Effect of Agricultural Lands Afforestation and Tree Species Composition on the Soil Reaction, Total Organic Carbon and Nitrogen Content in the Uppermost Mineral Soil Profile

Ondřej HOLUBÍK[1], *Vilém PODRÁZSKÝ*[2], *Jan VOPRAVIL*[1], *Tomáš KHEL*[1] *and Jiří REMEŠ*[2]

[1]*Department of Soil Science and Soil Conservation, Research Institute for Soil and Water Conservation, Prague-Zbraslav, Czech Republic;* [2]*Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic*

Abstract

Holubík O., Podrázský V., Vopravil J., Khel T., Remeš J. (2014): **Effect of agricultural lands afforestation and tree species composition on the soil reaction, total organic carbon and nitrogen content in the uppermost mineral soil profile**. Soil & Water Res., **9**: 192–200.

Forests occupy one third of the world's land area and govern carbon (C) transfers and influence nitrogen (N) content in the biosphere. Afforestation leads to soil changes of specific dynamics, often accompanied by acidification. Especially at higher altitudes this effect is accelerated and increased with the stand age since forestation. The change in soil C and N content following afforestation is controlled by a number of factors, including: previous land use (grasslands, cropland, etc.), tree species, soil cultivation method, soil properties (clay content, pH), stand age, site management, topography, and climate. In the Czech Republic, large area changes in land use took place in the last centuries – forests covering roughly 20% in the 18th century currently occupy almost 34%, with still increasing tendencies. This paper compares basic soil properties (soil reaction, total soil organic carbon as well as total nitrogen contents) of the agricultural land and land afforested 40–60 years ago. The results confirmed the key role of afforestation in the change of soil organic matter dynamics after establishing new forests on the former agricultural lands in the uppermost mineral soil part of the Orlické hory Mts. region in the Czech Republic. During that time, comparatively substantial changes in soil organic matter and nitrogen were registered. Afforestation considerably increased organic matter content in the studied A-horizons of different land use types. Soil development resulted in a high production of C and N pools under the forest stands, contrary to agricultural land. In general, afforestation caused significant soil acidification. The common tendency of higher acidity of forest soils compared to agricultural ones was documented in the studied case as well. The general tendencies of soil reaction and soil organic matter dynamics at the studied sites are comparable to those in other regions of the Czech Republic.

Keywords: acidification; afforestation; carbon; nitrogen; soil reaction

Forests occupy one third of the world's land area and govern carbon (C) transfers and influence nitrogen (N) content through photosynthesis, respiration, and specific organic matter turnover, representing important C and N pools (Brown & Lugo 1990). Forest ecosystems store more than 80% of all terrestrial aboveground C and over 70% of all soil organic carbon (SOC) (Batjes 1996; Six *et al.* 2002). Land use change causes perturbation of the ecosystems and can influence the C and N stocks and fluxes. Effective biotransformation and sequestration of SOC depends mainly on soil characteristics, seasonal variations (temperature, humidity), level of microbial processes, and availability of essential nutrients determined by the C/N ratio (Stevenson 1985). Afforestation of agricultural land can reverse some of the degradation processes and cause enhancement or sequestration of biomass as well as of the C and N stock (Silver *et al.* 2000; Ross *et al.* 2002; Vesterdal *et al.* 2002).

The change in the soil C and N content following afforestation is controlled by a number of factors, including: previous land use (grasslands, cropland, etc.), tree species, soil cultivation method, soil properties (clay content, pH), stand age, site management, topography, and climate (Guo & Gifford 2002; Jackson *et al.* 2002; Lal 2005; Jandl *et al.* 2007). Paul *et al.* (2002), reviewing 43 afforestation studies, found the key factors to be (in the order of importance): (*i*) previous land use, (*ii*) climate, (*iii*) the type of forest. Afforestation ultimately leads to acidification of soils. Grieve (2001) revealed the afforestation with conifers as the main reason for soil acidification at higher altitudes. This effect is accelerated and increased with the stand age since forestation (Alrikson & Olson 1995; Wall & Hytönen 2005; Kacálek *et al.* 2007).

SOC fluxes after afforestation. A number of studies have been conducted to investigate induced SOC changes after afforestation (Wellock *et al.* 2011) with different conclusions: (*i*) no change (Davis 2001; Davis *et al.* 2003; De gryze *et al.* 2004; Peri *et al.* 2010), (*ii*) increase (Guo & Gifford 2002; Del Galdo *et al.* 2003; Hooker & Compton 2003; Mao *et al.* 2010), (*iii*) decrease (Perrott *et al.* 1999; Ross *et al.* 1999; Chen *et al.* 2004). Several studies have shown a similar trend, where initially there was a reduction in SOC stocks in a brief period following afforestation, as the decomposition of soil organic matter exceeded the input of organic matter from the trees. The initial decline was observed for 3–35 years following the agricultural abandonment (Aweto 1981; Zak *et al.* 1990; Richter *et al.* 1999). Over time soil organic matter input increases with the productivity of the forest stands and soils switch from being a C source to a C sink (Zak *et al.* 1990; Trouve *et al.* 1994; Bashkiin & Binkley 1998; Paul *et al.* 2002; Vesterdal *et al.* 2002; Turner *et al.* 2005; Ritter 2007; Hu *et al.* 2008; Laganiere *et al.* 2010; Mao *et al.* 2010).

Afforestation in the Czech Republic. Large area changes in land use were typical also for the Czech countries in the last centuries – the forest coverage enlarged from roughly 20% to almost 34% today, with still increasing tendencies. There are records available on old villages that were destroyed and the area covered by forest. Also targeted reforestation took place, increasing the forest area in some regions, e.g. probably 18 000 ha of land were forested at the end of the 19th and at the beginning of the 20th century (Kacálek & Bartoš 2002). Situation was different in submountain and lowland conditions (Skaloš *et al.* 2012). Intensity of afforestation increased considerably since the end of the World War II, with population changes in Central and East Europe. In the Czech Republic this trend was particular for the mountain areas close to the state border, by planting as well as just with spontaneous succession (Černý *et al.* 1995; Kacálek & Bartoš 2002; Klíma 2003; Topka 2003). Changes in forest land area (ca. 100 000 ha) were also connected with ethnical changes along the Czech state border as a result of German population transfer; new shifts in land use were associated with the depression of agricultural production in the 1990s reflecting the state subsidies policy (Macků 2006) and EU regulations.

An enormous production linked with lower stability and high potential economic effect was documented for newly established stands (Bartoš *et al.* 2006, 2007; Dušek & Slodičák 2009). Both review (Kacálek *et al.* 2007) and original articles have documented a very high potential of the afforested agricultural soil to capture carbon in the surface humus and also in the uppermost mineral soil horizon. The yearly surface humus accumulation exceeded often 1 t/ha and the carbon content in the uppermost layer of the mineral soil frequently doubled (Podrázský & Remeš 2008; Menšík *et al.* 2009; Podrázský & Procházka 2009; Podrázský *et al.* 2009, 2010; Hatlapatková & Podrázský 2011). Processes of nutrient misbalances are leading to insufficient nutrient supply and foliage yellowing in many regions (Vacek *et al.* 2009).

This paper compares basic soil properties (soil reaction, total soil organic carbon as well as total nitrogen contents) of agricultural lands and a land afforested 40–60 years ago in the mountain region of the Czech Republic. It is supposed that the original soil status was comparable with that at the beginning of the forestation activities.

MATERIAL AND METHODS

Sites description. Two research sites were chosen: (1) Lomy-Deštné (16°18'39–57''E; 50°17'8–13''N) and (2) Pěčín-Neratov (16°25'53–56''E; 50°09'29–37''N). Both sites are located in the Rychnov nad Kněžnou district in the Protected Landscape Area of the Orlické hory Mts. at an altitude of 705–720 m. It was classified as MT3 climatic region due to mildly warm and humid climate (Quitt 1971), with mean annual precipitation of 707 and 848 mm and mean annual temperature of 7.3 and 7.0°C, respectively (Moravec & Votýpka 1998). Geologically, both sites belong to the Orlické hory-Kladsko crystalline complex (Opletal *et al*. 1980) with Paleozoic metamorphic rocks (amphibolites, phyllites, and schists) giving rise to silty loam soils of Haplic Cambisol type (FAO 2007).

A continuous forest inventory has been conducted at these two localities approximately since 1960. The present survey was based on data from soil sampling taken at both localities in 2005. Large areas of agricultural lands were afforested here with different tree species. The age of the stands ranges 40–60 years. The forest type varies from medium rich to acid sites, characterized by the spruce-beech forests (Piceto-Fagetum).

Soil sampling and analyses. The afforested stands (Table 1) were sampled at 21 sites, 16 sites with pure tree species stands (monocultures) and 5 sites with mixture of tree species. Each locality represented an area of 50 × 50 m of forest stand established 40–60 years ago on originally agricultural lands. In each forest stand, six individual pits were dug and samples from particular horizons were taken. The grassland and cropland sites were sampled as the reference sites (Table 1) to emulate soil properties prior to afforestation. Data for agricultural lands were obtained from the national database for identical soil types (Haplic Cambisol), soil forming substrate (crystalline complex), and climatic conditions (MT3 climatic region).

Totally 155 soil samples (50 plots) from the uppermost soil mineral horizons (0–20 cm) were taken for basic soil analyses of fine particles (< 2 mm) (ISO 11464 2006). Total organic carbon (TOC) was determined as total oxidized carbon (C_{ox}) according to ISO 14235 (1998); total nitrogen (TN) was analyzed according to CSN ISO 11261 (1995). Potentiometric determination of pH (KCl) was conducted according to ISO 10390 (1996). Cation-exchange capacity (CEC) and exchangeable cations (H, Al, Ca, Mg, and K) was leached in $BaCl_2$ solution and measured by AAS-Varian240 (ISO 13536 1995).This practice is commonly used for evaluating of not fully comprehensive data sets (Menšík *et al.* 2009).

Statistical analysis. The data set was processed separately for each mentioned soil characteristic. The accompanying data set of the sorption complex (Table 2) is expressed as mean ± standard deviation. In graphic presentation (Figures 1–4), each of the values is expressed as a median from a defined number of measurements (Table 1) with minimal and maximal value; the box expresses percentile of 25–75% probability of values. Significant difference was determined (by F-test) as a ratio of the variance values (for $n – 1$) on $P = 0.01$ significance level. All data were statistically processed using STATISTICA 10 (StatSoft CR 2012).

Table 1. Characteristics of the sampled sites

Land use	Species	Abbreviation	No. stands	No. samples
Forest (monoculture)	Norway spruce (*Picea abies*)	PI	7	42
	European beech (*Fagus sylvatica*)	BE	3	18
	Norway maple (*Acer platanoides*)	MA	1	6
	European larch (*Larix decidua*)	LA	2	12
	Speckled alder (*Alnus glutinosa*)	AL	2	12
	Silver birch (*Betula pendula*)	BI	1	6
Forest (mixture)	Silver birch (*Betula pendula*) + Norway spruce (*Picea abies*)	BI+PI	2	12
	Silver birch (*Betula pendula*) + European ash (*Fraxinus excelsior*) + Speckled alder (*Alnus glutinosa*)	BI+AS+AL	1	6
	European ash (*Fraxinus excelsior*) + Norway maple (*Acer platanoides*) + European larch (*Larix decidua*)	AS+MA+LA	1	6
	Speckled alder (*Alnus glutinosa*) + Silver birch (*Betula pendula*) + European beech (*Fagus sylvatica*)	AL+BI+BE	1	6
Grassland	Common yarrow (*Achillea millefolium*), woodland forget-me-not (*Myosotis sylvatica*), along with various grass (*Poace*) species	G	17	17
Cropland	various agricultural crops	C	12	12
Total			50	155

Table 2. Organo-mineral complex composition of soil samples from individual stands (mean ± standard deviation)

Species	Characteristic of sorption complex							Sum/CEC (%)
	H^+	Al^{3+}	Ca^{2+}	Mg^{2+}	K^+	Sum base	CEC	
	(mmol⁺/100g)							
PI	1.8 ± 0.7	10.6 ± 2.0	1.5 ± 1.4	0.4 ± 0.2	0.2 ± 0.1	2.1 ± 1.6	14.6 ± 2.8	14 ± 9
BE	2.4 ± 1.3	10.0 ± 2.1	1.2 ± 0.7	0.4 ± 0.1	0.4 ± 0.1	2.0 ± 0.8	14.4 ± 4.1	14 ± 3
LA	1.2 ± 0.4	9.8 ± 2.2	0.8 ± 0.5	0.3 ± 0.2	0.3 ± 0.4	1.4 ± 1.0	12.4 ± 3.1	11 ± 6
MA	1.0 ± 0.7	8.3 ± 3.0	3.0 ± 2.4	0.5 ± 0.4	0.4 ± 0.2	4.0 ± 2.9	13.3 ± 1.6	31 ± 22
AL	2.7 ± 1.0	11.3 ± 1.7	4.1 ± 2.1	0.9 ± 0.3	0.5 ± 0.1	5.6 ± 2.6	19.6 ± 2.9	28 ± 11
BI	0.4 ± 0.1	3.0 ± 0.6	6.3 ± 1.8	1.0 ± 0.3	0.7 ± 0.2	8.0 ± 2.0	11.4 ± 1.7	69 ± 9
BI+PI	3.3 ± 0.5	10.8 ± 0.8	1.9 ± 0.8	0.5 ± 0.1	0.4 ± 0.1	2.8 ± 0.8	17.0 ± 1.2	17 ± 5
BI+AS+AL	1.3 ± 0.4	8.8 ± 1.0	2.0 ± 0.8	0.4 ± 0.1	0.4 ± 0.1	2.9 ± 1.1	13.0 ± 1.7	22 ± 6
AS+MA+LA	0.2 ± 0.1	0.8 ± 0.4	11.2 ± 0.8	2.1 ± 0.2	0.8 ± 0.1	14.1 ± 1.1	15.2 ± 0.8	93 ± 2
AL+BI+BE	3.4 ± 0.4	11.1 ± 0.4	1.4 ± 0.3	0.5 ± 0.0	0.4 ± 0.1	2.4 ± 0.4	16.9 ± 0.4	14 ± 3
G	19.0 ± 4.3	2.8 ± 0.1	3.0 ± 1.1	0.5 ± 0.2	0.1 ± 0.1	7.3 ± 4.6	16.8 ± 4.8	45 ± 21
C	11.5 ± 0.5	2.9 ± 0.1	7.7 ± 0.3	1.1 ± 0.0	0.3 ± 0.0	12.5 ± 10.7	16.5 ± 2.9	60 ± 23

PI – Norway spruce; BE – European beech; LA – European larch; MA – maple; AL – Speckled alder; BI – silver birch; AS –European ash; G – grassland; C – cropland; CEC – cation exchangeable capacity; Sum – sum of basic cations

RESULTS AND DISCUSSION

Acidification and buffering effect after afforestation were influenced and documented by characteristic changes in the soil organo-mineral complex (Table 2). The results of pH (KCl) showed significantly high acidification of all forest tree species on afforested agricultural lands compared to cropland sites (Figure 1). Forest stands showed by 1.5–2.0 units lower pH (KCl) values than agricultural lands. Only mixed stands of ash, maple, and larch (AS+MA+LA) exhibited comparable values. In this case, the nutrient uptake and surface humus formation could have played a crucial role in the acidification since afforestation. In other studies, this factor was of minor importance, the main one being the bedrock (Augusto *et al.* 2003; Rejšek *et al.* 2010) or acid deposition (Iwald *et al.* 2013), which was almost fully comparable, even identical, with our results. Other variants did not significantly differ from each other. Especially the beech did not exhibit an increased soil reaction, i.e. acidification prevention. From the pH point of view, the forest stands can be aligned in the following order: AS+MA+LA > BI > MA > BI+AS+AL > PI/LA > AL > BE/BI + PI/AL + BI + BE (Figure 1). The mixed stand of maple, ash, and larch is suitable from the soil effect and stabilization aspects as well as from the aspect of production (larch). Acidification was more pronounced at the sites with coniferous tree species than at those improved by broad-leaves.

In the present study, concordantly with Binkley and Valentine (1991) and Hagen-Thorn *et al.* (2004), acidification was observed as a decrease of pH and bases saturation in the uppermost soil mineral horizons. The spruce (PI) acidified mostly

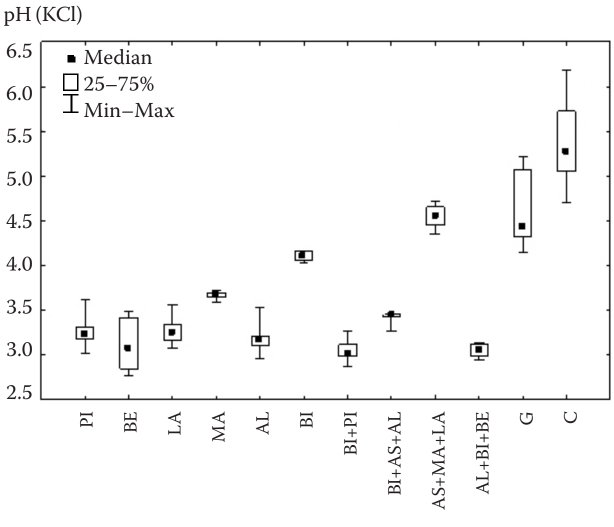

Figure 1. Evaluation of pH (KCl) soil differences on particular stand and site type; PI – Norway spruce; BE – European beech; LA – European larch; MA – maple; AL – Speckled alder; BI – silver birch; AS –European ash; G – grassland; C – cropland

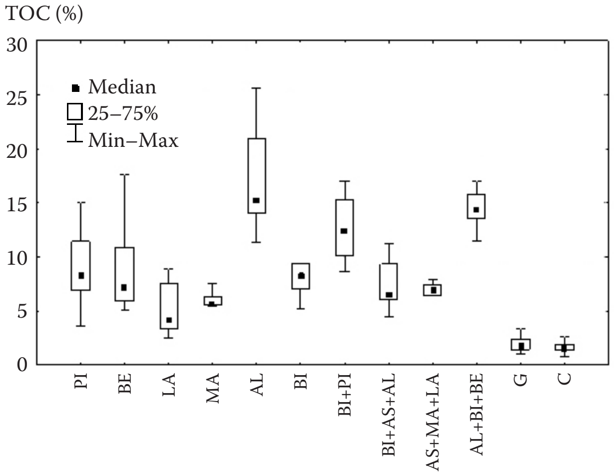

Figure 2. Evaluation of total organic carbon (TOC) differences on particular stand and site type; PI – Norway spruce; BE – European beech; LA – European larch; MA – maple; AL – Speckled alder; BI – silver birch; AS –European ash; G – grassland; C – cropland

the upper 15 cm of the mineral soil and caused decrease of exchangeable bases (Ca, Mg, and K) and of base saturation as well. Along with Hatlapatková and Podrázský (2011) we may state that the beech affected the soil surface lesser than the other broadleaved species.

Highly positive effects of birch on the soil reaction have been known from Czech afforested agricultural sites especially at higher altitudes if compared to the effect of various spruce species and other conifers at afforested agricultural sites (Podrázský & Procházka 2009; Podrázský *et al.* 2010). Climax tree species also similarly affected the soil acidity, the preparatory species often showed slower acidification of the studied sites. This effect contributes to rapid mobilization, transformation, and sequestration of the organic matter.

Afforestation of agricultural lands is regularly connected with a high increase in the sequestration of organically bound carbon and nitrogen by the newly developing forest ecosystems, with high C content of 45% and N content of 0.5–1.5%. These elements are fixed in the increasing biomass (10–15 t·ha/a) and surface organic matter (OM). The holorganic layers accumulate carbon in the observed amounts of 0.5–2.5 t·ha/a (OM) with broad C content of 17–50% and N content of 0.1–2.0% (Podrázský *et al.* 2009; Hatlapatková & Podrázský 2011). A considerable increase in C accumulation in the uppermost soil mineral horizon has been observed since forestation, during the last 40–60 years. TOC contents in agricultural lands shifted from 1.6–1.8% to 4.24% (LA)–15.16% (AL) (Figure 2). The main source of TOC is the humified litter of the tree species, mixed by bioturbation into deeper horizons (Menšík *et al.* 2009).

On the observed plots (Figure 2), the differences in TOC were significantly higher for all forest soils compared to those of agricultural lands with the exception of the pure European larch stand. The differences among forest tree species were not significant. The forested and agricultural stands were ordered by TOC as follows: AL > AL+BI+BE > BI+PI > PI > BI > BE > AS+MA+LA > BI+AS+AL > MA > LA >> G > C (Figure 2). Alder can be considered as the carbon content increasing species. It produces litter with very favourable characteristics for biological transformation and humification, increasing nitrogen content (Figure 3) as well as cation-exchange capacity (Table 2). Alder as a preparatory species can play a very important role in the management of afforestation (Podrázský *et al.* 2005). Higher quality and content of soil dissolved organic C species was documented in afforested stands also by Wu and Xu (2005).

The total nitrogen content and its relation to the carbon content (C/N ratio) is, among others, a very important indicator of the soil organic matter transformation and quality (Šrámek *et al.* 2012). Statistically not provable but higher N content was observed in the stands with alder dominance or co-dominance (AL, AL+BI+BE) compared to the set of stands represented by BI, BI+AS+AL, and AS+MA+LA (Figure 3). The N-enriching role of alder is obvious, which corresponds with other published data (Podrázský *et al.* 2005;

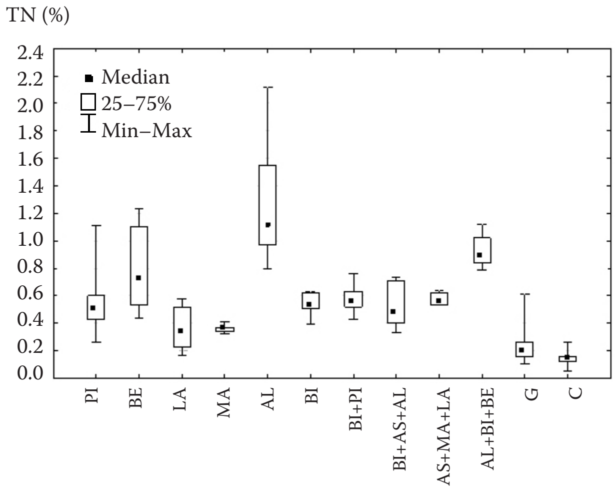

Figure 3. Evaluation of total nitrogen (TN) content differences on particular stand and site type; PI – Norway spruce; BE – European beech; LA – European larch; MA – maple; AL – Speckled alder; BI – silver birch; AS –European ash; G – grassland; C – cropland

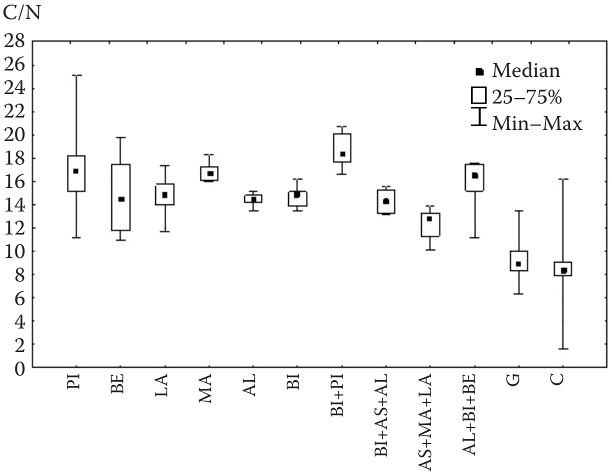

Figure 4. Evaluation of C/N ratio differences on particular stand and site type; PI – Norway spruce; BE – European beech; LA – European larch; MA – maple; AL – Speckled alder; BI – silver birch; AS –European ash; G – grassland; C – cropland

Rejšek *et al.* 2010) as well as general knowledge and consequent forest management (Binkley 1986; Kuneš *et al.* 2012). Especially the basic and general significant difference between conifers and broad-leaves was not proven in the studied case, confirming minor importance of tree species composition if compared to site (climatic and soil genesis) and geological bedrocks (Paul *et al.* 2002; Augusto *et al.* 2003). But the differences between the N pools under the agricultural and afforested land use are significant in this study (Figure 3). Also different types of nitrogen compounds prevailing in forest and agricultural lands may play an important role (Podrázský & Remeš 2008).

The evaluation of soil organic matter quality by the C/N ratio demonstrates the positive impact of forest stands on effective C sequestration and soil organic C stock production (Figure 4). In this study, the forest stands produced humus forms with higher C/N quotient, indicating delayed organic matter decomposition and longer C storage in forest soils. The highest values detected in the stands of spruce (PI) dominance/co-dominance agree with the slower decomposition potential of the litter of this species (Binkley 1986; Augusto *et al.* 2003). Despite of this fact, the C/N ratio values of the studied forest stands do not exceed the value of 20, which is limiting for the humification problems onset (Šrámek *et al.* 2012).

CONCLUSION

The results confirmed the key role of afforestation in the change of soil organic matter dynamics after establishing new forests on the former agricultural lands in the uppermost mineral soil part. In the studied area, i.e. in the Orlické hory Mts., the afforestation took place 40–60 years ago, since the 1950s. During that time, relatively high changes in soil organic matter and nitrogen were registered.

The afforestation increased considerably the organic matter content in the studied uppermost soil mineral horizon. Soil development resulted in the increase of total carbon content from 1.6–1.8% up to 15%, with a range of 4.2 to 15.2%. Especially the dominance of preparatory species like birch and even more alder resulted in high total soil carbon increase. The effects of climax species of Norway spruce and beech were comparable.

The highest nitrogen contents were documented in the alder stands.

In general, afforestation caused significant soil acidification. The pH (KCl) value decreased from the values of 4.4–5.3 to ca 3.0 in many cases. The common tendency to acidification of forest soils was also documented in this paper. General tendencies of soil reaction and soil organic matter dynamics comparable to the trend in other regions were confirmed.

Acknowledgements. Supported by the Ministry of Agriculture of the Czech Republic – Project No. QH82090 (30%) “Changes of the soil properties due to grassing, afforestation or in the long-term abandoned land regarding to soil, landscape and water conservation in the Czech Republic”, Project No. MZE 0002704902 (20%) “The integrated systems of protection, improvement and use of soil, water and landscape in agriculture and rural development”, Project No. QJ1320122 (30%) “Optimization of the afforestation management of the agricultural lands in relation to enhancement of the landscape retention”, and Project No. QJ1230056 (20%) “The impact of the expected climate changes on soils of the Czech Republic and the evaluation of their productive functions”.

References

Alrikson A., Olsson M.T. (1995): Soil changes in different age classes of Norway spruce (*Picea abies* (L.) Karst.) on afforested farmland. Plant and Soil, **168/169**: 103–110.

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

Aweto A.O. (1981): Secondary succession and soil fertility restoration in south-western Nigeria. II. Soil fertility restoration. Journal of Ecology, **69**: 609–614.

Bartoš J., Petr T., Kacálek D., Černouhous V. (2006): Wood production of first-generation forests on agricultural land. In: Neuhöferová P. (ed.): Proc. Agricultural Land Afforestation, a Challenge to Forestry Sector. Kostelec n. Č. l., ČZU, Prague, 81–88. (in Czech)

Bartoš J., Šach F., Kacálek D., Černohous V. (2007): Tree species composition of first-generation forest on afforested agricultural land from economical viewpoint. Zprávy lesnického výzkumu, **52**: 11–17 (in Czech).

Bashkin M.A., Binkley D. (1998): Changes in soil carbon following afforestation in Hawaii. Ecology, **79**: 828–833.

Batjes N. (1996): Total carbon and nitrogen in the soils of the world. European Journal of Soil Science, **47**: 151–163.

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

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.

Brown S., Lugo A.E. (1990): Effects of forest clearing and succession on the carbon and nitrogen content of soils in Puerto Rico and US Virgin Islands. Plant and Soil, **124**: 53–64.

Černý Z., Lokvenc T., Neruda J. (1995): Afforestation of Non-forest Soils. 1st Ed., Institute of Education of the Ministry of Agriculture, Prague. (in Czech)

Chen C., Xu Z., Mathers N. (2004): Soil carbon pools in adjacent natural and plantation forests of subtropical Australia. Soil Science Society of America Journal, **68**: 282–291.

Davis M. (2001): Soil properties under pine forest and pasture at two hill country sites in Canterbury. New Zealand Journal of Forestry Science, **31**: 3–17.

Davis M.R., Allen R.B., Clinton P.W. (2003): Carbon storage along a stand development sequence in a New Zealand Nothofagus forest. Forest Ecology and Management, **177**: 313–321.

De Gryze S., Six J., Paustian K., Morris S.J., Paul E.A., Merckx R. (2004): Soil organic carbon pool changes following land-use conversions. Global Change Biology, **10**: 1120–1132.

Del Galdo I., Six J., Peressotti A., Cotrufo M.F. (2003): Assessing the impact of land use change on soil C sequestration in agricultural soils by means of organic matter fractionation and stable C isotopes. Global Change Biology, **9**: 1204–1213.

Dušek D., Slodičák M. (2009): Structure and static stability of stands under different regimes of thinning on former agricultural land. Zprávy lesnického výzkumu, **54**: 12–17. (in Czech)

FAO (2007): World Reference Base for Soil Resources 2006. 1st update 2007. World Soil Resources Reports No. 103. FAO, Rome.

Grieve I.C. (2001): Human impacts on soil properties and their implications for the sensitivity of soil systems in Scotland. Catena, **42**: 361–374.

Guo L.B., Gifford R.M. (2002): Soil carbon stocks and land use change: a meta analysis. Global Change Biology, **8**: 345–360.

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.

Hatlapatková L., Podrázský V. (2011): Restoration of surface humus layers on afforested agricultural soils. Zprávy lesnického výzkumu, **56**: 228–234 (in Czech)

Hooker T.D., Compton J.E. (2003): Forest ecosystem carbon and nitrogen accumulation during the first century after agricultural abandonment. Ecological Applications, **13**: 299–313.

Hu Y.L., Zeng D.H., Fan Z.P., Chen G.S., Zhao Q., Pepper D. (2008): Changes in ecosystem carbon stocks following grassland afforestation of semiarid sandy soil in the southeastern Keerqin Sandy Lands, China. Journal of Arid Environments, **72**: 2193–2200.

ISO 11261 (1995): Soil Quality – Determination of Total Nitrogen – Modified Kjeldahl method. ISO, Geneva.

ISO 13536 (1995): Soil Quality – Determination of the Potential Cation Exchange Capacity and Exchangeable Cations Using Barium Chloride Solution Buffered at pH = 8.1. ISO, Geneva.

ISO 10390 (1996): Soil Quality. Determination of pH. Czech Standard Institute, Prague.

ISO 14235 (1998): Soil Quality – Determination of Organic Carbon by Sulfochromic Oxidation. ISO, Geneva.

ISO 11464 (2006): Soil Quality – Pretreatment of Samples for Physico-chemical Analysis. BSI, London

Iwald J., Löfgren S., Stendahl J., Karltun E. (2013): Acidifying effect of removal of tree stumps and logging residues as compared to atmospheric deposition. Forest Ecology and Management **290**: 49–58.

Jackson R.B., Banner J.L., Jobbagy E.G., Pockman W.T., Wall D.H. (2002): Ecosystem carbon loss with woody plant invasion of grasslands. Nature, **418**: 623–626.

Jandl R., Lindner M., Vesterdal L., Bauwens B., Ba-ritz R., Hagedorn F., Johnson D.W., Minkinnen K., Byrne K.E. (2007): How strongly can forest management influence soil carbon sequestration? A review. Geoderma, **137**: 253–268.

Kacálek D., Novák J., Špulák O., Černohous V., Bartoš J. (2007): Conversion of afforested agricultural-land soils towards forest soil conditions restoration – review. Zprávy lesnického výzkumu, **52**: 334–340 (in Czech).

Kacálek D., Bartoš J. (2002): The issue of unproductive agricultural land afforestation in the Czech Republic.

In: Karas J., Podrázský V. (eds): Annual Int. Seminar Current Trends in Forest Management. September 16–17, 2002, Kostelec nad Černými lesy, 39–45. (in Czech)

Klíma J. (2003): The development project of afforestation of agricultural and forest soils. Lesnická práce, **82**: 308–309. (in Czech)

Kuneš I., Baláš M., Koňasová T., Zahradník D., Balcar V., Špulák O., Kacálek D., Jakl M., Jaklová J., Dytrtová I. (2012): Cultivation of speckled alder under harsh mountain conditions. Journal of Forest Science, **58**: 234–244.

Laganiere J., Angers D.A., Parc D. (2010): Carbon accumulation in agricultural soils after afforestation: a meta-analysis. Global Change Biology, **16**: 439–453.

Lal R. (2005): Forest soils and carbon sequestration. Forest Ecology and Management, **220**: 242–258.

Macků J. (2006): Strategy and criterions for selection of reforestation agricultural plots. In: Neuhöferová (ed.): Proc. Agricultural Land Afforestation, a Challenge to Forestry Sector. January 17, 2006, Kostelec nad Černými lesy. (in Czech)

Mao R., Zeng D. H., Hu Y.L., Li L.J., Yyng D. (2010): Soil organic carbon and nitrogen stocks in an age-sequence of poplar stands planted on marginal agricultural land in Northeast China. Plant and Soil, **332**: 277–287.

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

Moravec D., Votýpka J. (1998): Climatic Regionalization of the Czech Republic. Vol. 1, Carolinum, Charles University in Prague, Prague. (in Czech)

Opletal M., Domečka K., Čech S., Čuta M., Fajst M., Holub V., Kačura G., Líbalová J., Pošmourný K., Sekyra J., Střída M., Šalanský K., Šulcek Z., Tásler R., Valečka J. (1980): Geology of Orlické hory Mts. Academia, Prague. (in Czech)

Paul K.I., Polglase P.J., Nyakuengama J.G., Khanna P.K. (2002): Change in soil carbon following afforestation. Forest Ecology and Management, **168**: 241–257.

Peri P.L., Gargaglione V., Martinez P.G., Lencinas M.V. (2010): Carbon accumulation along a stand development sequence of Nothofagus antarctica forests across a gradient in site quality in Southern Patagonia. Forest Ecology and Management, **260**: 229–237.

Perrott K.W., Ghani A., O'Connor M.B., Waller J.E. (1999): Tree stocking effects on soil chemical and microbial properties at the Tikitere Agroforestry Research Area. New Zealand Journal of Forestry Science, **29**: 116–130.

Podrázský V., Remeš J. (2008): Rapidity of forest soil character restoration of afforested localities of the Orlické hory Mts. Zprávy lesnického výzkumu, **53**: 89–93. (in Czech)

Podrázský V., Procházka J. (2009): Effects of the reforestation of agricultural lands on the humus form development in the middle altitudes. Scientia Agriculturae Bohemica, **40**: 41–46.

Podrázský V., Ulbrichová I. Kuneš I., Folk J. (2005): Green alder effects on the forest soils in higher elevations. Journal of Forest Science, **51** (Special Issue): 38–42.

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

Podrázský V., Kapička A., Kouba M. (2010): Restoration of forest soils after bulldozer site preparation in the Ore Mountains over 20 years development. Ekológia (Bratislava), **29**: 281–289.

Quitt E. (1971): Climatic regions of Czechoslovakia. Academia, Studia Geographica 16, GÚ ČSAV, Brno. (in Czech)

Rejšek K., Haveraaen O., Sandnes A., Somerlíková K. (2010): Soil characteristics under selected broadleaved tree species in East Norway. Journal of Forest Science, **56**: 95–306.

Richter D.D., Markewitz D., Trumbore S.E., Wells C.G. (1999): Rapid accumulation and turnover of soil carbon in a reestablishing forest. Nature, **400**: 56–58.

Ritter E. (2007): Carbon, nitrogen and phosphorus in volcanic soils following afforestation with native birch (*Betula pubescens*) and introduced larch (*Larix sibirica*) in Iceland. Plant and Soil, **295**: 239–251.

Ross D.J., Tate K.R., Scott N.A., Feltham C.W. (1999): Land-use change: effects on soil carbon, nitrogen and phosphorus pools and fluxes in three adjacent ecosystems. Soil Biology and Biochemistry, **31**: 803–813.

Ross D.J., Tate K.R., Scott N.A., Wilde R.H., Rodda N.J., Townsed J.A. (2002): Afforestation of pastures with *Pinus radiata* influences soil carbon and nitrogen pools and mineralization and microbial properties. Australian Journal of Soil Research, **40**: 1303–1318.

Silver W.L., Ostertag R., Lugo A.E. (2000): The potential for carbon sequestration through reforestation of abandoned tropical agricultural and pasture lands. Restoration Ecology, **8**: 394–407.

Six J., Conant R.T., Paul E.A., Paustian K. (2002): Stabilization mechanisms of soil organic matter: implications for C-saturation of soils. Plant and Soil, **241**: 155–176.

Skaloš J., Engstová B., Trpáková I., Šantrůčková M., Podrázský V. (2012): Long-term changes in forest cover 1780–2007 in central Bohemia, Czech Republic. European Journal of Forest Research, **131**: 871–884.

StatSoft CR (2012): STATISTICA – Data Analysis Software System. Version 10.0. Available at www.statsoft.com

Stevenson F.J. (1985): Cycles of Soil. Carbon, Nitrogen, Phosporus, Sulfur, Micronutrients. John Wiley & Sons, Inc., New York.

Šrámek V., Fadrhnosová V., Vortelová L., Lomský B. (2012): Development of chemical soil properties in the western Ore Mts. (Czech Republic) 10 years after liming. Journal of Forest Science, **58**: 57–66.

Topka J. (2003): Afforestation of agricultural land and completion of the project. Lesnická práce, **82**: 350–352 (in Czech)

Trouve C., Mariotti A., Schwartze D., Guillett B. (1994): Soil organic carbon dynamics under Eucalyptus and Pinus planted on savannahs in the Congo. Soil Biology & Biochemistry, **26**: 287–295.

Turner J., Lambert M.J., Johnson D.W. (2005): Experience with patterns of change in soil carbon resulting from forest plantation establishment in eastern Australia. Forest Ecology and Management, **220**: 259–269.

Vacek S., Hejcman M., Semelová V., Remeš J., Podrázský V. (2009): Effect of soil chemical properties on growth, foliation and nutrition of Norway spruce stand affected by yellowing in the Bohemian Forest Mts., Czech Republic. European Journal of Forest Research, **128**: 367–375.

Vesterdal L., Ritter E., Gundersen P. (2002): Change in soil organic carbon following afforestation of former arable land. Forest Ecology and Management, **169**: 137–147.

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

Wellock M.L., La Perle C.M., Kiely G. (2011): What is the impact of afforestation on the carbon stocks of Irish mineral soils? Forest Ecology and Management, **262**: 1589–1596.

Wu J.G., Xu D.Y. (2005): Dissolved organic carbon concentrations in soil under different land uses in the Liupan Mountain Forest Zone. Acta Phytoecologica Sinica, **29**: 945–953.

Zak D.R., Grigal D.F., Gleeson S., Tilman D. (1990): Carbon and nitrogen cycling during old-field succession: constraints on plant and microbial biomass. Biogeochemistry, **11**: 111–129.

Received for publication November 19, 2013
Accepted after corrections May 26, 2014

Corresponding author:

Bc. Ondřej Holubík**,** Výzkumný ústav meliorací a ochrany půdy, oddělení pedologie a ochrany půdy, Žabovřeská 250, 156 27 Praha 5-Zbraslav, Česká republika; e-mail: holubik.ondrej@vumop.cz