Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/forestsystems
doi: http://dx.doi.org/10.5424/fs/20112003-11042

Forest Systems 2011 20(3), 437-443
ISSN: 1131-7965
eISSN: 2171-9845

Former agriculture impacts on properties of Norway spruce forest floor and soil

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Abstract

Forest floor is considered a major feature distinguishing forest from agricultural soils. Forest floor develops as forest stands grow and is composed of more or less altered plant-tissue biomass accumulated on the soil surface. Our study's aim was to find whether properties of both the organic layers and mineral soil differ according to the land-use history of the sites compared. Each site included an afforested area of immature 50-year-old spruce forest (AFF) on formerly agricultural land plus an adjacent area of old-growth 100-year-old spruce stand (FOR). The localities are situated at altitudes ranging between 600 and 850 metres above sea level. From the results of our study it can be concluded that both forest floor and mineral soil had higher pH and Ca concentration at formerly agricultural sites. C/N ratio is significantly lower in afforested soil. First-generation humus was significantly higher in phosphorus.

Key words: afforestation; land use; legacy of agriculture; *Picea abies* (L.) Karst.

Resumen

Impactos en las propiedades del suelo de los bosques de pinabete en terrenos agrícolas abandonados

El piso forestal es considerado una de las principales características distintivas de los suelos forestales frente a los agrícolas. El piso forestal se desarrolla según crecen las masas forestales y se compone de tejidos de vegetales de la biomasa más o menos alterados acumulados en la superficie del suelo. El objetivo de nuestro estudio fue determinar si las propiedades de las capas orgánicas y minerales del suelo difieren de acuerdo a la historia del uso del suelo de los sitios. Cada sitio incluye un área reforestada de bosque de pinabete inmaduro de 50 años de edad (AFF) en antiguo terreno agrícola, más un área adyacente madura de pinabete de 100 años de edad. Las localidades se encuentran en altitudes que oscilan entre 600 y 850 metros sobre el nivel del mar. De los resultados de nuestro estudio se puede concluir que tanto el suelo del bosque como el suelo mineral tenían un pH más alto y mayor concentración de Ca en los sitios agrícolas abandonados. La relación C/N es significativamente menor en los suelos reforestados. La primera generación de humus presentó un significativamente mayor contenido en fósforo.

Palabras clave: reforestación; uso del suelo; *Picea abies.*

Introduction

A surface organic layer forms as forest stand grows and creates canopy. This layer is an important source of organic matter to the soil. Over time, organic matter consisting of plant tissues (litterfall) accumulates on the soil surface. This material is collectively referred to as forest floor (Briggs, 2004). As this forest floor decomposes, it creates organic horizons such as litter, fermented material and humus typical of forest soil. A presence of these surface organic layers is a principal visible feature distinguishing forest from agricultural soils (Briggs, 2004). Agricultural cultivation has such an important impact on soil properties that they no longer resemble those of a forest soil (Torreano, 2004). From a historical point of view, the beginning of deforestation for agricultural purposes dates back to the Neolithic Age (Ložek, 1999; Olofsson and Hickler, 2008). Thousands of years of cultivation have probably been a key earth-transforming process (Wiliams, 2000). However, forest land that had been converted into fields, meadows and pastures can once again become forest land due to both succession and artificial afforestation. This is a common practice for managing abandoned or less-productive agricultural land. In such cases, some environmental features of the new forests still reflect the former agriculture. For instance,

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Received: 24-11-10. Accepted: 29-07-11.

tillage and fertilization lead to formation of an arable horizon and changes in the distribution of soil organic matter (Domżał *et al.*, 1993). Such ameliorative measures have long-term impacts on the properties of soils being altered to grow crops (Bedrna, 2002). The altered soil properties can be found decades and even centuries after afforestation (Szujecki, 1996; Ritter *et al.*, 2003; Morris, 2004; Wall and Hytönen, 2005; Wall and Westman, 2006; Koerner *et al.*, 1997; Verheyen *et al.*, 1999; Richter *et al.*, 2000; Dupouey *et al.*, 2002) and can be considered as a legacy of former agriculture. For example, thick A horizons that are high in soil organic matter and phosphorus and which are key factors for classifying profiles as formerly cultivated (Singer and Munns, 1996) help to prove manuring in the past (Ellert and Gregorich, 1996; Oheimb *et al.*, 2008).

Our study focuses on properties of both forest floor and soil on sites experiencing different land use in past decades. The samples were taken beneath Norway spruce [*Picea abies* (L.) Karst] stands established during the 1950s, when a decreased number of inhabitants had led to a surplus of marginal agricultural land. Although the new stands greatly changed the soil environment, we had supposed that some soil properties typical of cultivated soils had long endured and were also impacting on properties of the surface organic layers. This study deals with alteration of soil properties by comparing formerly agricultural (AFF) to old-growth (FOR) forest soil and addresses the research question: Do both forest floor and soil of afforested agricultural land 50 years after afforestation differ from those of long-term forest origin?

Materials and methods

The study area (Fig. 1) represents soils derived from metamorphic rocks, *i.e.* phyllites, greenschists (metabasites), mica schists and gneisses (Opletal and Domečka, 1983), north-eastern Bohemia, Czech Republic. The localities on gneiss, phyllite and greenschist were situated at altitudes ranging between 590 and 650 metres above sea level while those on mica schist were located at altitudes ranging between 750 and 850 metres above sea level. All localities include two sites of different land-use history. We focused our analysis on neighbouring wooded sites of formerly agricultural and old-growth origins to provide reliable data from comparable site conditions. The first-rotation stands could be easily distinguished from long-term forest land because tip-up mounds were missing. These local terrain disturbances usually form in soil when the uprooted base of a fallen tree excavates mineral soil (Schaetzl *et al.*, 1989). If the mounds were present in stands, we would consider such sites as long-term forest. In addition to the locally disturbed soil surface, recognition of the new stands on formerly agricultural soil was possible from such evidence as remnants of buildings and former baulks. Sampling was done three or four times within each of the two sites (afforestation and old-growth origin). In total, we sampled eight localities. Forest floor samples were taken using a square iron frame (625 cm^2) to demarcate an area for collecting all enclosed forest floor material. This permitted us to calculate dry-mass weight per unit area. Both forest floor and mineral soil (0-10 cm topsoil) samples were analysed for pH measured in H_2O, plant-available nutrient element (P, K, Ca, Mg) concentrations (mg kg^{-1}) using the Mehlich III method (Mehlich, 1984; Zbíral, 1995), humus (carbon) content (% by the Springel-Klee method), and N content (% by the Kjeldahl procedure). Mean values were calculated from particular samples taken in both variants (different land-use origin sites) at all localities in order to avoid pseudo-replications. Data were standardized (*i.e.* the mean of a variable was subtracted from a given value of that variable and the value thus obtained was divided by the standard deviation). For purposes of analysis, we used PCA (principal component analysis) and RDA (redundancy analysis) methods. Calculated significance level (p-value, see Fig. 3) were obtained using a Monte Carlo permutation test. Data was analysed using CANOCO 4.5 software. The data were also ana-

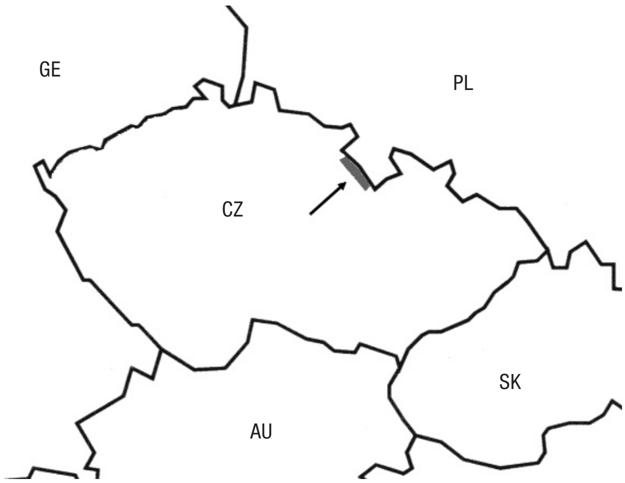

Figure 1. Localization of the study area (grey), Czech Republic.

lysed by two-sided paired t-test (Zar, 2009) using UNISTAT software.

Results

Analysis of forest-floor humus showed a positive correlation between concentrations of base nutrients (Ca, Mg) and pH in both formerly agricultural and long-term forest sites (Fig. 2). However, humus of first-generation forests was found to have significantly higher pH and calcium concentration compared to humus of long-term origin. In addition to these characters, we also found the first-generation humus to be significantly higher in concentration of plant-available phosphorus (Table 1).

Concentrations of magnesium, calcium and potassium (Fig. 2) showed a strong correlation in formerly agricultural soil, whereas those nutrients in forest soil showed only weak correlation. Calcium and pH showed significantly increased values in formerly cultivated soil (Table 1). There was also a significantly lower C/N ratio compared to soil covered with long-term spruce forest. In addition to the other analyses, the RDA method confirmed the importance of pH, Ca and P as soil properties in telling us how the formerly cultivated soil differs from the long-term forest soil (Fig. 3).

Among the eight localities investigated, six of the afforested 50-year-old stands had lower amounts of forest floor dry mass compared to old-growth spruce stands (Fig. 4). One locality showed the same trend but the difference was not found to be significant. Just one locality had nearly the same values for both the afforestation and neighbouring old-growth forest.

Discussion

Preparing soil for agricultural purposes means chiefly optimizing nutrient supply and pH by means of such

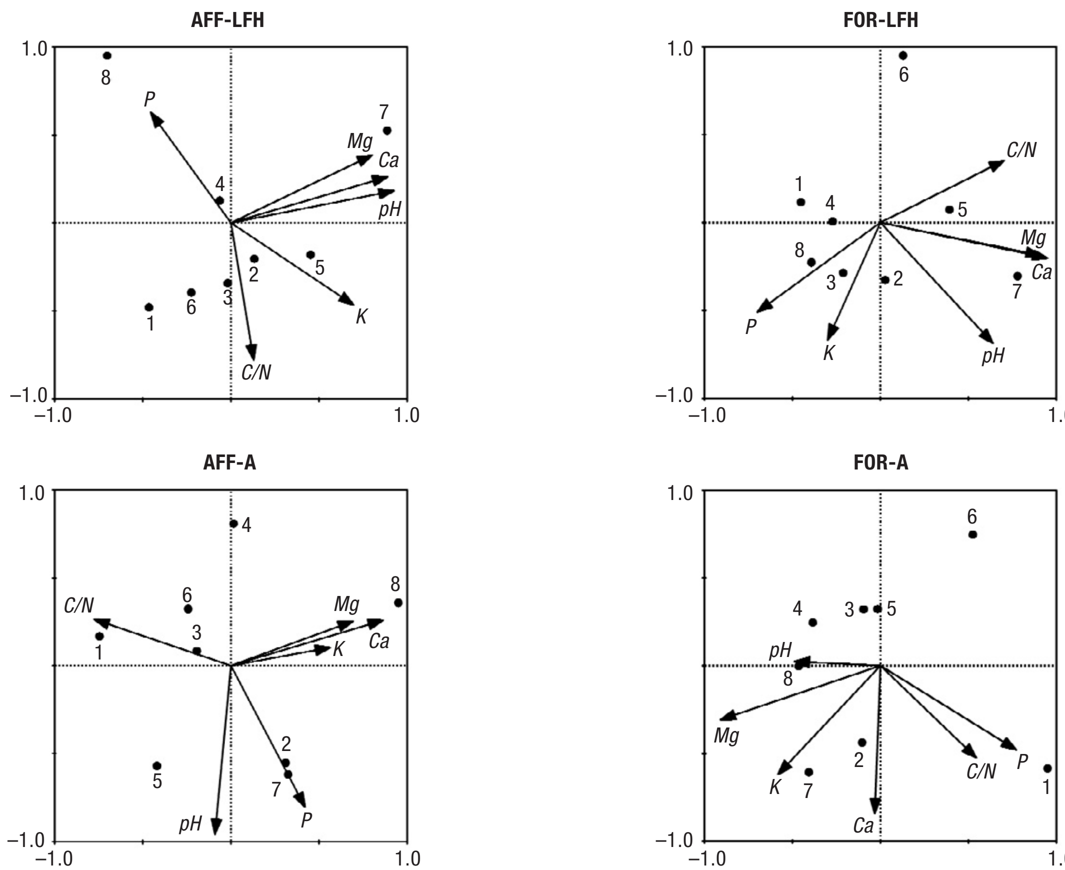

Figure 2. PCA of forest-floor (LFH) and mineral topsoil (A) samples of both variants. Captions: AFF, 50-year-old afforestation; FOR, long-term 100-year-old forest; LFH [L, fibric material, relatively undecomposed, F, hemic material, moderately decomposed, H, sapric material, highly decomposed amorphous humus (*source:* Briggs, 2004)]; 1-8 denote eight sampled localities.

Table 1. P-values for two-sided paired t-test, without correction for multiple testing; eight replications were considered

Layer	Variable	AFF	FOR	AFF-FOR	p-value
LFH	P (mg kg^{-1})	44.85	33.10	11.75	0.0035
	Ca (mg kg^{-1})	1,447.21	1,144.21	303.00	0.0062
	K (mg kg^{-1})	318.63	325.06	–6.44	0.7209
	Mg (mg kg^{-1})	135.10	140.96	–5.85	0.4345
	pH	3.78	3.60	0.18	0.0129
	C/N	21.01	19.09	1.92	0.3471
A	P (mg kg^{-1})	16.50	5.02	11.48	0.1604
	Ca (mg kg^{-1})	253.85	212.80	41.05	0.0475
	K (mg kg^{-1})	63.02	63.04	–0.02	0.9967
	Mg (mg kg^{-1})	33.92	35.80	–1.89	0.2912
	pH	4.00	3.78	0.22	0.0023
	C/N	14.21	18.58	–4.38	0.0165

Captions: LFH, forest floor; L, fibric material, relatively undecomposed; F, hemic material, moderately decomposed; H, sapric material, highly decomposed amorphous humus (source: Briggs 2004); A, mineral topsoil (0-10 cm); AFF, afforested agricultural land; FOR, long-term forest.

ameliorative measures as adding both natural and man-made amendments. For instance, optimizing phosphorus content is considered a principal worldwide cultivation practice since almost all soils have naturally low contents of plant-available phosphorus. Therefore, increased content of this nutrient in soil can be attributed to deliberate ameliorative efforts in the past (Bedrna, 2002). Formerly agricultural soils (Koerner *et al.*, 1997; Falkengren-Grerup *et al.*, 2006; Armolaitis *et al.*, 2007; Oheimb *et al.*, 2008; Valtinat *et al.*, 2008) and contemporarily cultivated soils (Ellert and Gregorich, 1996; Smal and Olszewska, 2008, Podrázský *et al.*, 2009) have been shown to be better supplied with phosphorus relative to uncultivated soils. In measuring phosphorus concentrations in forest floor at our study sites, we found increased values also for formerly cultivated sites. The trend of increased phosphorus was found also in topsoil, though the difference was not significant. In our study, both forest floor and topsoil of afforestation origin were also higher in calcium compared to those of old-growth forest and showed a trend similar to that reported by Wall and Hytönen (2005), who had investigated Norway spruce afforestations in Finland. One of the most important characteristics indicating restoration of a forest-soil environment is pH, which is to say that pH decreases following afforestation (Grieve, 2001; Thuille and Schulze, 2006). Norway spruce is considered to be the most important species contributing to increased soil acidification (Binkley and Valentine, 1991; Brandtberg *et*

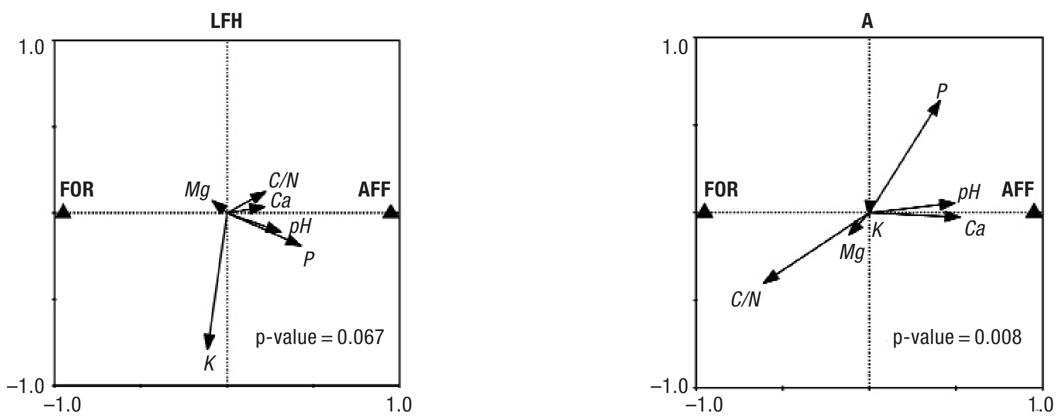

Figure 3. RDA of forest floor (LFH) and mineral topsoil (A 0-10 cm) samples. Captions: FOR, long-term forest (100 years old); AFF, afforested agricultural soil (50 years old); L, fibric material, relatively undecomposed; F, hemic material, moderately decomposed; H, sapric material, highly decomposed amorphous humus (*source:* Briggs, 2004).

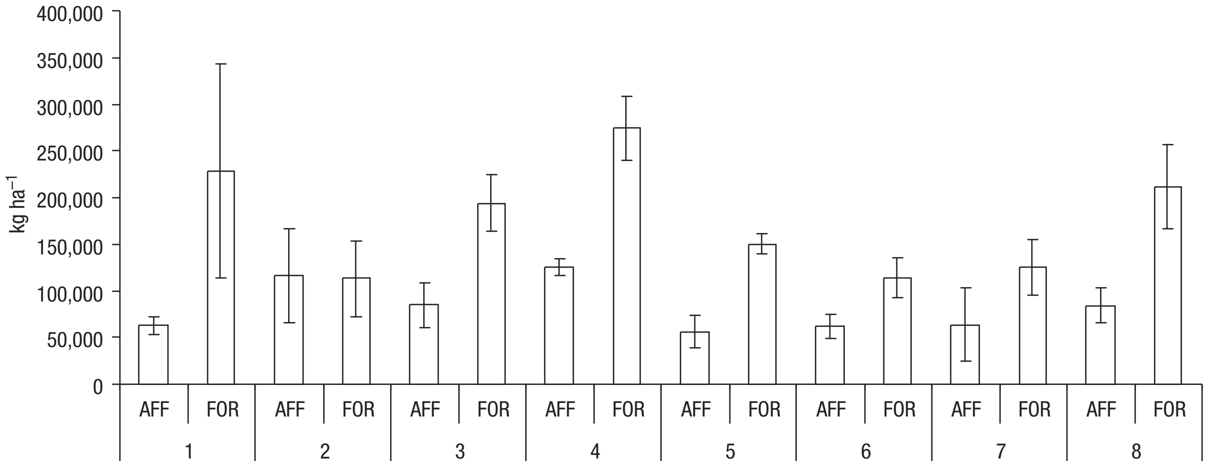

Figure 4. Mean quantity of forest floor dry mass (L, F and H horizons altogether) of spruce origin. Captions: AFF, afforested agricultural land; FOR, long-term forest; L, fibric material, relatively undecomposed; F, hemic material, moderately decomposed; H, sapric material, highly decomposed amorphous humus (*source*: Briggs, 2004); error bars denote standard deviation. 1-8 denote eight sampled localities.

al., 2000; Podrázský and Štěpáník, 2002; Augusto *et al.*, 2002, 2003; Hagen-Thorn *et al.*, 2004). For our study sites, a certain trend of higher pH in both forest floor and topsoil on former agricultural land was found compared to neighbouring old forests. Stand age may also be a factor here. Alriksson and Olsson (1995), Ritter *et al.* (2003), Wall and Hytönen (2005), Cerli *et al.* (2006), and Smal and Olszewska (2008) all had confirmed an important role of age in relation to increasing acidification, as they had found lower pH in forest floor and soil of older stands origin compared with younger afforestation. Keersmaeker *et al.* (2004) had found no correlation between age and pH, however, even though pH's variability was greater in soil of long-term forest origin. The higher pH in our study seems attributable to former liming, as reported by Ritter *et al.* (2003).

The C/N ratio appears to be a very good indicator as to degree of humus decomposition and soil organic matter quality (Batjes 1996). The raw forest floor humus of young, initial-stage accumulation has high C/N values since the organic layer covering the soil is composed mainly of assimilatory tissues, flowers, twigs and bark (Briggs, 2004; Thuille and Schulze, 2006) high in carbon. As this almost intact plant matter decomposes, the C/N value decreases and conditions as to nitrogen supply improve (Singer and Munns, 1996). As carbon is turned into carbon dioxide during decomposition, the CO_2 is released and the remaining nitrogen decreases the C/N ratio of organic matter forming humus (Šimek, 2003). We therefore can estimate the rate of forest floor humification using the C/N ratio. Comparing topsoil C/N ratios for continuous and afforested sites, many authors (Ellert and Gregorich, 1996; Koerner *et al.*, 1997; Compton *et al.*, 1998; Jussy *et al.*, 2002; Ritter *et al.*, 2003; Prévosto *et al.*, 2004; Oheimb *et al.*, 2008; Smal and Olszewska, 2008; Valtinat *et al.*, 2008) have found significantly lower values in formerly agricultural soil in comparison with forest soil. In agreement with information from the literature, we found significantly lower C/N ratios in 0-10 cm of topsoil of formerly agricultural soil compared to adjacent long-term forest soil.

A carpet of organic matter layers forming forest floor is likely to be the principal visible feature of forest soils (Torreano, 2004). The forest floor covering soil develops as litterfall occurs in young forest stands. Such initially accumulated organic material cannot yet be considered a completely formed forest floor, because this layer consists mainly of non-altered dead plant material. The organic layer occurs in Norway spruce stands roughly ten years after afforestation. Ouimet *et al.* (2007) reported the beginning of forest floor accumulation at a similar age. A certain trend of quanttative increase in the amount of surface humus (carbon) has been found in relation to increased age (Keersmaeker *et al.*, 2004; Cerli *et al.*, 2006, 2008; Niu and Duiker, 2006; Ouimet *et al.*, 2007) for forest stand or in comparing both younger forest stands situated on formerly agricultural soil with old-growth forest on at least semi-natural sites (in terms of weight of dry mass: Podrázský and Remeš, 2007, Podrázský and Procházka, 2009; as to thickness of forest floor, storage of carbon and nitrogen: Alriksson and Olsson, 1995; Thuille and Schulze, 2006; Oheimb *et al.*, 2008; Ritter *et al.*, 2003). Except for two comparative sites, we also found significant differences between 50-year-old afforestation and adjacent long-term forest in terms of their having different amounts of forest floor.

Conclusions

The study reported in this paper has shown that it was still possible to recognize a legacy of former deliberate cultivation in soils covered with first-generation Norway spruce stands. It can be concluded that formerly agricultural soil can be distinguished from soil covered with long-term stands in terms of higher nutrient concentrations (of calcium and phosphorus), pH and lower C/N ratio. These higher values are likely to reflect artificial fertilization in the past. The formerly cultivated mineral soil was higher in calcium (254 mg kg^{-1}) compared to forest soil (213 mg kg^{-1}). Soil pH was also higher (4.00) in afforested soil compared to long-term forest soil (3.78). Forest floor under first-generation forest was also higher in both calcium and pH. In addition to calcium and pH, the new forest floor was higher in phosphorus (45 mg kg^{-1}) compared to non-cultivated forest soil (33 mg kg^{-1}).

Acknowledgements

The study was undertaken with financial support from the Ministry of Agriculture of the Czech Republic within projects QH91072 and MZe 0002070203. We also thank Mr. Gale Allen Kirking for editing the language.

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