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Short communication

Differences in soil chemistry between early and late succession of oak-hornbeam forest after grassland abandonment

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Abstract – Changes in C and nutrient cycling during succession are well studied, however, results can be contrasting for different nutrients and successional sequences. We analyzed soil chemical differences between early and late succession of oak-hornbeam forest. Late forest succession efficiently retained plant-available P, and total Mn, Zn, Fe, Cu, and Ni pools in the soil, as their concentrations were similar to those of early-successional grasslands. Available K, soil organic C, and organic matter content, as well as C:N and C:S ratios were higher in late than in early succession. Soil organic N and S concentrations did not differ between the stages.

Keywords: ecosystem development, *Epimedio-Carpinetum betuli*, forest restoration, oak forest development, soil-vegetation relationships

Introduction

Generally, due to increment of litter rich in lignocellulosic components during late forest succession, nutrient mineralization rate is expected to decelerate, and large amounts of nutrients become captured within tree biomass. Also, due to the different functional compositions of most grassland and forest communities, it can be expected that these two vegetation types will exert different influences on nutrient retention and cycling. Plants in most early successional stages such as grasslands (except those growing on very nutrient-poor soils) are often characterized by lower C:N and C:P ratios, higher N and P contents, and lower content of lignocellulosic components in their tissues than those of species from late successional stages, such as forests (Vitousek et al. 1988, Poorter et al. 2004, Cortez et al. 2007). Therefore, it can generally be expected that litter mineralization will be much faster in early successional grasslands than in late successional stages, especially because the high content of lignocellulosic components (primarily that of lignin) in the tissues of late successional tree species delays the release of nutrient forms available to plants.

Here, we report local-scale differences in soil chemical properties between early and late succession of oak-hornbeam forest (association *Epimedio-Carpinetum betuli* (Horvat 1938) Borhidi 1963) after cessation of agricultural land use (i.e. grassland abandonment) in NW Croatia.

Materials and methods

Study area

The study was conducted in the surroundings of Brlog Ozaljski village, near the city of Ozalj in NW Croatia. Existing grasslands at the study site are used as hay-pastures dominated by *Avenula pubescens* (Huds.) Dumort. (i.e. as occasionally grazed meadows), and after abandonment, the succession pathway is the following: successional grasslands (2–5 years), *Cornus sanguinea* L. and *Prunus spinosa* L. shrubs (5–15 years), *Populus tremula* L. stage (15–30 years), and oak-hornbeam forest (> 30 years). This last forest stage represents the *Epimedio-Carpinetum betuli* association. The soil type was slightly leached calcic cambisol on biolithitic and bioclastic limestones.

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Soil sampling and analyses

To analyse the differences in soil chemistry between the early and late successional stages, six pairs were selected, each containing early successional stage of grassland and the late successional stage of forest, as close to each other as possible. Each pair of grassland and forest plots represented a block. The grasslands selected for this purpose were recently used hay-pastures undergoing colonization with successional grasses, whereas forest plots selected for this purpose were late successional mixed stands of *Populus tremula*, *Carpinus betulus* L., and *Quercus petraea* (Matt.) Liebl. and/or *Q. robur* L. Soil was sampled from the top soil at a depth of 0–10 cm. Soil sampling was performed from February 28 to March 2, 2020, before the beginning of the vegetation season.

Soil analyses were carried out using air-dried, homogenized, and sieved soil samples (< 2 mm sieve). The details about soil chemical analyses are given in On-line Suppl. Tab. 1.

Tab. 1. The results of blocked ANOVA for the differences in soil chemical properties between early succession (i.e. grassland stage) and late succession (i.e. forest stage) (n = 6) If the block effect was insignificant (P > 0.25), then the F and P values for the succession effect corresponded to those of simple one-way ANOVA, whereas if the block effect was significant (P < 0.25), then the F and P values for the succession effect corresponded to that of blocked ANOVA (i.e. two-way ANOVA without replication); SOC – soil organic carbon, SOM – soil organic matter, N – soil organic nitrogen, S – soil organic sulfur, C:N – soil carbon to nitrogen ratio, C:S – soil carbon to sulfur ratio, N:S – soil nitrogen to sulfur ratio, P_A and K_A – ammonium lactate-extracted plant available phosphorus and plant available potassium, respectively, Mn – soil total manganese, Zn – soil total zinc, Cu – soil total copper, Ni – soil total nickel, Fe – soil total iron.

Soil feature	F	Block effect	Succession effect
pH 1 M KCl	0.0003	**0.19**	0.99
SOC, g kg^{-1}	8.28	0.81	**0.02**
N, g kg^{-1}	0.29	0.84	0.61
S, g kg^{-1}	1.17	0.55	0.30
C:N	296	**0.03**	**< 0.0001**
C:S	7.32	0.50	**0.02**
N:S	0.20	0.80	0.67
P_A, mg (100 g)$^{-1}$	2.28	0.57	0.19
K_A, mg (100 g)$^{-1}$	7.41	**0.01**	**0.04**
Mn, mg kg^{-1}	0.11	0.35	0.75
Zn, mg kg^{-1}	0.55	0.49	0.48
Cu, mg kg^{-1}	0.21	0.75	0.66
Ni, mg kg^{-1}	0.99	**0.16**	0.36
Fe, g kg^{-1}	1.49	0.49	0.25

Data analysis

The differences in soil chemistry between early and late succession were analyzed by two-way analysis of variance (ANOVA) without replication in order to account for inter-site variation (i.e. including the block effect). One-way ANOVA without blocking was used for the variables that were not significantly influenced by inter-site variation (i.e. if the block effect was > 0.25). Threshold value of 0.25 was chosen for assessment of the significance of the block effect because it is more stringent than the usual threshold of 0.05 for the purpose of determining the inter-site variation of the soil chemical properties. The data was analyzed using PAST 4.03 software.

Results and discussion

The results suggested that the SOC content in the top soil was 16.4 g kg^{-1} higher on average ($P < 0.05$), in the late successional forest stage than in the grassland stage (Tab. 1 and On-line Suppl. Tab. 2). The forest stage also had higher C:N ($P < 0.0001$) and C:S ratios ($P < 0.05$) than the grassland stage in the top soil, whereas soil organic N and S concentrations and soil N:S ratio were not different ($P > 0.05$) (Tab. 1). The K_A concentration in the top soil of the late successional forest stage was higher ($P < 0.05$) than that of the grassland stage, whereas no significant differences in the concentrations of P_A and total Mn, Zn, Cu, Ni, and Fe were found between the two stages ($P > 0.05$) (Tab. 1). Detailed results of our soil laboratory analyses are given in On-line Suppl. Tab. 2.

The late successional forest stage had higher SOC contents in the topsoil than the early successional grassland stage, with a mean increase of 39%. This is expected, as the soil organic matter (SOM) in late successional forest has a wider C:N ratio than that of early successional grassland, and originates from the litter rich in lignocellulosic components, thus, being more resistant to degradation than grassland SOM in topsoil. In addition, soil organic N and S were not increased in late-successional forest stage, even though an increase could be expected because of the high SOM content in the forest stages that organic N and S originate from (David et al. 1982). Indeed, litter of early successional grassland should have higher N and S contents, but lower C:N and C:S ratios than that of late successional forest. Therefore, the loss of N and S via mineralization is faster in grassland than in forest stage, in which litter is more stable and decomposes much more slowly, which is expected to result in a longer retention of soil organic N and S in the forest than in grassland stage. On the other hand, soil C:N and C:S ratios in the topsoil were significantly higher in the late successional forest stage than in the early successional grassland stage. Increased soil C:N ratio in the forest stage could indicate that N mineralization in this stage is somewhat slower than in grasslands. Studies have suggested that N mineralization is slower in forest soils than in those of early successional stages, and that this is due to various processes related to the inhibition of nitrification (Rice and

Pancholy 1972). However, the results of studies that compared N mineralization in forest stages to that in early--successional stages vary (Robertson and Vitousek 1981, Vitousek et al. 1989, Yan et al. 2009), thus, a soil C:N ratio alone is not necessarily a reliable measure for evaluating N mineralization rates.

In the present study, soil K_A concentration was significantly higher in the late successional forest than in the grassland stage. As the effects of secondary succession on soil K pool are still understudied, it is hard to make a generalized conclusion about K cycling during succession; however, an increase in soil K pool following secondary succession has been already reported (Liu and Huang 2005). It is hard to conclude which reasons exactly underlie the increased K_A concentration under forest stages. Either trees possess an ability to substitute K^+ from the crystal lattice of clay minerals with H^+, thus efficiently extracting it into the soil labile pool (Boyle and Voigt 1973), or they are also able to efficiently increase its concentration through leaf litter deposition and throughfall. As the soil was sampled from the top soil, all processes are likely to contribute simultaneously to the increase in K supply. Further studies on plant nutritional statuses and litter decomposition rates during succession are required to clarify this.

On the other hand, no differences in concentrations of P_A, and total Mn, Zn, Cu, Ni, and Fe in top soil were found between the grassland and the forest stage. Indeed, overall nutrient pools in the whole food chain of forest ecosystems are higher than in grasslands, however, nutrients are continuously being stored in the living trees and slowly decomposing dead biomass, thus, their turnover to the mineral soil is expected to be slower than that of hay-pastures. Despite this, supplies of the mentioned elements were efficiently retained in the topsoil of the late successional forest stage in the present study.

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