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Impacts of Norway spruce (*Picea abies* L., H. Karst.) stands on soil in continental Croatia

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A quantitative analysis of pedo-physiological indicators aimed at determining changes in the soil attributable to the effects of spruce plantations was done. The study was conducted at eight sites in central and north-western Croatia where spruce plantations were planted in the late 20th century. At each site, a pedological profile was opened within the spruce plantation and the endo-morphological parameters of the soil were determined. Composite soil samples from two depths (0-10 cm and 10-20 cm) and from the forest floor were taken in the spruce plantation and compared with samples taken at plots covered by natural vegetation (natural stands) located in the surroundings. The following pedo-physiographic indicators were measured on the collected soil samples: quantity of forest floor, particle size distribution of soil, pH values in H_2O and in $CaCl_2$ aqueous solution (concentration 0.01 mol dm^{-3}), content of C_{org}, content of N_{tot} and content of bioavailable nutrients (using the Mehlich III method). The results showed that the forest floor had a higher mass in the spruce plantations than in natural stands. The mineral soil showed clear trends of influence of the spruce plantations on soil in terms of reduced pH values. Most plots in the spruce plantations showed a lower nitrogen content in the soil, a higher C/N ratio and lower content of bioavailable phosphorus. This study provides an insight into the amelioration effects of spruce plantations on soil, and represent a reliable basis for decision-making in planning specific interventions in terrestrial ecosystems, such as the establishment of new forest plantations.

Keywords: Spruce Plantation, Forest Soil, Chemical Properties of Soil, Forest Floor

Introduction

In continental Croatia, which is similar to Central Europe in terms of climate and lithological properties, Norway spruce stands are not natural forests, but are artificial plantations. Significant planting of forests in Croatia began in the latter half of the 20th century, and was at its highest intensity from 1960 to 1990 (Perić et al. 2006). Spruce plantations were established in relatively small areas, from one to tens of hectares, in order to either reforest degraded lands (due to livestock grazing, soil erosion, etc.), in which spruce was the pioneer species, or for the purpose of converting poorly managed stands (coppice, thickets) into productive stands (Oršanić et al. 2000). Research has shown that certain species, tipically when planted in a monoculture, have varying impacts on soil (Klimo 2000). The specificity of such impacts is associated with the nature of the tree species, in terms of the quality and quantity of the organic matter participating in humus production, nutrient cycling, fertility maintainance and ecological stability of the forest ecosystem (Augusto et al. 2002, Mareschal et al. 2010, Kostić et al. 2016), leading to a modification of local microclimate and pedoclimate. Furthermore, the specific influences of vegetation on soil are associated with the macroclimatic conditions which will determine the production of organic matter and the dynamics of its humification and mineralisation (Berg & McClaugherty 2008). For these reasons, forest plantations can significantly modify physical and chemical properties of soil and soil processes (Moukoumi et al. 2006). Berger & Berger (2012) stated that coniferous tree species, due to the compounds in needles that take longer to decompose, slow nutrient cycling and microbiological activity, which leads to a lowering of soil pH. Previous research has shown that planting with conifers results in an increased stock of organic carbon in the soil (Vesterdal et al. 2008), lower pH values and changes in the content of carbon and nitrogen in soil (Binkley & Valentine 1991, Perković et al. 2007). Most studies on soil impacts have been conducted on natural and planted stands of Norway spruce (Lesná & Kulhavy 2003, Klimo & Kulhavy 2006, Galvan et al. 2008), since this is the most common species used in forest plantations of continental Europe. In particular, research during the last decades has focused on soil acidification and the reduced stand vitality resulting from climate change. At elevations less than 900 m a.s.l., spruce stands often contribute to the development of district cambisol and podzolic soils, *e.g.*, soils with acidic to very acidic reactions that are relatively poor in nutrients (Berger et al. 2004, Penízek & Zádorova 2012).

This study is based on the knowledge from the Central European spruce mono-

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cultures, which are currently affected by problems including massive diebacks. This has been associated with aero-pollution, soil acidification, bark beetle outbreaks, fungal diseases, etc. The objectives of this study were: (i) to examine the overall effects of spruce plantations on soil and to determine possible unfavourable effects of the tree species (Norway spruce) on soil; (ii) to examine the quantitative indicators of soil physiography in order to determine the soil changes that could be attributed to spruce plantations, and to evaluate the significance of such changes.

Material and methods

Study area

Eight localities were selected in central and north-western Croatia (Tab. 1, Fig. 1) where spruce plantations have been established during the latter half of the 20th century within the vegetation belts of beech, fir-beech and oak forests. Sampling sites were selected so as to include different types of spruce stands with regard to soil properties, climate and stand age (over 30 years). According to Koppen's climatic classification (Šegota & Filipčić 2003) the study area shows a temperature humid climate with hot summer (Cfb). The climate data were provided by the Croatian Meteorological and Hydrological Service from meterological stations that are the nearest to the investigated sites (Tab. 1). Natural stands at sites Ivanec, Lepoglava, Sošice i Žumberak belong to the beech forest with dead nettle (*Lamio orvalae-fagetum* /Horvat 1938/ Borhidi 1963), Medvednica and Macelj sites to the beech-fir forests (*Festuco drymeiae-Abietum* Vukelić et Baričević 2007) and sites Bosiljevo and Jalžabet forest to the sessile oak and common hornbeam (*Epimedio-Carpinetum betuli* /Horvat 1938/ Borhidi 1963). On the site Jalžabet, a degradation stage of sessile oak forest with bracken fern (*Pteridium aquilinum*) as dominant species was found. The specific information about study sites is given in Tab. 1.

Soil sample collection and analysis

At each selected locality, composite soil samples were collected both at a plot within the spruce plantation and in one nearby plot covered by natural vegetation (natural stand) located in close proximity of the plantation (Fig. 1, Tab. 1). Five composite samples of forest floor were also taken at each plot to calculate the forest floor load (Mg ha^{-1}). Each composite forest floor sample consisted of three subsamples taken within a frame of 25 × 25 cm, and the total fresh weight was measured considering all layers taken together (L, F and H horizons). The composite soil samples from the depths 0-10 cm and 10-20 cm were taken using an 80 mm diameter plastic probe and consisted of five subsamples taken at intervals of 1 m in a cross-shaped distribution. At each locality, five composite samples were taken from each layer, both in the spruce plantation and in the natural stand (20 samples per locality, totalling 160 samples). In each spruce plantation, a pedological profile was opened for the purpose of describing the endo-morphological properties of the soil. The following parameters were determined: share of soil skeleton by genesis horizons, thickness of horizons and total depth of the profile (FAO 2006). For

Tab. 1 - Basic characteristics of the study sites. The second row of each site represent the natural vegetation (reference plots).

Site	Vegetation type	Long E Lat N	Exposure (°)	Inclination (%)	Stand age (yrs)	Altitude (m a.s.l.)	Mean temp. (° C)	Precipitation (mm)	Parent material	Soil type (WRB)	Soil texture
Bosiljevo	Spruce culture	15°18′ 19″ E 45°24′ 50″ N	310	5	41	212	10.9	1095	Loess sediment on fossil red soil	Haplic Cambisol (Dystric)	Silt loam
	Sessile oak	15°18′ 16″ E 45°24′ 50″ N	300	7	41						
Ivanec	Spruce culture	16°07′ 07″ E 46°12′ 03″ N	10	26	36	423	10.2	1050	Dolomitized limestone	Leptic Calcisol	Silt clay loam
	Montane beech forest	16°07′ 13″ E 46°12′ 01″ N	0	29	80						
Jalžabet	Spruce culture	16°26′ 38″ E 46°14′ 29″ N	270	15	30	230	10.8	820	Loess sediment	Haplic Cambisol (Dystric)	Silt loam
	Sessile oak	16°26′ 39″ E 46°14′ 31″ N	270	5	30						
Lepoglava	Spruce culture	16°02′ 12″ E 46°16′ 12″ N	20	24	30	260	10.2	1050	Limestone	Leptic Cambisol (Dystric)	Silt clay loam
	Montane beech forest	16°01′ 53″ E 46°16′ 49″ N	20	25	80						
Macelj	Spruce culture	15°49′ 15″ E 46°14′ 54″ N	195	27	44	330	9.3	1196	Sandstone	Haplic Cambisol (Dystric)	Sand loam
	Beech-fir forest	15°49′ 23″ E 46°14′ 47″ N	190	32	80						
Medvednica	Spruce culture	15°58′ 51″ E 45°55′ 03″ N	20	26	85	765	7.1	1252	Greenschist	Haplic Cambisol (Dystric)	Loam
	Beech-fir forest	15°58′ 58″ E 45°55′ 08″ N	20	28	100						
Sošice	Spruce culture	15°23′ 15″ E 45°44′ 08″ N	65	24	38	765	10.9	1079	Limestone	Leptic Cambisol (Dystric)	Silt loam
	Montane beech forest	15°23′ 17″ E 45°44′ 04″ N	65	24	28						
Žumberak	Spruce culture	15°28′ 38″ E 45°46′ 58″ N	220	13	55	720	10.9	1079	Marl	Haplic Cambisol (Dystric)	Silt clay loam
	Montane beech forest	15°28′ 37″ E 45°46′ 59″ N	220	15	105						

laboratory analyses, air-dried soil samples were used. Samples were crumbled and sieved twice (2 and 0.2 mm mesh – ISO-11464 1994). The following pedo-physiographic parameters were measured for each sample: particle size distribution (ISO-11277 2009), pH value of soil in H_2O and in $CaCl_2$ aqueous solution (concentration 0.01 mol dm^{-3} – ISO-10390 2005), carbonate content - volumetric method (ISO-10693 1995), carbon content (C_{tot} – ISO-10694 1995) and nitrogen content (N_{tot} – ISO-13878 1998) using the Flash 2000® Combustion NC Soil Analyzer (Thermo Fisher Scientific, Waltham, MA, USA). The forest flooor samples were sieved through 2 mm sieve in laboratory and the minerals were extracted from organic soil. Forest floor samples were dried at a temperature of 50 °C (Pernar et al. 2013) until constant mass was reached and used to determine the forest floor load per unit area. The share of bioavailable elements (P, K, Ca, Mg and Fe) following extraction by Mehlich III solution was determined using atomic emission spectrometry with inductively coupled plasma ICP-AES (Mehlich 1984).

For all the analysed variables, detailed descriptive analysis was obtained for each site. The differences between plantations and natural stands were tested using the *t*-test when the condition of homogeneity of variance was met; otherwise, the non-parametric Mann-Whitney U-test was used. All statistical analysis was performed using the software package Statistica® ver. 8.0 (StatSoft Inc., Tulsa, OK, USA).

Results and discussion

Forest floor

The analysis of data by site revealed that there was a greater accumulation of the forest floor layer (L, F and H – together) in spruce plantations in comparison to natural stands, with the exception of the site Ivanec (Fig. 2). The greater mass of forest floor in natural stands at Ivanec compared to the corresponding plantation could be due to the site aspect (north-facing), which results in a slower decomposition of organic matter, and the age of the natural stands. Many studies reported a larger accumulation of forest floor load in spruce plantations in comparison with beech forests (Bagherzadeh et al. 2008, Fabiánek et al. 2009, Berger & Berger 2012) or oak forests (Perković et al. 2007), which are the reference stands in this study. The reason of the greater accumulation of organic matter in spruce plantations is the slower decomposition of organic material (needles) due to the higher ratio of slowly decomposing organic compounds (Haider 1992, Gartner & Cardon 2004, Berger & Berger 2012). According to Kubartová et al. (2009), the rate of decomposition of organic remnants increases in the following order: common pine < spruce < Douglas fir < beech. Furthermore, the higher accumulation of organic matter in spruce plantations largely depends on other habitat properties, particularly climate and soil quality (Johnson & Curtis 2001). Spruce plantations show a different microclimate compared to broadleaved forests, mainly due to the lower insolation of soil and the higher interception of precipitation, thus affecting the process of decomposition of organic matter. In this study, the average mass of the forest floor in spruce plantations was about 30 % higher than in natural stands. The greatest difference was found at the site Bosiljevo, where the forest floor mass in the spruce plantation was three

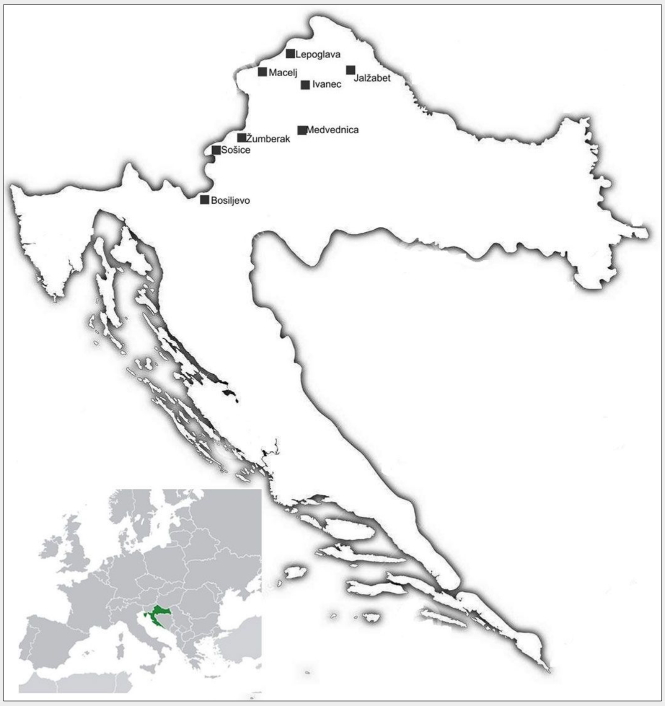

Fig. 1 - Geographic distribution of the sampled stands (black squares) in Croatia.

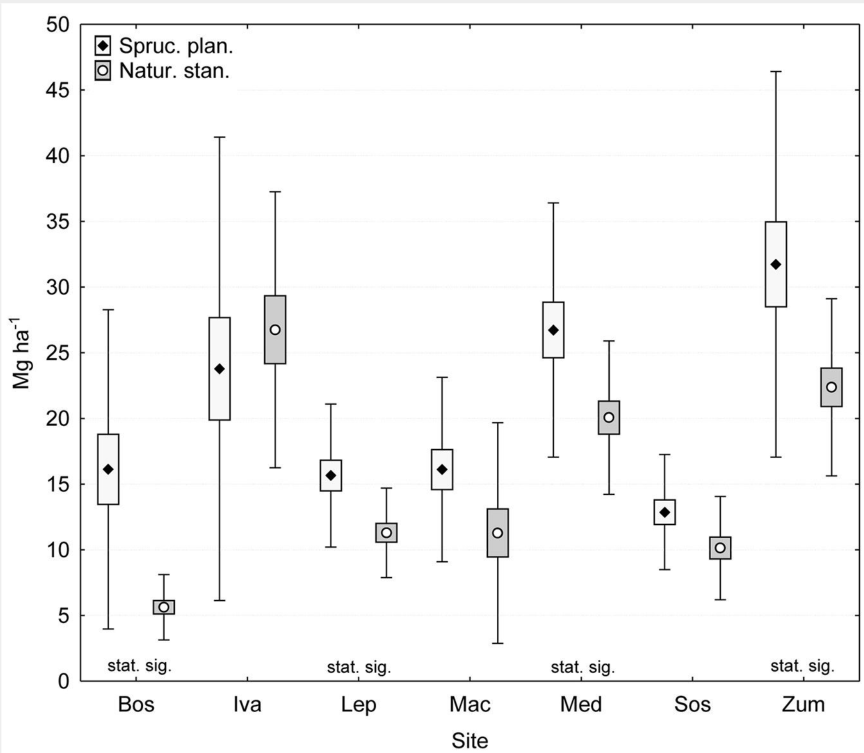

Fig. 2 – Results of the *t*-test or Mann-Whitney U test on the differences in the accumulation of leaf litter between spruce plantations (Spruc. plan.) and natural stands (Natur. stan.) at each study site (Bos - Bosiljevo; Iva - Ivanec; Jal - Jalžabet; Mac - Macelj; Med - Medvednica; Sos - Sošice; Zum - Žumberak):, (stat. sig.): statistically significant.

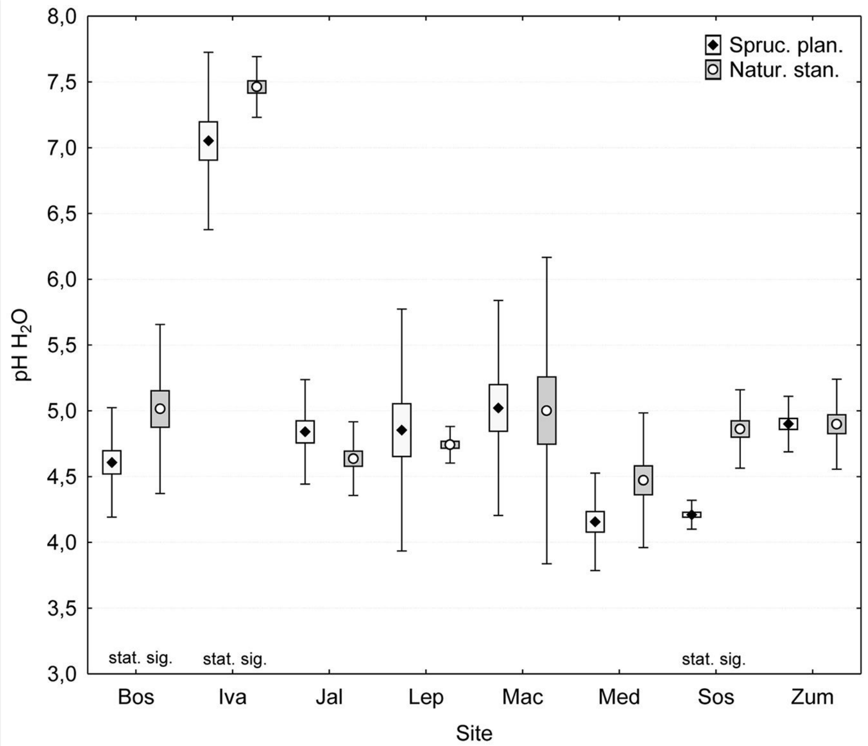

Fig. 3 - Soil pH_{H2O} in the surface layer (0-10 cm). Differences were tested between spruce plantations (Spruc. plan.) and natural stands (Natur. stand) at the study sites (Bos - Bosiljevo; Iva - Ivanec; Jal - Jalžabet; Lep - Lepoglava; Mac - Macelj; Med - Medvednica; Sos - Sošice; Zum - Žumberak); (stat. sig.): statistically significant.

times greater than in the corresponding natural stand. Considering the average value (arithmetic mean), the forest floor mass in spruce plantations ranged from 12.87 Mg ha^{-1} (Sošice) to 31.74 Mg ha^{-1} (Žumberak), as opposed to 5.63 Mg ha^{-1} (Bosiljevo) to 26.76 Mg ha^{-1} (Ivanec) in natural stands. According to Perković et al. (2007), the forest floor stock ranged from 17.5 to 31 Mg ha^{-1} in 35-40 year old spruce plantations planted in pedunculate oak and hornbeam habitat, which was two to three times higher than in the natural stand. Klimo & Kulhavy (2006) found a higher stock of forest floor (over 50 Mg ha^{-1}) in spruce plantations within the range of beech forests than in beech stands in the Czech Republic, which could be attributed to the greater humidity of the study area. Statistically significant differences were found at the sites Žumberak, Medvednica, Lepoglava and Bosiljevo (Fig. 2), which confirms the findings reported elsewhere (Bagherzadeh et al. 2008, Perković et al. 2007).

Soil properties

In the surface soil layer (0-10 cm), the pH value was lower in the spruce plantations than in the natural stands. The same trends were found for both pH_{H2O} and pH_{CaCl2}. A slightly higher pH value in spruce plantations was found at the sites Jalžabet and Lepoglava, though the differences were not statistically significant (Fig. 3). Lower pH values in the surface layer of soil in spruce plantations were found at the sites Bosiljevo, Ivanec and Sošice (Tab. S1 in Supplementary material). The lowest pH value in spruce plantations was found in the district cambisol over green slate rock at the site Medvednica (pH_{H2O} 4.16 ± 0.19; pH_{CaCl2} 3.39 ± 0.11), while the highest pH value was found over dolomitised limestone at the site Ivanec (pH_{H2O} 7.05 ± 0.34; pH_{CaCl2} 6.45 ± 0.40 – Fig. 2, Tab. 1). Previous reports indicated that Norway spruce contributes to increase the soil acidity (Hagen-Thorn et al. 2004, Berger & Berger 2012, Kostić et al. 2012), which is largely confirmed by the findings of this study. Stand age has also been proven to affect soil pH in spruce plantations. Cerli et al. (2006), Podrázsky & Remeš (2007) and Smal & Olszewska (2008) pointed out the influence of stand age on soil acidification, with lower pH values in soil of older stands in comparison to younger spruce plantations. Accordingly, the reason for the slightly higher pH values of soil in spruce plantations at the sites Jalžabet and Lepoglava could be attributed to the relatively young age of those plantations. Furthermore, the Jalžabet control plot also includes eastern bracken fern (*Pteridium aquilinum*), a species that also promote soil acidification (Wood 1995, Johnson-Maynard et al. 1998).

In the deeper soil layer (10-20 cm), statistically significantly lower pH values in spruce plantations were found at the sites Bosiljevo and Sošice, while at all other sites pH was lower but not significantly different, with the exception of the site Lepoglava where pH values were higher than in the natural stands (Tab. S1 in Supplementary material).

Organic carbon content in the surface soil layer (0-10 cm) were higher in natural stands, with the exception of the sites Lepoglava and Sošice, though differences were statistically significant only at the sites Macelj, Jalžabet and Ivanec (Tab. S1). The results obtained in this study differ from those in Vesterdal et al. (2008), who reported that reforestation with coniferous species results in increasing organic carbon stocks in the soil. In the deeper soil layer (10-20 cm), organic carbon content was lower than in the surface layer, while the relationship between the spruce plantations and natural stands by site was similar to that observed in the surface layer (Tab. 2). The highest organic carbon content in the surface layer (0-10 cm) was found at the sites Medvednica (SP: 116.1 g kg^{-1}; N: 115.4 g kg^{-1}) and Ivanec (SP: 54.8 g kg^{-1}; N: 114.9 g kg^{-1}), where the largest accumulation of forest floor was also found (Fig. 2, see also Tab. S1 in Supplementary material).

The nitrogen content showed an identical pattern as the total carbon content at the study sites. As a rule, the nitrogen content in the surface layer was higher in the natural stands, with the exception of the sites Lepoglava and Sošice. A number of studies (Meiwes et al. 2002, Bagherzadeh et al. 2008, Kostić et al. 2012) reported that beech litter has higher nitrogen content than spruce litter, determining a more

Tab. 2 - Correlation coefficients bewteen the tested soil parameters. (*): p<0.05.

-	pH_{H2O}	pH_{CaCl2}	C org	N tot	C/N	Ca	Fe	K	Mg	P
pH_{H2O}	1.00	-	-	-	-	-	-	-	-	-
pH_{CaCl2}	0.97*	1.00	-	-	-	-	-	-	-	-
C org	0.10	0.17*	1.00	-	-	-	-	-	-	-
N tot	0.22*	0.30*	0.97*	1.00	-	-	-	-	-	-
C/N	-0.23*	-0.29*	-0.04	-0.21*	1.00	-	-	-	-	-
Ca	0.89*	0.91*	0.30*	0.41*	-0.31*	1.00	-	-	-	-
Fe	-0.51*	-0.49*	0.31*	0.22*	0.14	-0.44*	1.00	-	-	-
K	-0.14	-0.08	0.40*	0.38*	-0.16*	-0.01	0.51*	1.00	-	-
Mg	0.87*	0.89*	0.26*	0.36*	-0.27*	0.86*	-0.34*	0.08	1.00	-
P	-0.19*	-0.14	0.26*	0.23*	0.03	-0.07	0.40*	0.41*	-0.06	1.00

favourable C/N ratio in the soil. A higher nitrogen content generally suggests higher quality leaf litter and faster humus production. The highest nitrogen content in the surface soil layer was found at Medvednica (SP: 7.7 g kg^{-1}; N: 8.7 g kg^{-1}) and Ivanec (SP: 10.3 g kg^{-1}; N: 3.9 g kg^{-1}). The nitrogen content and C/N ratio in the forest soil are important parameters for determining the influence of different tree species on the functioning of forest ecosystems (Vesterdal et al. 2008). The C/N ratio is a very good indicator of the quality of organic matter in the soil (Batjes 1996), and a ratio higher than 25 reflects slower decomposition processes (Swift et al. 1979). When C/N < 30, the decomposition of the leaf litter typically takes a year, while for higher C/N values (50-70), decomposition may last from 3 to 40 years, and the lacking nitrogen is taken up from the soil. Numerous studies have found a higher C/N ratio in spruce plantations in relation to oak forest (Perković et al. 2007) or beech forest (Bagherzadeh et al. 2008, Vesterdal et al. 2008, Prietzel & Bachmann 2011, Berger & Berger 2012). This is corroborated by the findings presented here, where the C/N ratio was higher in spruce plantations, with the exception of two sites (Sošice and Žumberak), where the highest variability of this parameter was seen in the natural stands (Tab. S1). The C/N ratio in the soil surface layer in spruce plantations was in the range from 13.9 to 15.4, as opposed to 11.1 to 19.7 in natural stands. With increasing depth, the C/N ratio is reduced (Kostić et al. 2016). In the present study, the C/N ratio at depths of 10-20 cm in the spruce plantations ranged from 11.1 to 14.9, as opposed to 9.8 to 17.5 in natural stands. These results indicate the lesser variability of the C/N ratio in the soil of spruce plantations in comparison to natural stands. Hypothetically, an increase in the C/N ratio will result in slower decomposition, the accumulation of organic matter and a greater carbon sink in spruce stands. However, it should be noted that at all study sites, both spruce plantations and natural stands, a C/N ratio of less than 20 was observed, indicating a favourable and rapid decomposition of the forest floor.

The bioavailable phosphorus in the surface soil layer (0-10 cm) in spruce plantations ranged from 5.42 mg kg^{-1} (Bosiljevo) to 46.91 mg kg^{-1} (Jalžabet). In the natural stands, the variability was lower, ranging from 7.60 mg kg^{-1} (Sošice) to 19.88 mg kg^{-1} (Macelj). The site Jalžabet had two to three times larger concentration of phosphorus in the spruce plantations than in natural stands (Tab. S1 in Supplementary material). Prudhomme et al. (2017) reported that phosphorus concentration in spruce plantations following extraction with Mehlich III solution ranges from 9.12 to 12.10 mg kg^{-1}. At the sites Bosiljevo, Ivanec and Macelj, a higher phosphorous content was found in the natural stands, while at other sites the content was higher in spruce plantations. Bagherzadeh et al. (2008) and Kostić et al. (2012) reported higher average phosphorus concentrations in beech forest than in spruce plantations. On the other hand, Hansen et al. (2009) stated that beech litter has a higher share of all macronutrients except phosphorus than spruce litter. With increasing of the depth, the phosphorus content is reduced at all sites, which agrees with the results by Pernar et al. (2009), who stated that the phosphorus content is generally higher in the humus-accumulation horizon. The concentration of bioavailable phosphorus in the soil layer at 10-20 cm ranged from 3.64 mg kg^{-1} (Ivanec) to 29.29 mg kg^{-1} (Jalžabet) in spruce plantations, and from 1.62 mg kg^{-1} (Žumberak) to 15.26 mg kg^{-1} (Macelj) in natural stands. In the deeper soil layer, the phosphorus content was generally higher (though not significantly) in spruce stands, with the exception of the site Ivanec (Tab. S1).

The concentration of bioavailable potassium in the surface soil layer (0-10 cm) in spruce plantations ranged from 27.90 mg kg^{-1} (Žumberak) to 137.69 mg kg^{-1} (Medvednica), as opposed to the range of 33.77 mg kg^{-1} (Žumberak) to 120.47 mg kg^{-1} (Bosiljevo) in natural stands. The potassium content was higher in natural stands, with the exception of the sites Ivanec, Jalžabet and Medvedica (Tab. S1 in Supplementary material). A lower potassium content in spruce plantations than in beech stands was also confirmed by Bagherzadeh et al. (2008). In the deeper soil layer, the potassium content was lower. As in the case of phosphorus, this is attributed to the accumulative effect of vegetation in the surface layer of the soil, while this is less common for calcium and magnesium (Vanmechelen et al. 1997). In deeper soil layers, the potassium content is generally higher in spruce plantations, with the exception of the sites Ivanec and Jalžabet. The concentration of bioavailable potassium in the soil layer 10-20 cm ranged from 21.60 mg kg^{-1} (Žumberak) to 72.42 mg kg^{-1} (Medvednica) in spruce plantations, and from 20.03 mg kg^{-1} (Žumberak) to 93.49 mg kg^{-1} (Medvednica) in natural stands. Higher variability in the potassium ratio was found at all localities in the natural stands (Tab. S1 in Supplementary material).

The bioavailable calcium did not show clear differences between natural stands and spruce plantations. Similar results were also reported by Podrázsky et al. (2018), who examined the differences between common fir stands and spruce plantations. A statistically higher share of calcium in the surface soil layer in natural stands was found at the sites Sošice and Ivanec, higher share at the sites Bosiljevo and Medvednica, while at all other sites, the ratio was higher in the spruce plantation (Tab. S1). In particular, the Ivanec site, lying on dolomitised limestone, stands out due to the many-fold higher concentrations of calcium than at the other sites (SP > 2000 mg kg^{-1}; N > 2000 mg kg^{-1} – Tab. S1). For all the localities examined in this study, a statistically significant positive correlation was found between soil pH and bioavailable calcium concentration (r = 0.89-0.91, $p<0.05$ – Tab. 2).

The bioavailable magnesium was generally higher in natural stands than in spruce plantations. The higher values of bioavailable magnesium in spruce plantations in the surface layer was found at the sites Medvednica and Žumberak, while in the deeper layer, this was higher only at Žumberak. The highest value of bioavailable magnesium was found at the site Ivanec (> 500 mg kg^{-1}), while the lowest was found at the site Sošice (< 50mg kg^{-1} – Tab. S1). The observed pattern for mobile magnesium across different sites was similar to that observed for calcium; indeed, a positive correlation was found between these elements (r = 0.86, $p<0.05$), as well as between pH and magnesium (r = 0.87-0.89, $p<0.05$ – Tab. 2).

The content of bioavailable iron at the study sites showed no clear patterns between the spruce plantations and natural stands. On carbonate substrates (Ivanec, Lepoglava and Sošice) the concentration values of iron in the surface soil layer were higher then in spruce plantations, while at the remaining sites the concentration values were higher in natural stands, though not statistically significant (Tab. S1). The lowest values of iron concentration were found at the site Ivanec, where the concentration of calcium was highest, which is not surprising given the carbonate substrate. A negative correlation was found between the content of bioavailable iron and calcium (r = -0.46, $p<0.05$ – Tab. 2). The reason for the lower concentration values of iron observed in soils with carbonate substrate is the formation of less soluble iron carbonates (Lindsay & Schwab 2008).

In summary, we found no clear and characteristic relationship between the concentration values of bioavailable fraction of elements between the spruce plantations and natural stands. This can largely be attributed to the properties of the leaf litter of spruce, beech and fir, which were the main species in this study. Bergmann (1988) stated that the concentrations of these bioelements are virtually identical among the leaves of beech and needles of fir and spruce trees.

This study showed that spruce plantations affect soil pH, forest floor mass and C/N ratio, while the differences observed for the other parameters cannot be clearly attributed to spruce plantations. Other factors, such as the different plantation age (Tab. 1) as well as different lithological and bioclimatic conditions among plot pairs and sites, could mask further differences thus hindering the interpretation of the results. However, the objective of this study was to determine recognizable and easily observable influences of Norway spruce plantations on forest soil, which stand out despite the diverse conditions that are typical in this part of Europe. On the other hand, several studies suggested that in addition to tree species, the substrate and micro- and macroclimate can also have a substantial effect on the chemical parameters of soil (Augusto et al. 2002, Hagen-Thorn et al. 2004).

Conclusions

The objective of this study was to analyse the effect of spruce plantations of different age grown on different soils under various climatic conditions on soil characteristics, and compare them to those found in close natural stands. The results showed a clear influence of spruce plantations on several soil parameters. The mass of the forest floor was on average 30 % higher in spruce plantations than in the surrounding natural stands. A lower soil pH was also observed, indicating the soil acidification which occurs in Norway spruce plantations. At most sites, the soil in spruce plantations had a lower nitrogen content and, as a consequence, a higher C/N ratio, indicating poor quality organic matter. Further, the content of bioavailable phosphorous was lower in plantations than in natural stands, while no differences were determined for the other tested elements (potassium, calcium, magnesium and iron). Our results allow drawing the main conclusion that spruce plantations have an unfavourable influence on soil in comparison to the natural vegetation.

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Supplementary Material

Tab. S1 - Chemical properties of soil in natural stands (control) and Norway spruce plantations.

Link: Perkovic_3023@suppl001.pdf

