How does legacy of agriculture play role in formation of afforested soil properties?

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ABSTRACT: Soil properties of forest ecosystems depend on synergy of both parent material and organisms living in the soil, i.e. tree species communities including related plant and animal species. However these soils were not left intact being converted into agricultural land; addition of both nutrients and organic matter and cultivation using tillage led to increased fertility of topsoil. Even long-term afforested soils show differences which are considered as legacy of past agriculture. The change remains detectable for decades; though the altered properties are obvious especially couple of years after planting (approximately 10 years). We found increased concentrations of nutrients (P, K, Ca, and Mg) and subsequent increased base saturation (V %) in former tilled soil only. Moreover, there were no differences between topsoil and subsoil properties (69% and 72%, respectively). In addition to significantly lower saturation (both 0–10 cm and 11–30 cm layers) detected in the long-term-forest and 50-year-afforested (both covered with Norway spruce stands) soils in comparison with adjacent 10-year-old afforestations, there was found significantly lower base saturation in topsoil horizons compared to underlying ones.

Keywords: afforestation; agricultural land; soil properties; plant-available nutrients; Norway spruce

Soils are derived from rocks exposed at the Earth's surface weathering under particular climatic conditions; in addition to inanimate environment, their properties are affected by biota i.e. bacteria, fungi, soil animals and plants (Singer, Munns 1996). The formation of soils under natural conditions leads to creation of soil pedon mosaic within a landscape. Such soil types had developed prior to beginning of agricultural colonization. Thereafter the soil properties were altered due to deforestation, addition of manure or deliberate fertilization (Maclaren 2004) and tillage of topsoil horizons having such important impacts on soils that they no longer resemble forest soils (Torreano 2004). Even though the agricultural practices have altered soil properties, Bedrna (2002) considers such process as continuation of natural development; though the process results into both positively influenced (ameliorative process) and negatively influenced (degradation process) soils.

The study focuses on properties of soil samples taken from mineral (0–10 cm, 11–30 cm) horizons of soils that underwent different land use in last decades. The point is that in addition to the naturally inherited properties, agricultural cultivation is perhaps the most important soil-forming and even soil-creating factor of soil genesis being likely the oldest human-induced alteration of soil properties. Even rather extensive thousands years lasting amendment including a primitive tillage lead to formation of extraordinarily thick A horizons high in soil organic matter and phosphorus which are key factors to classify profiles as formerly cultivated (Singer, Munns 1996) proving legacy of manuring (Ellert, Gregorich 1996; Oheimb et al. 2008).

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Moreover, there were large shifts in land use in the past; the forests were converted into fields, meadows and pastures which become forest land again due to both succession and artificial afforestation. Large area was afforested mainly in 50s when roughly 200,000 ha of less-productive areas have been afforested in the Czech Republic (Míchal et al. 1992). Despite new stands changed the soil environment strongly, we supposed there were still different soil properties typical of cultivated soils that endured for a long time. Therefore the study deals with alteration of soil properties due to land-use changes, especially in terms of change from agricultural to at least semi-forest soil addressing two research questions:

(1) Does recently afforested agricultural land differ from long-term-afforested one?
(2) Does long-term-afforested agricultural land differ from long-term forest soil?

MATERIALS AND METHODS

The soil samples were collected from forest soils of different land-use history. Among native tree species, Norway spruce grows on former agricultural land as the most frequent one in the Czech Republic being considered as the best productive though it is often threaten by insects and fungi. The Norway spruce has been reported as the most acidifying species under conditions of afforested agricultural land (Binkley, Valentine 1991; Augusto et al. 2002, 2003; Hagen-Thorn et al. 2004; Podrázský, Remeš 2007). Therefore we focused on analysis of neighboring sites providing reliable data from comparable site conditions (Wall, Hytönen 2005); there were sampled soils from recently afforested localities including adjacent spruce stands covering the former agricultural land for decades. Also samples of long-term forest land origin (duration of forest stand cover exceeds one rotation period) were taken if available. A total of 182 samples from 13 sites (Table 1) were studied. The sites represented soils derived from metamorphic and sedimentary rocks. The most frequent soil type was classified as cambisol (FAO) altered due to cultivation. The samples from 0–10 cm (topsoil) and 11–30 cm were analyzed for pH value (both pH H_2O and pH KCl), plant-available nutrient element (P, K, Ca, Mg) concentrations using Mehlich III method (Zbíral 1995), base saturation capacity, cation exchange capacity and hydrolysis acidity according to Kappen method (Valla et al. 1983). To process the data, a cluster analysis using NCSS software was applied; the cluster analysis was chosen to provide a first insight into data. Group average – unweighted pair-group method calculates cophenetic correlation coefficient; values above 0.75 are felt to be good (Meloun et al. 2005); this is the correlation between the original distances (Euclidean distance) and those that result from the cluster configuration. Second measure of goodness of fit is called delta (degree of distortion); values close to zero are desirable. To compare soil properties between topsoil horizons and underlying ones, the samples were divided into three groups by duration of forest cover. The first group represents samples that were taken from long-term forest soil and the other ones were of former agricultural land origin. These two groups were taken either in 50-year-old or 10-year-old afforestations. The samples were tested

Table 1. Sampled soil localities

Locality	Bedrock/soil (FAO)	Altitude (m a.s.l.)	GPS
Bačetín	phyllites/cambisol	490	50°18'34.928"N, 16°14'39.182"E
Branky	flysch sediments/luvic cambisol	350	49°27'24.853"N, 17°54'40.27"E
Bystré	metabasites, phyllites/cambisol	510	50°19'40.855"N, 16°14'56.785"E
Černý důl	mica schist, cambisol, podzol	600	50°12'12.292"N, 16°31'16.321"E
Deštenská stráň	mica schists/cambisol, podzol	800	50°18'47.962"N, 16°21'55.991"E
Dobřany	phyllites/cambisol	650	50°19'42.062"N, 16°17'18.44"E
Krahulec	phyllites/cambisol	590	50°19'44.199"N, 16°16'28.424"E
Neratov	glaukonitic sandstone, mica schist/podzol, cambisol	750	50°13'49.881"N, 16°31'43.705"E
Očelice	Cretaceous sediments/phaeozem	260	50°14'23.042"N, 16°3'37.823"E
Osečnice	phyllites/cambisol	600	50°15'47.473"N, 16°18'34.34"E
Polom	phyllites, amphibolites/cambisol	675	50°20'53.658"N, 16°18'9.967"E
Trčkov	mica schists/cambisol	780	50°18'46.968"N, 16°25'7.196"E
Uhřínov	diorite, amphibolites, phyllites/cambisol	530	50°13'34.113"N, 16°19'56.286"E

for significant differences in pH, nutrient concentrations and degree of base cations saturation between both 0–10 cm and 11–30 cm horizons using paired *T*-test (Zar 1998). In order to avoid misinterpretation in case of non-normal distribution, the *T*-test was followed by paired non-parametric Wilcoxon test. The data were processed using UNISTAT.

RESULTS AND DISCUSSION

A separate cluster which includes recently afforested localities provides the most important information resulting from cluster analysis. The samples within this new-afforestation cluster were collected from following localities: Očelice, Branky, Bačetín, Polom, Uhřínov and Krahulec. Except for Očelice representing bare meadow, all localities belong to formerly tilled land use type covered with new forest stands (thickets of age up to 10 years). On the other hand, the other 10-year-old afforestations situated on meadow soils derived from metamorphic crystalline rocks (Bystré) belong to different cluster of poorer soils. Furthermore, the adjacent forest-soil samples taken as control ones to the young afforestations (Branky, Polom, Uhřínov) belong also to the poorer soils cluster. The difference between the two clusters is obvious in terms of pH value (5.2 on the recently afforested tilled soils contrary to 3.9 on the former meadows, older afforestation or long-term forests), Ca concentration (2,649 mg/kg and 723 mg/kg, respectively), Mg concentration (250 mg/kg and 68 mg/kg, respectively) and degree of base cations saturation (84.4% and 50.3%, respectively). The values are always significantly higher in group of recently afforested tilled localities; therefore we consider the increased values as legacy of former fertilization (Fig. 1).

Also native array of soil horizons might have been altered due to agricultural land use changing proper-

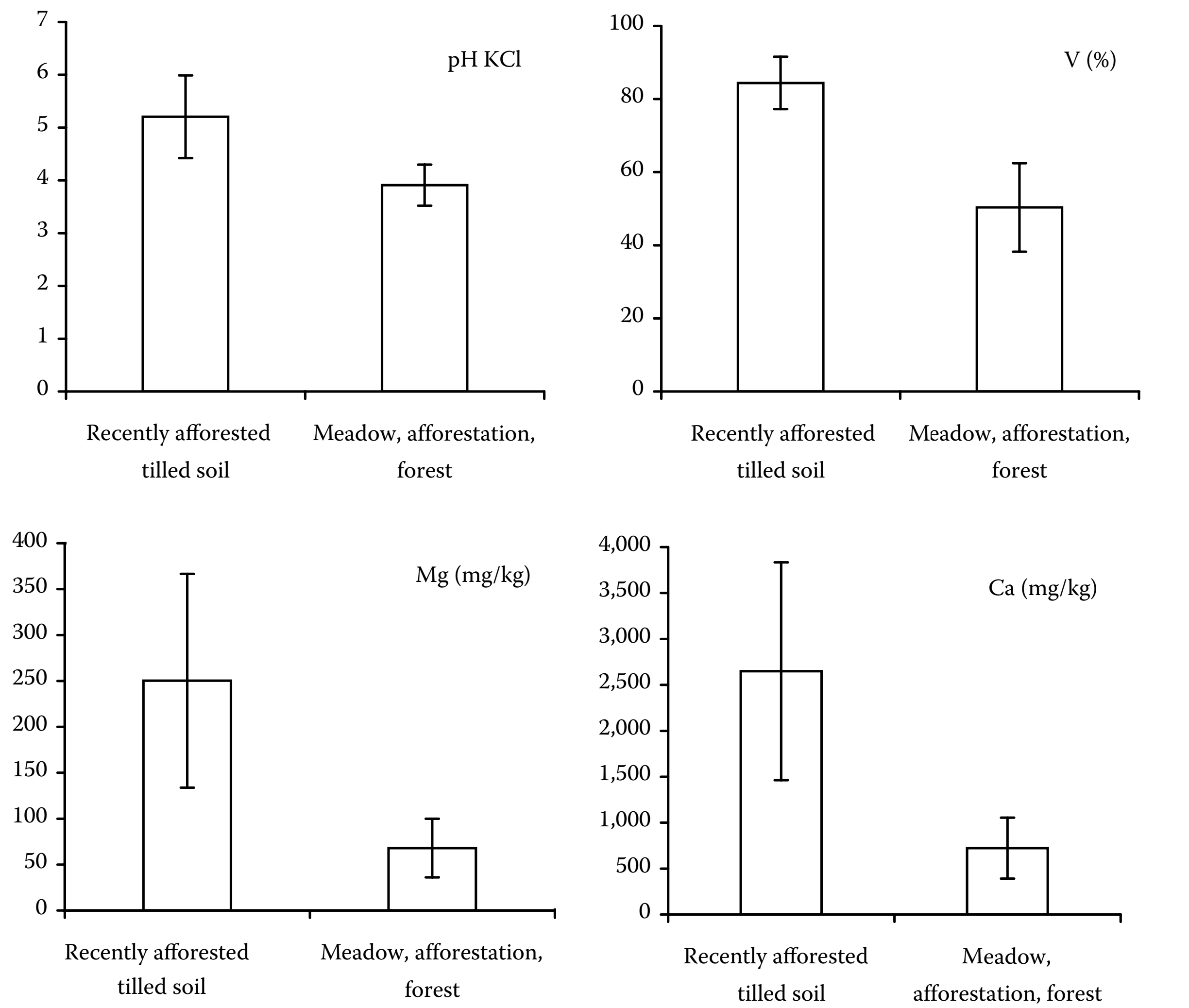

Fig. 1. Comparison of mean values of the most different soil sample clusters. The values of pH KCl, V (base saturation), and base cation concentrations are significantly higher in a group of young 10-years-old afforestation situated on formerly tilled soils (left bars). The error bars represent standard deviation of the mean

Table 2. Results of comparative analysis between variants – Forest land, Afforestation_10, Afforestation_50 (see Fig. 2 for the explanation) and soil layers (0–10 cm – topsoil; 11–30 cm – underlying horizon)

	Mean	Median	*P*-value	
	0–10/11–30	0–10/11–30	*T*-test	Wilcoxon
Forest land				
pH/H_2O	3.7/4.1	3.7/4.0	1.03E-09*	1.33E-05*
V%	15.8/22.3	14.4/20.0	5.37E-06*	3.62E-05*
P (mg/kg)	4.8/14.1	1.0/1.0	0.07	0.09
K (mg/kg)	67.8/50.6	62.0/46.0	3.44E-06*	8.43E-05*
Ca (mg/kg)	293/304	214/211	0.62	0.98
Mg (mg/kg)	47.4/39.5	43.0/30.0	0.01*	5.78E-03*
Afforestation_10				
pH/H_2O	5.6/5.7	5.7/5.6	0.35	0.16
V%	68.9/72.0	81.3/79.8	0.3	0.33
P (mg/kg)	38.3/35.1	22.5/10.0	0.66	0.38
K (mg/kg)	221.6/197.7	175.5/149.0	0.54	0.59
Ca (mg/kg)	1,868/1,951	1,904/1,638	0.62	0.35
Mg (mg/kg)	195.4/189.6	168/167	0.77	0.66
Afforestation_50				
pH/H_2O	4.0/4.4	4.0/4.3	5.61E-09*	4.72E-06*
V%	22.6/34.2	19.8/32.3	1.77E-06*	2.16E-05*
P (mg/kg)	7.5/5.1	4.0/3.5	0.13	0.35
K (mg/kg)	69.1/53.2	63.5/46.0	2.87E-05*	8.88E-05*
Ca (mg/kg)	276/304	250/250	0.32	0.70
Mg (mg/kg)	37.7/31.9	31/29	0.04*	0.03*

*Significant difference between variants at 0.05 significance level

ties in the profiles. We found significant differences using comparison analysis of the three groups of soils situated under conditions of long-term forest land, 50-year-old afforestation and 10-year-old afforestation in terms of properties of both upper and deeper layers. The topsoil of both long-term forest land and 50-year-old afforestation was significantly higher in K (by 17 and 16 mg/kg, respectively) and Mg (by 8 and 6 mg/kg, respectively) while having lower pH and base saturation (by 7% and 12%, respectively) compared to 10-year-old plantations situated on former agricultural land, where the differences between both soil layers were found insignificant (Table 2). Both tests provided the same results at 0.05 significance level. Among analyzed variables, a degree of base cations saturation illustrates legacy of agriculture the best. We found difference not only in horizons; the results reflect also land-use history. In accordance with the above-mentioned results, the young plantations show the highest level of base saturation (see Wall, Hytönen 2005) having values of both topsoil and underlying horizon nearly equal (69% and 72%, respectively). On the other hand, the difference between topsoil layer and deeper one seems to be obvious either in long-term-forest sites or in 50-year-old afforestations. Both types of site have increased base saturation in deeper layers (Alriksson, Olsson 1995); the difference was found significant for former fields. Moreover, the sites under conditions of altered land use 50 years ago remain still significantly higher (Wall, Hytönen 2005) in base saturation compared to forest soil (Fig. 2).

Also an age of the stands plays important role in process of forest environment restoration; Alriksson and Olsson (1995) reported significantly more acidic top soil under spruce stands at the age of 40–55 years compared to the other ones at the age of 20 years. We found similar trend since long-term forest sites covered with spruce were significantly more acidic compared to those spruce afforestations at the age of 50 years. Therefore the land use and subsequent legacy of manuring and fertilization play still important role when affecting particular soil conditions (Ritter et al. 2003).

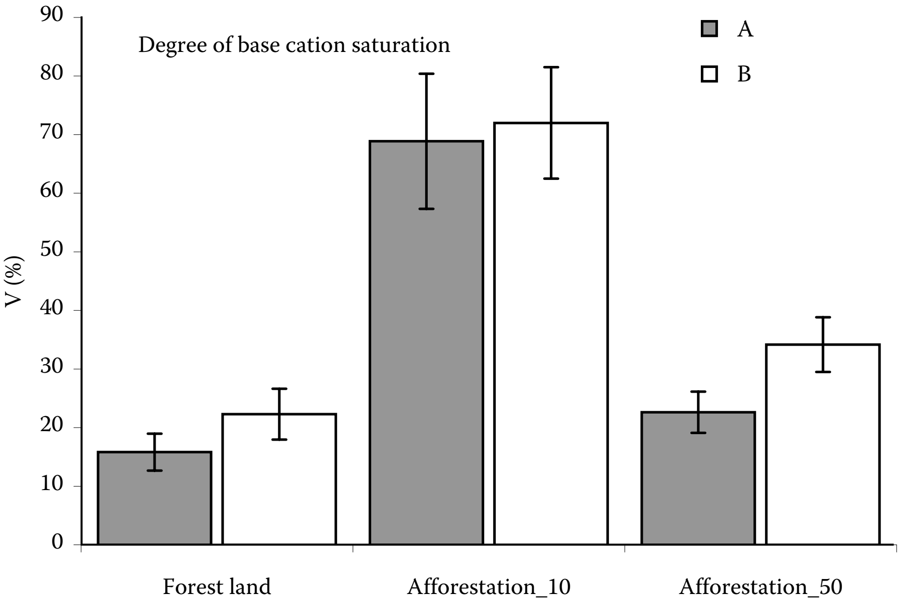

Fig. 2. Mean values of base cation saturation according to land-use history analyzed in both topsoil (A) and subsoil (B) horizons. Error bars represent confidence intervals at a 0.05 significance level. Forest land – soils covered with forest stand for more than one rotation period; Afforestation_10 – young stands not older than 10 years; Afforestation_50 – the stands at the age of approximately 50 years

CONCLUSIONS

Legacy of former agricultural practices has been of great importance so far in the soil covered with forest stand during first years after afforestation. In our study the degree of base cations saturation, pH, and concentrations of Ca and Mg were significantly higher in recently wooded formerly tilled soils than in comparative untilled ones (both of forest and former-meadow origins). The results of base saturation also reflect land-use history very well. There were found no significant differences between 0–10 cm and 11–30 cm samples within group of new plantations situated on formerly tilled soil. On the other hand, the differences were found either within group of forest soils or within group of roughly 50-year-old stands on former agricultural land. The base saturation values were significantly higher in deeper layers; even the difference between comparable horizons of forest soils and 50-years-afforested ones was found significant. Answering the research questions, there were found significantly altered soil properties due to cultivation on sites under conditions of initial forest stage. Adjacent older afforestations tend to restoration of properties of at least semi-forest soils being significantly lower in investigated variables compared with new forests on formerly tilled and fertilized sites. However, the 50-year-old afforestations have been significantly different (higher in nutrient concentrations and base saturation) from long-term forest stands. The study answers questions concerning cambisol sites ranging from lower to higher altitudes; further research is needed. In spite of experienced success in establishing forest under agricultural-soil conditions, new stands have to be regarded as a "transitive" stage of forest development because of pioneer character of such first-generation forest stands. Even though the legacy of agricultural practices may have endured in soils even for centuries after abandonment and afforestation, cultivation-induced soil properties do not represent any excessive risk for the new forests.

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Jak přispívají pozůstatky zemědělského hospodaření k formování půdních vlastností po zalesnění?

ABSTRAKT: Půdní vlastnosti lesních ekosystémů závisejí na vlastnostech matečného materiálu a organismech v půdě, tj. společenstev dřevin včetně souvisejících rostlinných a živočišných společenstev. Nicméně tyto půdy byly v důsledku zemědělského hospodaření změněny; dodání živin a organického materiálu vedlo ke zvýšení úrodnosti svrchní vrstvy půdy. Dokonce i některé dlouhodobě zalesněné půdy vykazují rozdíly považované za pozůstatky zemědělského hospodaření v minulosti. Tyto změny zůstávají patrné desítky let, ačkoliv změněné vlastnosti jsou zřetelné zejména v prvních letech po zalesnění (zhruba 10 let). Pouze v původně orané půdě jsme nalezli zvýšené koncentrace živin (P, K, Ca a Mg) a následně zvýšenou saturaci bázemi (V %). Navíc zde nebyl v tomto ohledu patrný žádný rozdíl mezi vlastnostmi svrchní části půdy a hlubšími horizonty (69 % a 72 %). Ve srovnání s desetiletými zalesněními byly detekovány signifikantně nižší saturace bázemi (obě vrstvy 0–10 cm a 11–30 cm) zjištěné jak pod dlouhodobými lesními porosty, tak pod 50 let starým zalesněním (obojí jsou porosty smrku ztepilého). Také saturace svrchní vrstvy půdy byla pod dlouhodobě lesními a padesát let zalesněnými porosty nižší ve srovnání s hlubšími vrstvami půdy.

Klíčová slova: zalesňování; zemědělská půda; půdní vlastnosti; živiny přístupné rostlinám; smrk ztepilý

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