% of total soil organic carbon (SOC) of the soil profile, bound especially to fine soil particles.

Afforestation of agricultural lands results in significant sequestration of new carbon and stabilization of old carbon in physically protected soil organic matter fractions, associated with microaggregates (53–250 μm) and silt and clay (< 53 μm) (Del Galdo et al. 2003). Several authors showed that afforestation increases SOC by 23% in the surface soil. The SOC sequestration depends on forest species and management (Del Galdo et al. 2003; Lal 2002; Lamlom, Savidge 2003; Blanco-Canqui, Lal 2004).

Introduced tree species are only of marginal significance in agricultural land afforestation but can substantially improve forest functions in specific conditions. Among them, Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) is the most important and its positive effects on soil characteristics – in comparison with domestic coniferous species – in European conditions were proved by many authors (Augusto et al. 2003; Podrázský, Remeš 2008; Menšík et al. 2009; Kubeček et al. 2014). On the other hand, information on the effects of grand fir (*Abies grandis* [Dougl. ex D. Don] Lindl) on soil characteristics is rather scarce (Podrázský, Remeš 2008, 2009).

The significance of introduced tree species in forming forest ecosystems can be evaluated e.g. on provenance plots where both timber and non-timber functions of every single tree species can be analysed. These plots were usually established in accordance with internationally approved rules, and despite being often underrated by both research and practical sphere at present, they can serve as model plots for many research projects on various tree species (Šika 1983; Vančura 1990; Kobliha, Janeček 2000; Kobliha et al. 2013; Petkova et al. 2014; Popov 2014).

The objective of our article is to document changes in soil properties on afforested agricultural lands with introduced tree species at medium altitudes, to supply evidence of tree species effects on soil development, and thus to broaden the knowledge of soil characteristics of lands afforested by important introduced tree species (e.g. Podrázský, Štěpáník 2002; Podrázský, Remeš 2008; Hagen-Thorn et al. 2004; Kacálek et al. 2006, 2007) within one case study.

MATERIAL AND METHODS

In the case study, we used a provenance plot primarily established for grand fir (*Abies grandis* [Dougl. ex D. Don]) research, and partially suitable for the study of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and Norway spruce (*Picea abies* [L.] (Karst). It is possible to compare the forest tree species plantation with the residues of grassland. The international provenance plot was established in 1980 in Natural Forest Area No. 18 – North Bohemian sandstone plateau – at 350–360 m a.s.l., and is managed by Hořice Forestry Office of Forests of the Czech Republic, Hrubá Skála Forest District. For the plantation, a part of former grassland in the middle of the forest complex was used. The average annual temperature of the locality is 7.8°C, average annual precipitation 703 mm. The parent material consists of cretaceous sandstone, the soil profile is composed of fine-grain sandy clay, forest type 3H1 – *Querceto-Fagetum illimerosum trophicum-Oxalis acetosella-Carex pilosa* on brown earth (i.e. Cambisols) on gentle slopes and slope bases.

The area of the plot is 0.84 ha and there are 9 provenances of grand fir, accompanied by Norway spruce, silver fir and Douglas-fir. There are three replications on this plot. The size of segments is 18 × 12 m, spacing 2 × 2 m. Fifty-four individuals were planted in one segment (6 rows by 9 plants). The seedlings were 3-years old in the forest nursery before planting; grand fir was container-grown, the rest of the species were planted bare-rooted. 162 seedlings of each provenance (species) were planted, i.e. 2106 seedlings in total. Until 2003, no tending intervention was performed on the plot; only dead or uprooted trees were removed. The stand was then thinned only to enable as many trees as possible to grow healthy, full crowns. Another planned thinning was carried out in 2014 to improve the stand stability, slenderness coefficient and even distribution of individuals on the whole plot.

Soil samples were collected with a soil probe of 6.5 cm in diameter; 4 bulk samples (each consisting of 5 cuts) for each tree species. The samples were analysed in Tomáš laboratory of Forestry and Game Management Research Institute in Opočno by standard methods:

- dry matter amount in holorganic horizons (t/ha) at 105°C,
- active (in water) and exchangeable pH in 1 N KCl, potentiometrically,
- characteristics of soil adsorption complex were determined by Kappen's method (S – base content, T – cation exchange capacity, H – hydrolytic acidity,

V – base saturation of adsorption complex),
– total nutrient content after mineralization of holorganic horizons using the mixture of sulphuric acid and selenium for mineralization (N, P, K, Ca, Mg), the N content was determined, total phosphorus content spectrophotometrically, K by flame photometry, Ca and Mg by AAS,
– total oxidizable carbon (humus after calculation) and nitrogen content (N) by the standard Kjeldahl method,
– combustible matter was determined as LOI at 550°C after 120 min,
– amount of available nutrients (P, K, Ca, Mg) by Mehlich III method and in a solution of citric acid (e.g. Hatlapatková, Podrázský 2011).

For statistical purposes, an analysis of variance for multiple comparisons – ANOVA (SPSS, Tulsa, USA) was used; subsequently, statistically significant differences between plots were identified by the pairwise comparisons method using Tukey's tests. The tests were carried out at 95% confidence level – STATISTICA (SPSS, Tulsa, USA). The horizons of the same type were compared, statistically homogeneous groups are indicated by the same indexes in the tables.

RESULTS

Table 1 documents how the tree species help to form a new layer of surface humus, the amount of total humus – oxidizable carbon (C_{ox}), total nitrogen and C/N ratio in the upper layer of soil. In the surface humus, no significant differences in the surface humus amount were revealed; grass litter (its amount) was rather insignificantly, though apparently higher in comparison with tree species which did not show almost any difference at all. Nevertheless, the grass cover did contain any live parts of turf, or mineral particles, which is proved by the lowest share of so called combustible matter and total humus and carbon content.

The trend was confirmed also by the statistically lowest amount of oxidizable carbon (or total humus) in the 0–5 cm layer of mineral soil on the grassland. In the case of tree species, grand fir showed the lowest amount of surface humus. Norway spruce and Douglas-fir did not show any apparent differences, not even in deeper layers of the mineral soil of all variants. No differences were found in the amounts of total nitrogen by Kjeldahl in the tree species. On the contrary, grass litter showed a lower concentration of nitrogen; in deeper layers the differences were insignificant.

No substantial differences were found in C/N ratio between the variants. Norway spruce had the highest C/N ratio in the surface layer of mineral soil. Statistically, there was a significant difference in comparison with the grassland. In the holorganic horizon, C/N was the same under Douglas-fir and grass. It was significantly higher under grand fir; under Norway spruce, the ratio was the least favourable. But even there, the values oscillated around 20, which is still considered a positive proof of ongoing humification.

The soil reaction, both active and potential, was significantly higher under grass cover and rather high under grand fir (Table 2), while it significantly

Table 1. Amount of surface humus, content of total carbon and nitrogen and C/N ratio in the upper soil layer in the Hrubá Skála locality

Species	Holorganic horizon	Dry matter ($t \cdot ha^{-1}$)	Humus (Springel-Klee)	Oxidizable carbon C_{ox}	Combustible matter	N (Kjeldahl)	C/N
			(%)				
Norway spruce	L–H	11.6^{a}	39.11^{b}	22.69^{b}	50.95^{a}	1.03^{a}	21.99^{c}
	0–5		4.75^{a}	2.75^{a}	9.04^{a}	0.39^{a}	7.17^{b}
	5–10		2.02^{a}	1.17^{a}	5.54^{bc}	0.27^{a}	4.40^{a}
Grand fir	L–H	10.0^{a}	29.82^{ab}	17.30^{ab}	41.87^{a}	1.00^{a}	17.26^{b}
	0–5		4.51^{a}	2.62^{a}	8.95^{a}	0.53^{a}	5.38^{ab}
	5–10		2.20^{a}	1.28^{a}	5.59^{c}	0.29^{a}	4.46^{a}
Grassland	L–H	15.5^{a}	11.87^{c}	6.89^{c}	21.08^{b}	0.56^{b}	14.05^{a}
	0–5		2.85^{b}	1.65^{b}	5.74^{b}	0.58^{a}	3.07^{a}
	5–10		1.97^{a}	1.14^{a}	4.21^{a}	0.30^{a}	3.76^{a}
Douglas-fir	L–H	12.8^{a}	23.94^{a}	13.88^{a}	36.86^{ab}	0.97^{a}	14.43^{ab}
	0–5		4.04^{a}	2.34^{a}	7.52^{ab}	0.48^{a}	5.00^{ab}
	5–10		2.10^{a}	1.22^{a}	4.27^{ab}	0.32^{a}	3.73^{a}

L–H indicates horizons (L+F+H), same letters indicate statistically homogeneous groups (the horizons of the same type were compared)

Table 2. Soil reaction and characteristics of the soil adsorption complex in the upper soil layer in the Hrubá Skála locality

Species	Horizon/depth (cm)	pH_{H_2O}	pH_{KCl}	S	H	T	V
				(mval/100g)			(%)
Norway spruce	L–H	5.61[a]	4.82[c]	31.83[b]c	23.53[a]	55.36[a]	57.74[ab]
	0–5	4.82[b]	3.83[a]	6.58[ab]	11.01[a]	17.59[bc]	37.20[ab]
	5–10	4.71[c]	3.70[a]	5.90[ab]	7.63[a]	13.53[bc]	43.32[ab]
Grand fir	L–H	6.53[bc]	5.36[a]	44.88[c]	16.75[a]	61.63[a]	71.94[a]
	0–5	5.02[ab]	3.84[a]	9.71[b]	9.41[a]	19.12[c]	50.26[b]
	5–10	4.98[a]	3.86[a]	7.96[b]	7.68[a]	15.64[c]	50.82[b]
Grassland	L–H	6.86c	5.40[a]	15.59[a]	6.87[b]	22.46[b]	69.01[a]
	0–5	5.23[a]	4.09[a]	4.52[a]	4.81[b]	9.32[a]	47.50[ab]
	5–10	5.33[b]	4.16[b]	3.62[a]	4.17[b]	7.79[a]	45.40[ab]
Douglas-fir	L–H	6.08[ab]	4.44[b]	18.83[ab]	22.05[a]	40.79[c]	46.06[b]
	0–5	5.17[a]	3.97[a]	3.76[a]	8.12[a]	11.89[ab]	29.08[a]
	5–10	5.16[ab]	4.21[b]	3.00[a]	8.12[a]	11.12[ab]	23.75[a]

L–H indicates holorganic horizons (L+F+H), S – bases content, H – hydrolytic acidity, T – cation exchange capacity, V – base content; same letters indicate statistically homogeneous groups (the horizons of the same type were compared)

dropped under Douglas-fir. The strongest acidification of soil surface was under Norway spruce. Despite the fact, the soil reaction remained rather high and is only slowly getting closer to values typical of forest soil (pH_{KCl} 3–4).

The content of bases in holorganic layers of grass cover was significantly lowest. It was slightly higher in Douglas-fir stands and significantly higher under the other tree species. The highest values were confirmed under grand fir. A similar trend – with lower values under Douglas-fir, was observed in both studied layers of mineral soil.

The amount of organic matter was closely related to the values of hydrolytic acidity (see H in Table 2). In the holorganic horizon, the lowest values were detected in the grassland, significantly higher in the holorganic layer of grand fir, followed by Douglas-fir and Norway spruce, with insignificant differences between the species. The lowest value of H was in the 0–5 cm layer of the grassland, the highest under Norway spruce. The same applies to the 5–10 cm layer with the highest values under Douglas-fir.

When we add the values of the base content and hydrolytic acidity, we get the value of cation exchangeable capacity – value of T. It is lowest in the holorganic layer in the grassland, followed by significantly higher values under Douglas-fir and then in Norway spruce and grand fir stands. In mineral layers, the order is as follows: grassland, Douglas-fir, Norway spruce and grand fir.

Base saturation of adsorption complex (ratio of base content and cation exchange capacity) is therefore highest (L–H layer) in grand fir stands and grassland, lower under Norway spruce and especially under Douglas-fir. In mineral layers, it is significantly highest under grand fir, higher under grass cover and lowest under Norway spruce and especially Douglas-fir.

The exchangeable titration acidity in holorganic layers was the lowest under grass cover and grand fir, significantly higher under Douglas-fir and especially under Norway spruce (Table 3). Its value was crucially determined by the content of exchangeable aluminium, exchangeable hydrogen content being almost zero in many cases. The values of total titration acidity, in mineral soil, together with exchangeable aluminium were highest under Douglas-fir, which might be caused by intensive

Table 3. Exchangeable acidity and its components (in $mval \cdot kg^{-1}$) in the upper soil layer in the Hrubá Skála locality

Species	Horizon/ depth (cm)	Exchangeable titration acidity	Exchangeable H^+	Exchangeable Al^{3+}
Norway spruce	L–H	14.00[b]	5.18[b]	8.83[b]
	0–5	72.01[b]	0.03[a]	71.98[b]
	5–10	50.79[b]	0.03[a]	50.76[b]
Grand fir	L–H	0.10[a]	0.10[a]	0.00[a]
	0–5	43.63[a]	0.03[a]	43.60[a]
	5–10	33.36[a]	0.03[a]	33.33[a]
Grassland	L–H	0.10[a]	0.10[a]	0.00[a]
	0–5	82.38[c]	0.03[a]	82.35[c]
	5–10	70.37[c]	0.03[a]	70.34[c]
Douglas-fir	L–H	9.20[b]	0.37[a]	8.83[b]
	0–5	92.63[d]	0.03[a]	92.60[d]
	5–10	84.88[d]	0.03[a]	84.85[d]

L–H indicates holorganic horizons (L+F+H), same letters indicate statistically homogeneous groups (the horizons of the same type were compared)

Table 4. Content of total nutrients (N–Mg in %) in holorganic horizons in the upper soil layer in the Hrubá Skála locality

Species	Horizon/depth (cm)	N	P	K	Ca	Mg
Norway spruce	L–H	1.06[a]	0.033[a]	0.31[a]	0.27[bc]	0.056[c]
Grand fir		0.95[ab]	0.038[a]	0.38[a]	0.31[c]	0.148[b]
Grassland		0.63[b]	0.013[a]	0.39[a]	0.08[a]	0.048[a]
Douglas-fir		0.96[a]	0.023[a]	0.32[a]	0.12[ab]	0.045[a]

same letters indicate statistically homogeneous groups

depletion of nutrients or, perhaps, by increased nitrification and nitrate leaching. It was significantly lower under grass cover, followed by Norway spruce and grand fir. From the surveyed tree species, grand fir showed the lowest acidification potential, which is also reflected in the pH value dynamics.

Table 4 shows the total nutrient content, analyzed only in holorganic horizons. The content of total nitrogen was significantly lowest in grass litter, which corresponds with the Kjeldahl nitrogen content; no apparent differences were identified between the other tree species. Forest ecosystems handle this nutrient far better and maintain its cycle. No statistically significant differences in the content of total phosphorus were found; the grassland, though, showed the lowest content. On the other hand, potassium content was almost identical in all cases.

Total calcium content was significantly lowest in the holorganic layer of grass cover; in contrast, the litter and transformed organic matter under forest tree species showed higher contents – almost insignificantly in Douglas-fir (though significantly in comparison with Norway spruce), but significantly in the other two species. Total magnesium content was almost the same under grass cover as under Douglas-fir; it was statistically higher under Norway spruce and still higher under grand fir. It is fairly remarkable that, in view of the nutrient cycle (in total form), Douglas-fir did not show any significant characteristics of a soil improving tree species when on the surveyed site compared to Norway spruce, in contrast to grand fir.

The highest content of available phosphorus (Table 5) in the holorganic layer was under grass cover; the tree species differed insignificantly, though a descending order was traceable: grand fir, Norway spruce, Douglas-fir. In mineral soil, the differences were not convincing, though the lowest content was found in the mineral soil of grassland.

It was also the humus layer of grassland where the content of available potassium was the highest (in a multiple manner), as well as in the upper mineral layer. Deeper, the content of this nutrient was fairly equal. Of the forest tree species, Douglas-fir showed rather the lowest content.

Increased content of available calcium occurred under the forest tree species, quite prominently in the holorganic layer, especially under grand fir, where it was most abundant also in the mineral soil. The high-

Table 5. Content of plant available nutrients (P–Mg in mg·kg^{-1}) in the upper soil layer in the Hrubá Skála locality

Species	Horizon/depth (cm)	Mehlich III			
		P	K	Ca	Mg
Norway spruce	L–H	73.0[a]	443.0[a]	3097.0[b]	188.0[a]
	0–5	37.3[a]	96.3[a]	785.0[ab]	77.5[a]
	5–10	17.8[a]	69.8[a]	676.0[a]	78.8[a]
Grand fir	L–H	93.5[ab]	328.0[a]	5437.5[a]	264.0[ab]
	0–5	26.5[a]	89.3[a]	958.8[b]	91.5[a]
	5–10	18.5[a]	70.5[a]	741.5[a]	96.3[a]
Grassland	L–H	112.5[b]	1086.5[b]	1705.5[a]	369.5[b]
	0–5	16.3[a]	102.3[a]	584.5[a]	78.0[a]
	5–10	11.8[a]	69.0[a]	590.5[a]	70.0[a]
Douglas-fir	L–H	69.5[a]	339.0[a]	2224.5[ab]	169.5[a]
	0–5	31.5[a]	76.3[a]	602.3[a]	62.0[a]
	5–10	14.8[a]	53.3[a]	484.5[a]	59.8[a]

L–H indicates holorganic horizons (L+F+H), same letters indicate statistically homogeneous groups (the horizons of the same type were compared) est content of available magnesium was found in the humus layer of grassland. In mineral layers, the differences were statistically insignificant, though the highest content was observed under grand fir.

DISCUSSION AND CONCLUSION

The effects of introduced tree species on the forest soil quality (including afforested agricultural land) have been studied only marginally so far. Among authors outside the Czech Republic, it was e.g. Augusto et al. (2002, 2003), who proved a positive effect of Douglas-fir in comparison with Norway spruce. In the Czech Republic, Kacálek et al. (2007, 2013) supplied evidence of positive effects of deciduous tree species on the initial development of humus forms in mixed stands, also with the presence of Douglas-fir. Menšík et al. (2009) documented deterioration of the quality of humus forms (higher accumulation of humus, increased acidity) under Douglas-fir stands in comparison with beech, and – in contrast – improvement of the conditions compared to Norway spruce. Similar effects of this most important introduced tree species were documented also by other teams (Podrázský, Remeš 2008; Podrázský et al. 2010; Kubeček et al. 2014).

In just under 35 years, the agricultural land afforested by forest tree species showed quite noticeable changes, recorded also by other authors in earlier years (Kacálek et al. 2007, 2013). Very soon, a layer of surface humus was formed with properties significantly different from both arable land (Podrázský et al. 2010) and afforested grassland (Kacálek et al. 2013). The surface layer of grass cover contains a higher amount of live rhizomes and other plant tissues (turf) and mineral admixtures as well.

In the Hrubá Skála locality, a new layer of surface litter started to accumulate in the initial stages of transformation. In young stands (34 years), neither pronounced accumulation of surface humus nor significant differences between particular tree species occurred at that time. A substantial part of the primary production of surveyed coniferous tree species was still retained by the biomass of stands. On the other hand, pedo-chemical properties of surface humus and top ± 10 cm of mineral soil show significant changes. We observe higher humus content in deeper horizons and decrease of pH values approximating to typical forest stands. A rather low content of organic matter in grassland soil causes a lower content of bases, and also higher base saturation of adsorption complex. A beginning efficient nutrient cycle in forest tree species stands was reflected in increasing amounts of nutrients (though not always statistically significant) in the holorganic horizons. A fairly positive role of grand fir became evident, which was confirmed by other authors (Podrázský, Remeš 2008, 2009), even though grand fir belongs to the group of fast-growing tree species (Fulín et al. 2013) taking up a lot of nutrients from the soil to support their intensive growth.

Surprisingly enough, a prominent soil-improving function of Douglas-fir, documented in other localities (Podrázský et al. 2010), did not manifest itself on the surveyed nutrient-rich site. It might be caused by its intensive growth and fast-decomposing litter, together with its limited ability to efficiently use nutrients (Kubeček et al. 2014). Loss of nutrients and bases as a result of high nitrification and washout of nitrates with accompanying cations might also be the reason (Zeller et al. 2010), as well as fixation of nutrients in the biomass with rather slow return in the form of litter. A specific influence of the site, different from other case studies, can also affect the result.

The soil is slowly acquiring dynamics typical of forest soils and in the horizon of several decades we are likely to see the fully developed forest soil. The legacy of previous use of the land will probably remain traceable in at least one generation of commercial forest (Hatlapatková, Podrázský 2011; Kacálek et al. 2011). Nevertheless, both the introduced tree species, i.e. grand fir and Douglas-fir, showed a relatively more positive pedo-chemical effect on the afforested agricultural land in the initial stages, in comparison with Norway spruce. Due to the site character, grand fir had the more positive effect of the two on the studied locality. Introduced tree species are not probably going to be grown massively in Czech forests any time soon, but their planting – even on limited areas – is worth considering, given the results.

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