

forstarchiv 80, 307–313
(2009)

DOI 10.237603004112-
80-307

© M. & H. Schaper
GmbH
ISSN 0300-4112
Korrespondenzadresse:
dirk.berthold@wki.
fraunhofer.de

Eingegangen:
06.08.2009

Angenommen:
30.10.2009

Effects of cultivating black locust (*Robinia pseudoacacia* L.) on soil chemical properties in Hungary

DIRK BERTHOLD¹, TORSTEN VOR² and FRIEDRICH BEESE¹

¹Department of Soil Science of Temperate and Boreal Ecosystems, University of Göttingen, Büsgenweg 2, 37077 Göttingen, Germany

²Department of Silviculture and Forest Ecology of the Temperate Zones, University of Göttingen, Büsgenweg 1, 37077 Göttingen, Germany

Abstract

Due to its symbiotic N₂ fixation, black locust (*Robinia pseudoacacia* L.) may improve the N and C status of soils. On the other hand it may also cause losses of cations and acidification through enhanced proton production by nitrification and leaching. The humus layer and the mineral soil to a depth of 50 cm at four different forest sites in Hungary dominated by *Robinia* were studied for their chemical properties in comparison with those under adjacent planted oak stands (*Quercus cerris* L. and *Quercus pubescens* Willd.). Elevated biomass accumulation resulted in significantly higher C, N, P and S contents of the forest floor under *Robinia*. A significant decrease in soil pH under black locust stands compared to oak stands was detected in the mineral soil. Higher proton concentrations as well as lower Mg²⁺ concentrations under black locust stands confirmed the hypothesis of nutrient depletion and acidification by cultivation of this tree legume. However, due to high variation of inventory data at the landscape level, the effects of black locust cultivation on soil chemical properties were less pronounced. In contrast, a comparison of several paired stands of locust and oak under comparable soil chemical environments showed that the spatial heterogeneity in soil properties was reduced. In addition, processes of soil degradation through black locust forests became more distinct. Another important aspect influencing the magnitude of soil degradation by N fixing trees is the continued cultivation at the same place. Soils under *Robinia* stands of the second generation showed significantly higher concentrations of H⁺ and Al³⁺ than those of the first generation forests. The impact of longer *Robinia* cultivation resulted in 70% higher Al³⁺ concentrations in soils of the second tree generation. Moreover, acid-indicating H⁺ concentrations were approximately 100% higher, and Fe³⁺ concentrations were 350% higher under second generation *Robinia*.

In spite of the observed changes in the chemical status of the Hungarian soils under *Robinia*, we do not expect severe reductions in tree growth caused by acidification and nutrient losses, even after repeated cultivation on the same site. However, sites with lower base saturation may suffer more under nutrient depletion caused by N fixation of *Robinia*. This possibility should be taken into account when considering the introduction of *Robinia pseudoacacia* as an alternative tree species with high growth rates even on nutrient poor soils.

Key words: acidification, black locust, N₂ fixation, *Robinia pseudoacacia* L., soil degradation, spatial heterogeneity

Introduction

Black locust, *Robinia pseudoacacia* L., is a nitrogen-fixing tree, native to south-eastern North America (Barett et al. 1990) where it grows in two disjunct areas between the 35° and 43° latitude (Little 1971, Fowells 1965, Huntley 1990). Worldwide, the land area covered by black locust plantations has increased in recent decades and is about 3 Mio. ha, only exceeded by species of *Eucalyptus* and *Populus* (Hanover et al. 1991). China (1 Mio. ha) and South Korea (0.5 Mio. ha) are the main world producers of black locust timber (Rédei 1998, Claasen 2001). In Hungary the area under black locust stands has increased from 201,000 ha in 1958 to 320,000 ha in 1994 and will increase by another 40,000 ha in the next twenty years (Molnár et al. 1994). The reasons for cultivating *Robinia pseudoacacia* are, 1) erosion control and reclamation of disturbed areas (Boring and Swank 1984a, Chang-Seok et al. 2003), 2) its tolerance against drought, 3) its excellent wood properties, and 4) its ability to fix atmospheric nitrogen (DeGomez and Wagner 2001). It is easy to regenerate from root suckers, grows efficiently on poor sites and improves nitrogen supply and element turnover (Ntayombya and Gordon 1995). Depending on stand age and density as well as on climatic conditions *Robinia* fixes 35–150 kg N ha⁻¹ a⁻¹, indicating a high capacity for N₂ fixation (Hoffmann 1960, Boring and Swank 1984b, Danso et

al. 1995). This amount of fixed N may exceed the demand for tree growth. The excess of nitrogen can either accumulate in the soil or is lost through leaching of nitrate or denitrification in case of soil N saturation. Nitrification and subsequent leaching cause soil acidification and loss of base cations (van Migroet and Cole 1984). Especially after clear cutting, the N accumulated in the organic matter undergoes fast release. After nitrification ground water contaminating nitrate together with nutrient cations can be leached (Feller et al. 2000, Piirainen et al. 2002, Prescott et al. 2003). Such processes have been described for legume forage crops and other N fixing tree species, such as red alder, *Alnus rubra* Bong. (Franklin et al. 1968, Bormann and DeBell 1981, van Migroet and Cole 1985, Binkley 1992).

Despite the large area planted with black locust, there is little information on the changes in soil properties and any effects on the sustainability of wood production in black locust stands. The growth of black locust has been observed and reported by foresters to decline when cultivated for several generations on the same site. But the reasons for this phenomenon were never analysed. Our main objective was to determine the impact of black locust cultivation on soil properties, with emphasis on N, C, pH as well as cations of the organic layer and mineral soil. For that purpose soils from black locust stands in Hungary have been compared with adjacent oak stands. Furthermore the effects of long-term growth of black locust on the same soil after two tree generations were investigated.



Figure 1. Geographic location of the selected forest regions of Hungary.

Material and Methods

Study sites and soils

To cover a wide range of soil and climatic conditions, pure stands of planted black locust and planted stands of two oak species, *Quercus cerris* L. and *Quercus pubescens* Willd., were selected from four different forest regions in Hungary: Site 1 (Pusztavács), Site 2 (Baktalóránthaza), Site 3 (Nagyatád) and Site 4 (Iván). The map of Hungary shows the regional distribution of the selected forest sites (Figure 1).

Geologically the sites are located in The Great and in The Little Hungarian Plain. The Great Hungarian Plain or Pannonian Plain is a Quaternary sedimentary basin containing fluvial sediments. Eolian transport has also been active and there are large loess and wind-blown sand deposits. Its boundaries are the Carpathians in the north and east, the Transdanubian Medium Mountains and Croatian Mountains in the southwest, and approximately the Sava River in the south. The Little Hungarian Plain is located in north-western Hungary, south-western Slovakia and eastern Austria. It is part of the Pannonian Plain which covers most parts of Hungary. The Little Hungarian Plain is a tectonic basin between the eastern periphery of the Alps and the Carpathians, filled with marine and fluvial sediments in the last 20 million years.

The selection of the sites was carried out in collaboration with the Institute of Soil Science of the Hungarian University of Sopron and the local Forest Departments. A total of 11 stands was analysed (6 black locust and 5 oak stands). All sites were characterized by low annual precipitation and high mean annual temperatures (Table 1). The dominant soil types were determined as sandy Cambisols. The sizes of the forest sites ranged between 3.0 and 30.0 hectares. The undergrowth of all stands was sparsely developed. Under black locust stands some nitrophilous species (*Urtica dioica*, *Chelidonium majus* and *Linum catharticum*) occurred, whereas in most oak stands no shrubs or herbaceous plants were present.

Soil sampling and analysis

At each site four plots were chosen randomly. In each plot, undisturbed humus and soil samples were taken, to a depth of 50 cm, in each of three replicates, resulting in 12 replicates for each site. Soil cores were subdivided into 10 cm intervals. Samples were taken from the black locust sites and the adjacent oak sites in the same way. The samples were dried at 40 °C (mineral soil) or 60 °C (organic layer), sieved (2 mm) and ground. The total C and N contents of the forest floor and mineral soil were analysed by dry combustion (C/N analyser; Vario Elementar Analysensysteme, Hanau, Germany). Total concentrations of P, S, K, Ca and Mg were determined using ICP-AES (Spectro Analytic Instruments, Kleve, Germany) after pressure digestion of samples in 65% concentrated HNO₃. Soil samples (2.5 g sieved material) were percolated with 1 N NH₄Cl and exchangeable cations (Na⁺, K⁺, Ca²⁺, Mg²⁺, Mn²⁺, Fe³⁺, Al³⁺) and analysed (ICP-AES 300 AA; Varian Inc., Darmstadt, Germany). The pH was measured with a digital pH-meter (WTW GmbH, Wesel, Germany) in 0.1 mol l⁻¹ KCl.

The long-term impact of black locust cultivation was investigated by comparing soil chemical (N status, pH, exchangeable cations) parameters between stands of first and second generation, continuously cultivated with that tree species. Black locust stands of the second generation were regenerated through stem sprouts and root suckers after clear cutting. According to Fuehrer (2005) rotation periods of Hungarian *Robinia* stands vary from 20 to 40 years. The black locust stands of the second generation in our study were established after a rotation period of 46 to 52 years. When conducting the research stands of the first tree generation were 40 to 50 years old (mean 45 years), whereas the age of the second generation stands ranged between 26 and 36 years (mean 31 years).

Analysis of variance (ANOVA) was performed by the program STATISTICA version 6.0 and the means were tested by the Mann-Whitney U-Test at $p < 0.05$ level.

Table 1. Comparison of the climatic and soil conditions of the four forest regions of Hungary.

Site	Elevation (m)	Precipitation annual/growth period (mm)	Temperature annual/growth period (°C)	Period of sunshine (hours/year)	Soil type
Site 1 (Pusztavács)	100-150	500/320	10.3/17.3	2050	sandy Cambisols
Site 2 (Baktalóránthaza)	100-150	570/350	9.7/17.1	1970	sandy Cambisols
Site 3 (Nagyatád)	100-150	760/460	9.9/16.2	1990	sandy Cambisols
Site 4 (Iván)	200	630/360	9.6/15.8	1860	loamy Cambisols (pseudogleyification)

Table 2. Comparison of mean (\pm standard deviation) dry mass of the organic layers, bulk density of the mineral soils and C, N, P and S pools (n = number of stands investigated).

Stand Type	Organic layer					Mineral soil (0-50 cm)				
	dry mass (kg m ⁻²)	C (t ha ⁻¹)	N (t ha ⁻¹)	P (kg ha ⁻¹)	S (kg ha ⁻¹)	bulk density (g cm ⁻³)	C (t ha ⁻¹)	N (t ha ⁻¹)	P (t ha ⁻¹)	S (t ha ⁻¹)
Black locust ($n = 6$)	5.4 ^a ± 3.1	8.3 ^a ± 4.7	0.6 ^a ± 0.3	31 ^a ± 17	59 ^a ± 30	1.2 ^a ± 0.1	32.9 ^a ± 18.8	3.0 ^a ± 1.7	1.4 ^a ± 0.2	0.83 ^a ± 0.74
Oak ($n = 5$)	2.8 ^b ± 1.7	4.7 ^b ± 3.1	0.3 ^b ± 0.2	19 ^b ± 11	27 ^b ± 22	1.3 ^a ± 0.1	33.4 ^a ± 9.2	2.7 ^a ± 1.0	1.4 ^a ± 0.4	0.88 ^a ± 0.54

Values denoted with different letters ^{a,b} are significantly different ($p < 0.05$, Mann-Whitney U-Test)

Results and Discussion

Overall comparison of soil properties

Besides the vegetation the forest floor is the most important storehouse for C and N (Table 2). The mean dry mass under black locust stands (5.4 kg m⁻²) was significantly higher than under oak stands (2.8 kg m⁻²). This elevated accumulation of organic matter resulted in significantly higher pools of total C, N, P and S. However, the total C pools in the organic layers (8.3 in locust and 4.7 t C ha⁻¹ in oak stands) were relatively low due to C concentrations of only 16-20%. Bulk density, concentrations and contents of C, N, P, and S of mineral soils on average did not differ among the two stand types. Total amounts of these elements (from the organic layer to 50cm depth per hectare) under black locust stands were 41.2 t C, 3.6 t N, 1.4 t P and 0.8 t S, compared to 38.1 t C, 3.0 t N, 1.4 t P and 0.9 t S under oak stands.

In previous soil inventories under different tree species (spruce, beech and pine stands) in Lower Saxony, Northern Germany, Berthold and Beese (2002) found 12-50 t C ha⁻¹ stored in the organic layer. For black locust stands in eastern Germany, Goldacker (2002) reported 9-19 t C ha⁻¹ and 0.7-1.2 t N in the litter layer. These values are similar to those obtained in the present study. Due to better climate and soil conditions, the Hungarian sites are generally characterized by intense biological activity and fast mineralisation of the organic matter (Dénes 1988). Therefore, humus layers are mostly very shallow and element stocks are relatively low. Considering 1.2 to 2.6 t N ha⁻¹ in the mineral soils under black locust stands in eastern Germany (Goldacker et al. 2002) and 2.7 to 3.0 t ha⁻¹ of stored N in the Hungarian soils, the amounts in the soils of both regions appear

to be very low. This result may be due to low N fixation and/or high mineralisation rates of organic N due to coarse texture and favourable climatic conditions. It is well established that the mineralisation of organic matter is generally more rapid in sandy, coarse-textured soils than in loamy, fine-textured soils (Strong et al. 1999).

Elevated amounts of organic matter in black locust soils, despite the favourable C/N ratios (Figure 2) and favourable climatic conditions, indicate reduced decomposability of the black locust litter. White et al. (1988) found that *Robinia pseudoacacia* leaflets after 863 days of decomposition still contained 81% of their original N. They concluded that this retention of N is caused by the greater potential to form stabilized fractions during decomposition. According to Berg and McClaugherty (2003) it is not the lignin content *per se* that is retarding the N mineralisation rate, but lignin in combination with high N concentrations. Significantly lower C/N ratios in black locust stands than in oak stands were observed for the forest floor and for the upper (0-30 cm) of mineral soil (Figure 2). This fact confirms the results mentioned above.

In the mineral soils down to 40 cm, pH values under black locust stands were significantly lower by approximately 0.2 units (Figure 3), supporting the hypothesis of enhanced acidification.

The percentage of M_a-cations also shows an increase in the upper part of the soils but is less pronounced in the deeper part (Table 3). All measured parameters are characterized by a high variability and the results do not differ significantly. However, consistency in the trends observed for different parameters is evident.

We present in Figure 4 the mean pH_{KCl} values, N stocks and the percentage of acid cations (M_a) for the compared adjacent locust and oak stands at the four inventory sites. Comparing the pairs of locust

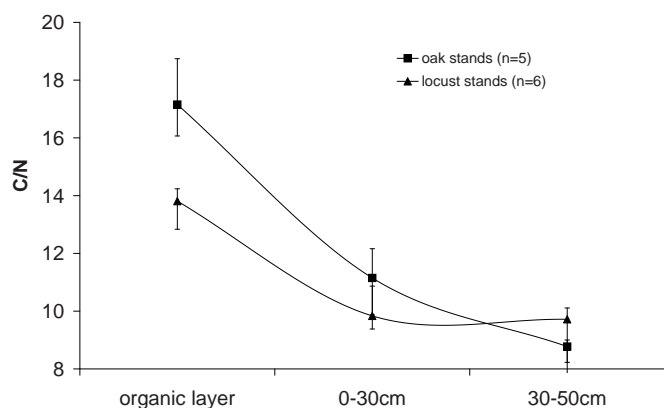


Figure 2. Comparison of C/N ratios under black locust and oak stands; n = number of stands; values are presented as median with quartiles (Q25, Q75).

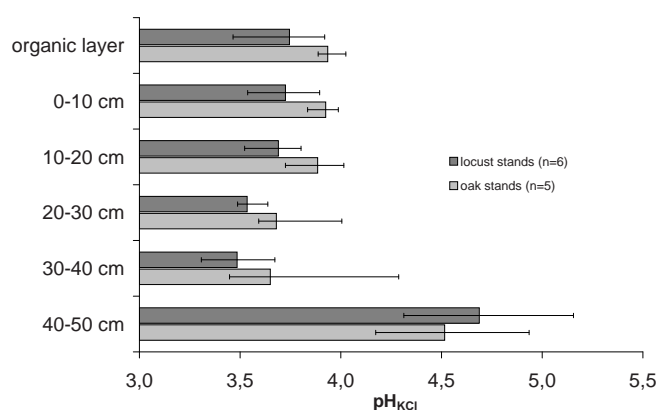


Figure 3. Comparison of pH_{KCl} values in the organic layer and mineral soils; values are presented as medians with quartiles (Q25, Q75).

Table 3. Comparison of mean (\pm standard deviation) cation exchange capacity (CEC_e), exchangeable base ($M_b \sum Na^+ K^+ Ca^{2+} Mg^{2+}$) and acid cations ($M_a \sum H^+ Mn^{2+} Fe^{3+} Al^{3+}$) in the mineral soils under black locust and oak stands. Significantly different values ($p < 0.05$) between stand types within the same depth are denoted by different letters (^{a, b}).

Stand type	Soil depth (cm)	CEC_e ($\mu mol_c g^{-1}$)	M_b and M_a (%)					
			Ca^{2+}	Mg^{2+}	H^+	Al^{3+}	M_b	M_a
Locust stands (n = 6 stands)	0-30	34.9 ^a ± 18.8	37.6 ^a ± 25.1	6.8 ^a ± 4.3	6.3 ^a ± 5.6	41.4 ^a ± 25.5	48.5 ^a ± 28.5	51.5 ^a ± 28.5
	30-50	59.9 ^a ± 58.4	44.7 ^a ± 29.7	8.9 ^a ± 5.2	2.1 ^a ± 2.2	38.8 ^a ± 31.0	57.1 ^a ± 33.2	42.9 ^a ± 33.2
Oak stands (n = 5 stands)	0-30	33.6 ^a ± 12.5	38.7 ^a ± 24.4	9.2 ^b ± 5.6	4.2 ^b ± 4.3	38.6 ^a ± 25.8	52.2 ^a ± 29.4	47.8 ^a ± 29.4
	30-50	31.8 ^a ± 16.4	40.9 ^a ± 27.8	12.3 ^b ± 7.9	1.8 ^a ± 2.2	39.1 ^a ± 31.9	57.0 ^a ± 34.4	43.0 ^a ± 34.4

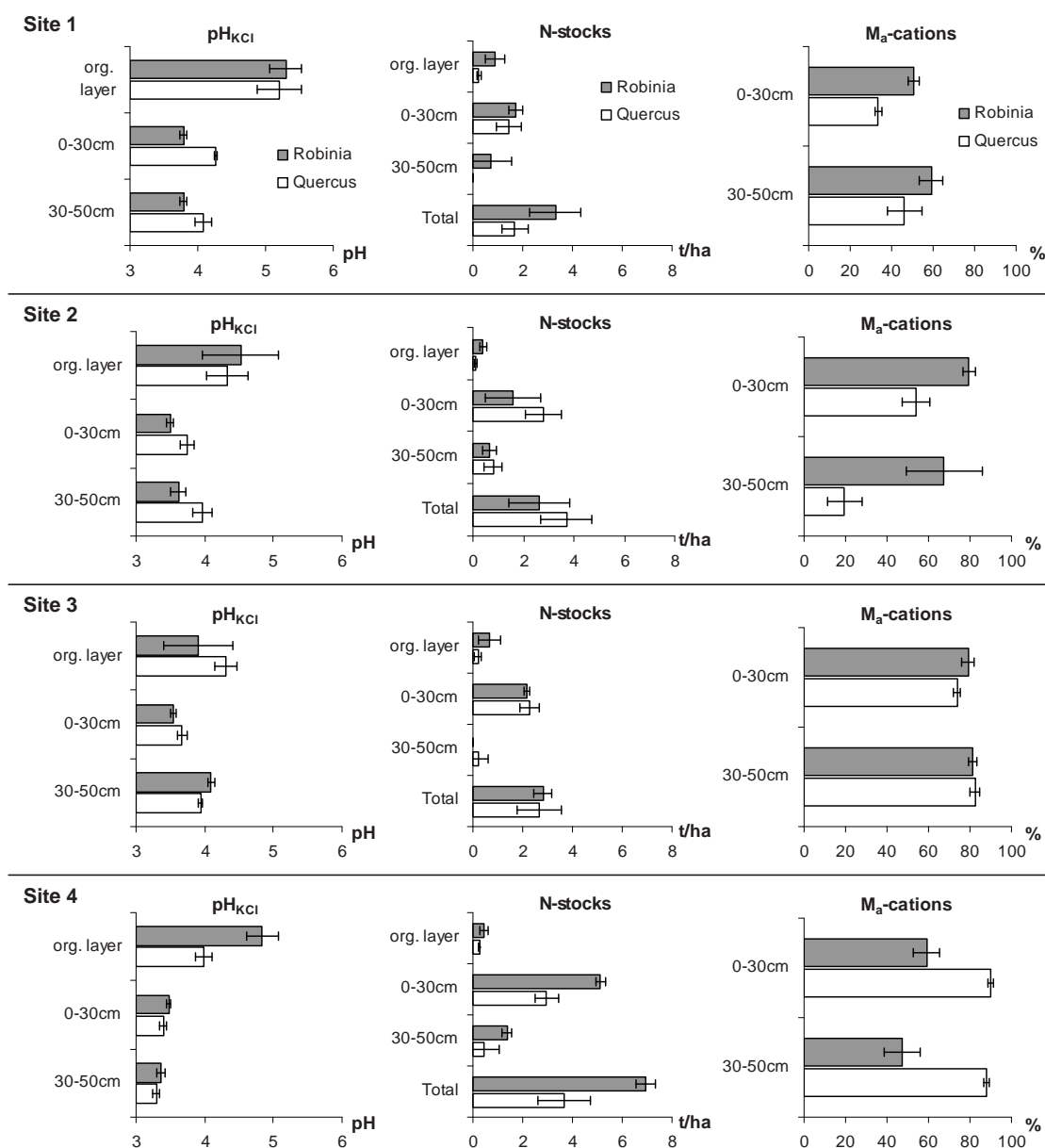


Figure 4. Comparison of mean (\pm standard deviation) pH_{KCl} values, N-stocks, exchangeable base (M_b) and acid cations (M_a) for paired stands of Hungarian forest sites: Site 1 (Pusztavács), Site 2 (Baktalórántháza), Site 3 (Nagyatád) and Site 4 (Iván); n = 12 replicates per horizon.

and oak stands on single sites, the situation is more complicated. And due to the specific site conditions the reaction patterns are different and have to be regarded separately. For all pairs (black locust and adjacent oak stands) the N accumulation in the organic layer under black locust was significantly higher than that under oak. On average 0.6 t N ha^{-1} were stored in the litter layer under black locust compared to 0.2 t N ha^{-1} in oak stands.

At sites 1 and 4 (Pusztavács and Iván) significantly elevated nitrogen accumulation was found in the mineral soil and the whole profile (Total = summation of all layers) under *Robinia*. From the humus layer down to 50 cm in the mineral soil approximately twice as much N (3.3 t and 6.9 t N ha^{-1} , respectively) was stored under stands of *Robinia* than under *Quercus*. Significantly lower pH values (mean 0.3 units lower) and higher concentrations of acid cations (M_a) in the mineral soils under black locust were found for adjacent stands at Pusztavács (Site 1), Bakalóránthazá (Site 2) and Nagyatád (Site 3). These results indicate that acidification and nutrient depletion occur through black locust cultivation. The changes were strongest in the main rooting zone. By comparing the average base saturation of 30% (variance 20 to 49%) in the upper soils (0-30 cm) under black locust with the average base saturation of 46% (variance 26 to 67%) under adjacent oak stands, the hypothesis of nutrient depletion by *Robinia* cultivation was confirmed. Site 4 was an exception. Due to differences in soil texture a significantly higher base saturation (44% M_b cations) under black locust and higher concentrations of M_a cations (H^+ , Fe^{3+} , Al^{3+}) under oak (89% M_a cations) were found. Despite significantly higher nitrogen accumulation under the *Robinia* stand no differences in acidification were detected.

Effects of growing black locust for successive generations

A decline in growth after repeated cultivation of *Robinia pseudoacacia* at the same place has been observed for stands in Hungary and eastern Germany by the local forest departments. It was hypothesised that long-term cultivation of black locust on the same site will cause chemical soil degradation. To analyse the effect of long-term growth of *Robinia* on chemical soil parameters, sites with stands of the first and second tree generation – continuously occupied by black locust stands – were compared. The two stands of the first tree generation were located in Pusztavács and Bakalóránthazá; stands of the second

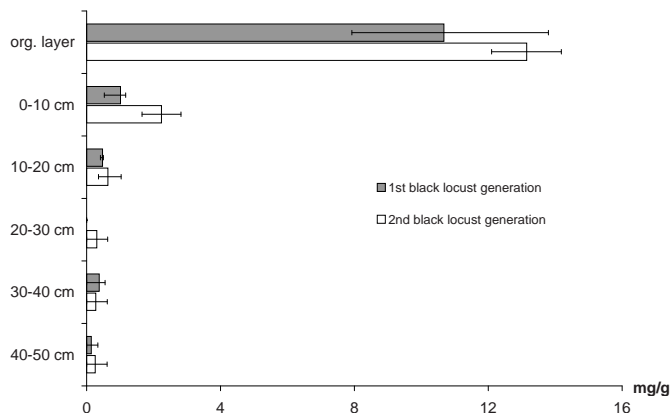


Figure 5. Comparison of mean nitrogen concentrations under black locust stands with their influence compared over the first and second generations. Values are presented as medians with quartiles (n = number of stands; 12 replicates per horizon).

tree generation (one stand per site) were located in Nagyatád and Iván. Forests of the second generation were established by clear cutting and regeneration by stem sprouts and root suckers. On average stands cultivated with *Robinia* of the first generation were 45 years old, whereas places with the second tree generation were affected for 80 years by black locust growth.

The accumulated organic matter in the forest floor of the second tree generation was low compared to that of the first generation (450 kg and 590 kg N ha^{-1} , respectively) due to higher decomposition rates during forest regeneration. But N concentrations in the humus layers and mineral soils under the second generation stands were higher (Figure 5), resulting in higher N accumulation in the soils under *Robinia* of the second tree generation. The mean total amount stored in soils (organic layer to 50 cm) under locust stands of the first and second tree generations was 2.9 t and 4.9 t N ha^{-1} , respectively (data not shown).

With increasing time of locust growth on the same site, an increase of exchangeable M_a cations (H^+ , Al^{3+} , Mn^{2+} and Fe^{3+} ions) and a decrease of pH occurred (Figures 6 and 7). The detected concentrations of exchangeable Al^{3+} did not change with increasing soil depths,

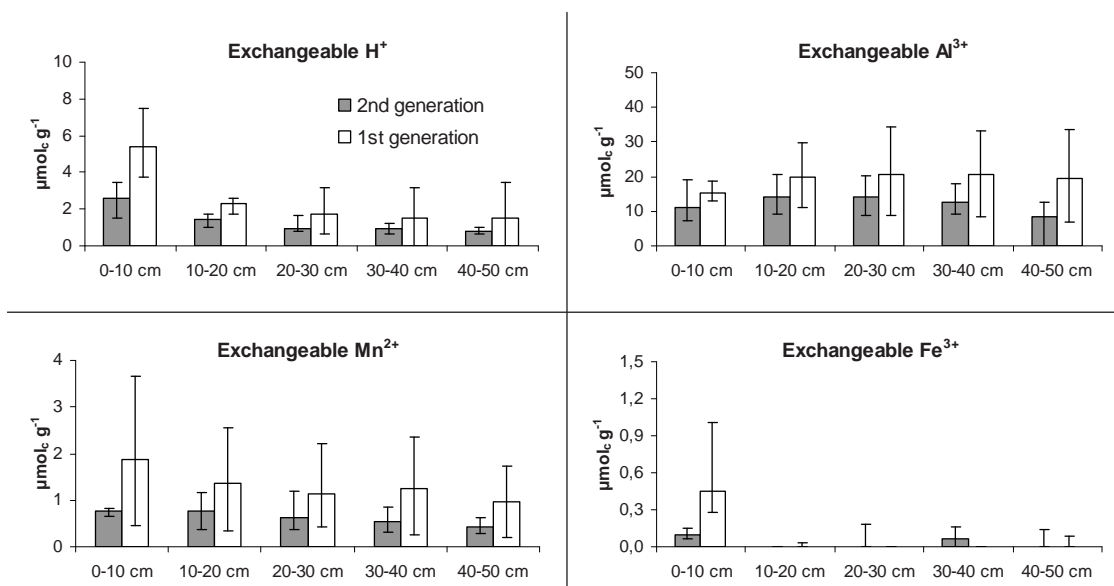


Figure 6. Comparison of mean concentrations of exchangeable H^+ , Al^{3+} , Mn^{2+} and Fe^{3+} under black locust stands of the first and second tree generations. Values are presented as medians with quartiles (n = number of stands; 12 replicates per horizon).

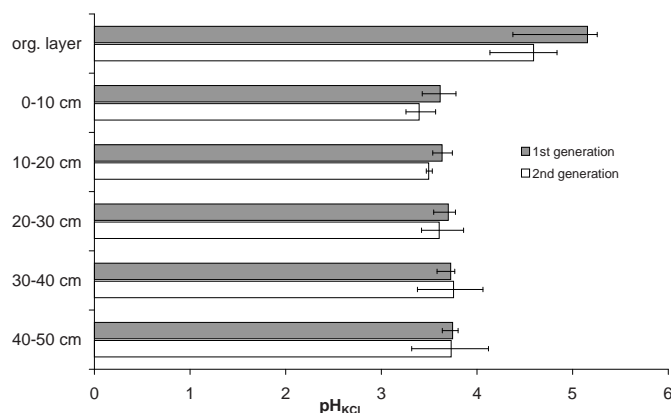


Figure 7. Comparison of mean pH_{KCl} values under black locust stands of the first and second tree generations. Values are presented as medians with quartiles (n = number of stands; 12 replicates per horizon).

whereas H^+ , Mn^{2+} and Fe^{3+} concentrations were significantly higher in the top soils of these sites. On average over the whole soil profile, $12 \mu\text{mol}_c \text{Al}^{3+} \text{g}^{-1}$ were measured under locust stands of the first and $20 \mu\text{mol}_c \text{Al}^{3+} \text{g}^{-1}$ under stands of the second generation. The impact of longer *Robinia* cultivation resulted in an approximately 70% higher Al^{3+} concentrations in soils of the second tree generation. Differences concerning H^+ and Fe^{3+} concentrations between stands of the first and second locust generation were most obvious in the soil depth of 0 to 10 cm. In these horizons, acid-indicating H^+ concentrations were approximately 100% higher, and Fe^{3+} concentrations were 350% higher under second generation *Robinia* (5.4 to $2.6 \mu\text{mol}_c \text{H}^+ \text{g}^{-1}$ and 0.45 to $0.1 \mu\text{mol}_c \text{Fe}^{3+} \text{g}^{-1}$, respectively). For the other horizons, differences were less pronounced. On average $2.5 \mu\text{mol}_c \text{H}^+ \text{g}^{-1}$ and $0.1 \mu\text{mol}_c \text{Fe}^{3+} \text{g}^{-1}$ were present in the soils of the second generation compared to $1.3 \mu\text{mol}_c \text{H}^+ \text{g}^{-1}$ and $0.03 \mu\text{mol}_c \text{Fe}^{3+} \text{g}^{-1}$ in the first generation. Concerning exchangeable Mn^{2+} , soils under black locust stands of the second tree generation had 100% higher concentrations than those under first generation stands (1.3 to $0.6 \mu\text{mol}_c \text{Mn}^{2+} \text{g}^{-1}$ respectively). The highest Mn concentrations were found in the upper soil horizons compared to lower horizons (1.9 to $0.8 \mu\text{mol}_c \text{Mn}^{2+} \text{g}^{-1}$, respectively). The profiles show a plausible pattern; however, due to high within-horizon variation the differences were not always significant.

Simultaneously, and compared to lower horizons, the base saturation decreased for the most mineral surface soils. These findings confirm the effects of *Robinia*, an N fixing tree, on chemical properties, especially in the surface mineral soil horizons, as reported by others (Franklin et al. 1968, Bormann et al. 1981, van Migroet and Cole 1985, Binkley 1992).

The increase in exchangeable H^+ and Al^{3+} ions after two generations of cultivation of black locust did not result in a similar decrease of pH values (Figure 7), because the pH value only represents a part of the acidity stored in the soil. However, soils from sites under second generation stands of black locust showed lower pH values. These values were based on measurements in 0.1 Mol KCl in the organic layer (0.6 units) and the upper part of the mineral soil; significant differences only were observed in the 10 to 20 cm (0.3 units) depth.

Conclusions

The study of soils under *Robinia pseudoacacia* stands showed clear trends of increases of soil N via symbiotic nitrogen fixation. This resulted in increasing soil acidification and loss of base cations. Compared to the effects of *Robinia* cultivation on more acidified soils (Berthold and Beese 2002, Goldacker et al. 2002), the impact on the Hungarian soils is less severe. The generally higher base saturation and buffer capacity of these soils are the main reasons for the less pronounced effects on soil chemical properties by black locust cultivation. However, after two generations of *Robinia* growth on the same site, negative effects on soil chemical properties are strongly pronounced. The data also demonstrate that a general pattern does not exist. Each site was responding differently to black locust cultivation, although the reasons are not clear. In spite of the observed changes in the chemical status of the Hungarian soils under *Robinia*, we do not expect severe reductions in tree growth caused by acidification and nutrient losses, even after repeated cultivation on the same site. The growth reductions observed in Hungary after continuous cultivation of black locust on the same site must have other reasons than chemical changes and/or acidification of the soil. Biotic factors, i. e. pathogens may play a dominant role, as this is well known from long-term cultivation of agricultural legumes (Bødker et al. 1993, Laszlovszky-Zmarlicka et al. 1998, Levenfors 2003).

However, sites with lower base saturation may suffer more under nutrient depletion caused by N fixation of *Robinia*. This risk should be taken into account when considering the introduction of *Robinia pseudoacacia* as an alternative tree species on nutrient poor soils.

References

- Barrett R.P., Mebrahtu T., Hanover J.W. 1990. Black locust: a multi-purpose tree species for temperate climates. In: Janick J., Simon J.E. (eds.) Advances in new crops. Timber Press, Portland, OR, 278-283
- Berg B., McClaugherty C. 2003. Plant litter. Springer, Berlin
- Berthold D., Beese F. 2002. Carbon storage in soils after afforestation in relation to management practices. Forst und Holz 57, 417-420
- Binkley D. 1992. Mixtures of nitrogen-fixing and non-nitrogen-fixing tree species. In: Cannel M.G.R., Malcolm D.C., Robertson P.A. (eds.) The ecology of mixed-species stands of trees. Black Scientific Publications, Oxford, 99-123
- Bødker L., Leroul N., Smeddegaard V. 1993. The occurrence in Denmark of black root rot of pea caused by *Thielaviopsis basicola*. Plant Pathology 42, 820-823
- Boring L.R., Swank W.T. 1984a. The role of black locust (*Robinia pseudoacacia* L.) in forest succession. Journal of Ecology 72, 749-766
- Boring L.R., Swank W.T. 1984b. Symbiotic nitrogen fixation in regenerating black locust (*Robinia pseudoacacia* L.) stands. Forest Science 30, 528-537
- Bormann B.T., DeBell D.S. 1981. Nitrogen content and other soil properties related to age of red alder stands. Soil Sci. Soc. Am. J. 45, 428-432
- Chang-Seok L., Hyon-Je C., Hoonbok Y. 2003. Stand dynamics of introduced black locust (*Robinia pseudoacacia* L.) plantation under different disturbance regimes in Korea. Forest Ecology and Management 189, 281-293
- Claasen A. 2001. Stichting Robinia. Wageningen, Netherlands, unpublished report
- Danso S.K.A., Zapata F., Awonaike K.O. 1995. Measurement of biological N_2 fixation of field-grown *Robinia pseudoacacia* L. Soil Biol. Biochem. 27, 415-419
- DeGomez T., Wagner M.R. 2001. Culture and use of black locust. Hort-Technology 1, 279-288
- Dénes L. 1988. Land evaluation studies in Hungary. Studies in geography in Hungary 23. Akad. Kiadó, Budapest
- Feller M.C., Lehmann R., Olanski P. 2000. Influence of forest harvesting intensity on nutrient leaching through soil in southwestern British Columbia. J. Sustain. For. 10, 241-247
- Fowells H.A. 1965. Silvics of forest trees of the United States. Department of Agriculture, Forest Service, Washington, D.C., USA

- Franklin J.F., Dyrness C.T., Moore D.G., Tarrant R.F. 1968. Chemical soil properties under coastal Oregon stands of alder and conifers. Forestry Sciences Laboratory, Pacific N.W. Forest and Range Experiment Station Corvallis, Oregon, USA
- Fuehrer E. 2005. Robinienwirtschaft in Ungarn – I. Die Robinie im praktischen Waldbau. Forst und Holz 60, 464-466
- Goldacker S. 2002. Veränderungen des bodenchemischen Zustandes durch die stickstofffixierende Baumart Robinie. Diploma thesis, Georg-August-University Göttingen, Germany, unpublished
- Goldacker S., Berthold D., Beese F. 2002. Bodenversauerung unter Robinie. AFZ/Der Wald 57, 1003-1006
- Hanover J.W., Mebrathu T., Bloese P. 1991. Genetic improvement of black locust: a prime agroforestry species. Forestry Chronicle 67, 227-231
- Hoffmann G. 1960. Untersuchungen über die symbiontische Stickstoffbindung der Robinie (*Robinia pseudoacacia* L.). Doctorial Thesis at the Faculty of Forestry, Humboldt-University, Berlin, Germany
- Huntley J.C. 1990. *Robinia pseudoacacia* L. In: Silvics of North America, Vol. 2, Hardwoods, 755-761
- Laszlovszky-Zmarlicka A., Cieslinski G., Smolarz K., Utkhede R., Veghelyi K. 1998. Replant problems in strawberry production. Acta Horticulturae 477, 131-133
- Levenfors J. 2003. Soil-borne pathogens in intensive legume cropping – *Aphanomyces* spp. and root rots. Doctoral thesis, Swedish University of Agricultural Science, Uppsala
- Little E.L. Jr. 1971. Atlas of United States trees, Vol. 1.: Conifers and important hardwoods. U.S. Department of Agriculture, Miscellaneous Publication 1146. Washington DC, USA
- Migroet H. van, Cole D.W. 1984. The Impact of nitrification on soil acidification and cation leaching in a red alder ecosystem. J. Environ. Qual. 13, 586-590
- Migroet H. van, Cole D.W. 1985. Acidification sources in red alder and Douglas fir soils – Importance of Nitrification. Soil Sci. Soc. Am. J. 49, 1274-1279
- Molnár S., Lang M., Molnár-Posch P. 1994. Das Robinienholz als Rohstoff der Zukunft. Holzforschung und Holzverwendung 1, 107
- Ntayombya P., Gordon, A.M. 1995. Effects of black locust on productivity and nitrogen nutrition of intercropped barley. Agroforestry Systems 29, 239-254
- Piirainen S., Finér L., Mannerkoski H., Starr M. 2002. Effects of forest clear-cutting on the carbon and nitrogen fluxes through podzolic soil horizons. Plant and Soil 239, 301-311
- Prescott C., Hope G.D., Blevins L.L. 2003. Effect of gap size on litter decomposition and soil nitrate concentrations in a high-elevation spruce-fir forest. Can. J. For. Res. 33, 2210-2220
- Rédei K. 1998. Black locust (*Robinia pseudoacacia* L.) growing in Hungary. Erdészeti tudományos intézet kiadványai 11. Budapest, Hungary
- Strong D.T., Sale P.W., Heylar K.R. 1999. The influence of the soil matrix on nitrogen mineralisation and nitrification. IV. Texture. Aust. J. Soil Res. 37, 329-344
- White D.L., Haines B.L., Boring L.R. 1988. Litter decomposition in southern Appalachian black locust and pine-hardwood stands: litter quality and nitrogen dynamics. Can J. For. Res. 18, 54-63