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ORIGINAL PAPER

Effects of Northern red oak (*Quercus rubra* L.) and sessile oak (*Quercus petraea* (Mattusch.) Liebl.) on the forest soil chemical properties

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Abstract

Northern red oak (*Quercus rubra* L.) is one of the most important introduced tree species in the Czech Republic, occupying about 6,000 ha with ca. 900,000 m^3 of the standing volume. The presented study aims to evaluate its soil forming effects on natural oak sites. Soil chemistry of the upper soil layers (F+H, A_h, B horizons) was studied in three pairs of stands of both species. In each stand, four bulk samples were taken separately for particular horizons, each consisting of 5 soil-borer cores. The soil characteristics analysed were: pH (active and potential), soil adsorption complex characteristics (content of bases, exchangeable cation capacity, base saturation), exchangeable acidity (exchangeable Al and H), total carbon and nitrogen content, and plant available nutrients content (P, K, Ca, Mg). Total macronutrient content (P, K, Ca, Mg) was analysed only in holorganic horizons. Results confirmed acidification effects of red oak on the upper forest soil layers such as decreased pH, base content, base saturation, all nutrient contents in total as well as plant-available form and increased soil exchangeable acidity (exchangeable Al) in comparison to the sessile oak stands, especially in holorganic horizons and in the uppermost mineral layer (A_h horizon). Northern red oak can be considered as a slightly site-soil degrading species in the studied sites and environmental conditions in comparison to native oak species.

Key words: red oak; sessile oak; humus forms; forest sites; pedochemical characteristics

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1. Introduction

Northern red oak (*Quercus rubra* L.) is one of the most important introduced tree species in many European countries, including the Czech Republic. It was planted for gardening purposes and especially for timber production on less favourable and degraded soils. Nowadays, it is recognized as an invasive alien plant very often and its valuation changed to negative one (Oosterbaan & Olsthorn 2005; Chmura 2013). Its stand area is about 6,000 ha with the growing stock of 900,000 m^3 in the Czech Republic according to summary forest management plans. The red oak area is like that of Douglas-fir even the latter species has higher growing stock (about 1,250,000 m^3) having lower mean age (Kouba & Zahradník 2011). It should be stressed that Douglas fir is the most productive species of all introduced species with site improving effects in the stands of domestic coniferous species (Podrázský et al. 2013, 2014; Kubeček et al. 2014; Pulkrab et al. 2014, 2015). On the other hand, northern red oak is a species quite common in parks and it is used for restoration of spoil banks. It is not understood as a species important for its production capacity only. The other interesting aspect is its resistance to tracheomycosis which is higher than of domestic oaks (Burkovský 1985; Gubka & Špišák 2010; Štefančík & Strmeň 2011). Dressel and Jäger (2002) recommend rather dry and acid sites as suitable or tolerable for northern red oak. Quite rare studies demonstrate higher wood production of red oak when compared to domestic oaks (Seidel & Kenk 2003; Kouba & Zahradník 2011). There is very limited evidence on the soil forming effects of this species comparing to native trees. The partial studies indicate no site improvement effects in European conditions, even slight soil degrading effects comparing to native broad-leaved species (Kantor 1989; Podrázský & Štěpáník 2002; Jonczak et al. 2015; Bonifacio et al. 2015). On the contrary, Northern red oak can significantly contribute to the afforestation of agricultural lands (Vopravil et al. 2015) due to its character of pioneer species.

The aim of the presented study is to evaluate the Northern red oak effects on the upper layers of forest soils in the stands of native Sessile oak (*Quercus petraea* (Mattusch.) Liebl.) and partly mitigate the lack of information on the effects of this species in the forest environment.

2. Material and methods

The study was performed in oak stands in the North-Western Bohemia. The area is a West part of the Natural Forest Area PLO 17 Polabí Lowland. Location of plots is given in the Table 1. The altitude of all plots varied between 220 – 330 m a.s.l. The investigated stands grow on comparable forest type: acid to medium rich oak and oak-beech sites (Viewegh 2003). Mean annual temperature of the area is 9 °C and mean annual precipitation 520 mm. The soil forming substrate is represented prevailingly by deep blown sands; this soil types of Arenic Cambisol (with gleying indices) developed prevailingly on this substrate (Němeček et al. 2011).

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There were three pairs of stands (red oak and sessile oak). In each stand, four bulk samples (distance ca. 50 m) were taken from particular horizons F+H, A_h, B. Each bulk sample consisted of 5 individual sampling cores (distance ca. 5 m) taken by soil borer of 6.5 cm diameter, separated for given horizons. Individual bulk samples were dried and analysed in the Laboratory Tomáš, Opočno, by standard methods (see e.g. Zbíral 2001; Špulák et al. 2016):

- Active and potential pH in H_2O and KCl respectively by potentiometric method,
- exchangeable acidity, content of exchangeable aluminium and hydrogen,
- sorption complex characteristics by Kappen (1929): S – base content, CEC – cation exchange capacity, BS – saturation of sorption complex by bases),
- content of total nutrients in holorganic horizons (N, P, K, Ca, Mg) after digestion with sulphuric acid and with selenium as a catalyst (Zbíral 2001),
- content of combustible matters, percentage of total oxidizable carbon (humus) and nitrogen was determined according to Kjeldahl methods, the combustible matter and Cox according to Springer-Klee method (e.g. Ciavatta et al. 1989; Kirk 1950),
- content of available nutrients (P, K, Ca, Mg) by Mehlich III method.

In each sampled stand, a bulk sample of the litter from the soil surface was collected, a part of it from particular cored points. Only content of total nutrients was determined for this material.

One way analysis of variance (ANOVA using software Statistica 12.1) was used after checking the normality of the data for soil analysis evaluation followed by post-hoc Tukey tests where corresponding horizons were compared on the usual level of significance ($p < 0.05$).

Table 1. Basic data on research plots of Northern red oak and sessile oak stands.

Species	Age [years]	Forest type	Elevation a.s.l. [m]	Latitude	Longitude
Red oak	49	1S6	276	50°21,575’	14°19,288’
	50	1K1	276	50°21,737’	14°19,398’
	103	1S6	300	50°22,172’	13°59,071’
Sessile oak	73	1S6	275	50°21,721’	14°19,964’
	111	1S6	280	50°22,228’	14°20,978’
	159	1C2	329	50°21,855’	13°58,966’

Notes: Forest types – 1 – oak vegetation altitudinal zone, 2 – beech-oak vegetation altitudinal zone, K – acid sites, S – medium rich sites, C – drying sensitive; third digit indicates more detailed forest type.

3. Results

There were documented differences between different soil horizons (F+H, A_h, B), in both set of stands, which is typical for the dynamics of forest soils. Differences in the studied characteristics between both species for the same soil layer were much less distinct. The pH/H_2O and pH/KCl in upper humus horizons and in horizons A_h, B under both species are given in Table 2. The pH/H_2O in humus layers under both species did not differ significantly; however, pH/KCl under red oak stand is significantly lower than under sessile oak in holorganic layer. There is a tendency of higher values of pH in F+H and A_h horizons while the values were practically identical in the B horizons.

Table 2. Soil reaction in particular horizons under red oak and sessile oak stands.

Horizon	pH/H_2O		pH/KCl	
	Red oak	Sessile oak	Red oak	Sessile oak
F+H	4.47 a	4.73 a	**3.53 a**	**3.94 b**
A_h	4.18 a	4.25 a	3.38 a	3.47 a
B	4.33 a	4.31 a	3.75 a	3.69 a

Note: The values with the same letter indicate no significant differences on the level ($p < 0.05$).

The exchangeable titration acidity was significantly higher in holorganic horizon under red oak as well as in organo-mineral horizon A_h (Table 3). The similar results show the Al^{3+} content. On the other hand, hydrogen content did not show significant differences under both species. The results suggest less favorable status of soils and tendency to acidification under red oak compared with sessile oak.

Table 3. Exchangeable acidity, hydrogen content and aluminium in particular horizons under red oak and sessile oak stands.

Horizon	Acidity		H^+ [meq kg^{-1}]		Al^{3+}	
	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak
F+H	**44.66 a**	**24.26 b**	9.70 a	8.69 a	**34.96 a**	**15.57 b**
A_h	**62.31 a**	**47.57 b**	2.20 a	2.75 a	**60.11 a**	**44.82 b**
B	49.78 a	41.42 a	1.20 a	1.07 a	48.58 a	40.35 a

Note: The values with the same letter indicate no significant differences on the level ($p < 0.05$).

Base content and base saturation are significantly higher in the holorganic horizons in the sessile oak stands. The same tendency was observed also in the organomineral A_h horizons; however, the differences were not significant. The significant differences were not pronounced in lower horizons (Table 4).

Table 4. Soil adsorption complex characteristics of the soil horizons under red oak and sessile oak stands.

Horizon	S [meq kg^{-1}]		CEC		BS [%]	
	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak
F+H	**27.39a**	**41.79b**	72.15 a	78.88 a	**37.35a**	**52.53b**
A_h	1.60 a	3.84 a	18.23 a	23.77 a	8.56 a	14.28 a
B	0.97 a	0.83 a	6.96 a	7.20 a	13.11 a	9.96 a

Note: The values with the same letter indicate no significant differences on the level ($p < 0.05$).

The content of combustible substances is lower under red oak but not significantly (Table 5). The same dynamics showed the total nitrogen and carbon content in the whole studied profile, the significant difference was documented for carbon in the Ah horizon while for nitrogen for both horizons A_h and B. This results in less favourable C/N ratio in the stands of red oak in all horizons (Table 5), even the differences were not significant.

Table 5. Total carbon and nitrogen content, its C/N ration and combustible substances in upper soil horizons under red oak and sessile oak.

Horizon	Total C ox [%]		Total N		C/N		Combustible substances [%]	
	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak
F+H	30.33 a	29.34 a	1.78 a	1.87 a	17.07 a	15.69 a	78.62 a	74.49 a
A_h	**6.46a**	**8.64b**	**0.40a**	**0.60b**	18.38 a	14.96 a	18.62 a	24.85 a
B	1.31 a	1.77 a	**0.09a**	**0.14b**	13.01 a	12.43 a	4.54 a	5.40 a

Note: The values with the same letter indicate no significant differences on the level ($p < 0.05$).

Plant available nutrient content is higher in the soil horizons under sessile oak in general (Table 6). For available phosphorus, statistically significant differences were found in the horizons F+H and A_h, for available potassium in the layers A_h and B, for available calcium and magnesium for F+H and A_h again.

Table 6. Plant available nutrient contents in particular horizons under red oak and sessile oak stands.

Horizon	P		K		Ca		Mg	
	[meq kg^{-1}]							
	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak
F+H	**29a**	**59 b**	744 a	1032 a	**2453 a**	**3964 b**	**443a**	**652b**
A_h	**3 a**	**13 b**	**108 a**	**201 b**	**280 a**	**527b**	**80a**	**127b**
B	3 a	2 a	**42 a**	**71 b**	263 a	280 a	59 a	67 a

Note: The values with the same letter indicate no significant differences on the level ($p < 0.05$).

The content of total nutrients was significantly higher in the horizon L under sessile oak with exception of calcium and magnesium (Table 7). The same trend was documented for F+H horizon for P and K, the differences were significant while the differences for N, Ca and Mg were not.

Table 7. Total nutrient content in the litter and F+H horizons under red oak and sessile oak.

Horizon	N		P		K		Ca		Mg	
	[%]									
	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak	Red oak	Sessile oak
L	**0.59a**	**0.80b**	**0.01a**	**0.03b**	**0.30a**	**0.43b**	1.15 a	1.24 a	0.15 a	0.16 a
F+H	1.70 a	1.80 a	**0.05a**	**0.07b**	**0.15a**	**0.21b**	0.19 a	0.38 a	0.05 a	0.06 a

Note: The values with the same letter indicate no significant differences on the level ($p < 0.05$).

4. Discussion and conclusion

Data concerning the effects of Northern red oak on forest soil are very limited. The data show distinct differences among the horizons which document the transformation of organic matter and changes of pedochemical soil characteristics typical for Cambisols (Němeček et al. 2011). Kantor (1989) compared the litter quality in the stands of different tree species in the Trutnov region. In contrast to other broadleaved species, especially to birch and alder, the litter quality of the red oak was not so high. This author groups red oak together with Scots pine as a species without site improving effects comparing to other broadleaved species (aspen, willow, beech, birch, alder). As the site degrading species were evaluated spruce species and Eastern white pine (*Pinus strobus* L.), which consists with our findings. Podrázský & Štěpáník (2002) studied the effects of particular tree species on afforested agricultural soils in the region of Český Rudolec. They compared the humus forms in the stands of red oak, birch, Norway spruce and European larch. Red oak did show more favorable effects on the new upper soil formation comparing to conifers (pH, soil adsorption complex characteristics, nutrient content), but less when compare to birch. The data suggests the red oak is more nutrient demanding, leading to decrease of nitrogen content under this species.

Also Bonifacio et al. (2015) documented slower litter decomposition and worsened nutrient dynamics under red oak stands. They demonstrated the accumulation of more extreme humus form (Mor instead of Dysmull-Hemimoder), slower litter decomposition and worsened phosphorus and calcium availability on natural site of English oak and well developed less fertile soils. Jonczak et al. (2015) studied the decomposition intensity of litter of different tree species (alder, beech, red oak, maple) using litter bags method. Alder produced leaf litter with the fastest decomposition, accelerating profoundly the nutrient dynamics, other broadleaves had very similar character of these processes. Comparing to our results, it can be concluded, that prominent site improving effects of the red oak on broadleaved species sites are not realistic. On the contrary, slight acidification effects can be expected comparing to native oaks. But red oak can play considerable stand forming and site improving role due to its resistance to extreme site conditions on degraded and devastated sites (Dimitrovský 1999, 2001; Kupka et al. 2007; Dimitrovský et al. 2008). Good growth of this species was confirmed also on abandoned agricultural lands, but protection against browsing is necessary in this case (Tužinský et al. 2015). These areas are relatively large throughout Europe, including the Czech Republic (Vopravil et al. 2015) and therefore the introduced species can play important role in this process (Podrázský et al. 2015, 2016). The evaluation of their effects on the soil ecosystem compartment can prevent many mistakes (Ehrenfeld 2003).

Significant effects of the red oak can be detected also on under storey vegetation. Its dynamic indicates more acid and nutrient poor sites with limited abundance of the nitrophilous vegetation. Also Kantor (1989) confirmed similar results for this species together with Scots pine. Straigyte et al. (2012) and Chmura (2013) described consistently the influences on the ground vegetation tending to more acid and nutrient poor sites. It is emphasized especially for lower nitrogen content in the soil, which is clearly indicated by the ground vegetation. They documented very good natural regeneration of the red oak, it can be considered as invasive one in many cases (Major et al. 2013).

Results confirmed visible negative effects of the Northern red oak on the sites, corresponding to the native sessile oak ecosystems. Higher acidity, lower soil reaction as well as bases and nutrient contents were documented in the holorganic and upper mineral soil horizons. In contrast to devastated soil remedial, this species can be considered as site degrading to some extent

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