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What Characteristics of Soil Fertility Can Improve in Mixed Stands of Scots Pine and European Beech Compared with Monospecific Stands?

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ABSTRACT

According to the current trends in forest management, endeavors are made to adjust the species composition to the site conditions and to increase the biodiversity. Changes in the species composition of forest stands lead to modifications of soil properties and nutrients cycle. The objective of the study was to evaluate the effect of monocultures (beech and pine) and mixed-species stands (pine-beech) on soil properties, particularly accumulation of soil organic carbon. We aim to demonstrate how different vegetation types influence soil properties in surface horizons of soil. The study sites are located in Germany and Poland under different tree stands *Pinus sylvestris* L., *Fagus sylvatica* L., and mixed-species stand. Contents of organic carbon and nitrogen, pH, and soil texture were analyzed. The studies conducted confirmed the positive effect of beech and mixed-species stands on acidification of surface soil horizons. We ordered the stands tested according to acidification effect on soils: pine stand > mixed stand > beech stand, which is consistent with previous studies. The most beneficial impact on the accumulation of organic carbon was observed in mixed-species stands in which beech and pine were found. Lower carbon-to-nitrogen (C/N) ratios confirm the high rate of organic matter decomposition and lower C/N ratio was reported in soil under beech stand in comparison to pine stands.

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Beech stands; forest soil properties; mixed-species stands; pine stands; soil organic carbon

Introduction

In recent years, interest in soil quality has been stimulated by the growing awareness of the fact that the soil is an important component of the biosphere, which functions not only to produce food, wood, and other forest resources, but it is also very important to maintain local, regional, and world quality of the environment (Doran and Zeiss 2000; Dumanski 2015). According to the current trends and forest policy, endeavors are being made to adjust the species composition to the site conditions and to increase the biodiversity in order to maintain forest sustainability. Site conditions (altitude, exposition, slope), climatic factors (temperature and humidity), and vegetation influence the soil conditions and soil properties via varying quantity and quality of organic matter (Ayres et al. 2009; Lasota, Błońska, and Zwydak 2016). Plant species have significant impacts on soil physical and chemical properties and quality of organic matter as well as on the abundance and composition of soil microbial community

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(Błońska, Lasota, and Gruba 2016; Ladygina and Hedlund 2010; Ushio et al. 2008). Not only forest litter but also roots affect the properties of soil. Effect of roots on the soil properties varies with soil type and plant species. The roots deliver organic matter that contains various components improving the soil quality (Baldrian and Šnajdr 2011). The rhizodeposits are used as carbon sources by soil microorganisms (Jones, Nguyen, and Finlay 2009). Forest stands affect soil characteristics through litter, which contain differing amounts of lignin and nitrogen. According to Hobbie et al. (2012), residue chemistry, especially lignin, could impact decomposition rate. Fertility and productivity of soil depend very much on the quality and quantity soil organic matter (SOM), which is the stock of nutrients. The rate of organic substances transformation depends largely on the quality of SOM, which is related to species composition of forest stands. An exhaustive knowledge of the mechanisms of organic matter decomposition is important for the proper forest management, particularly as these practices influence the nutrient cycle, carbon sequestration and, consequently, the productivity of forest ecosystems. Increased decomposition of organic matter is often observed in deciduous tree stands or in coniferous tree stands with significant admixture of deciduous species (Bonifacio et al. 2008; Légaré, Paré, and Bergeron 2005). In Central Europe, pure coniferous stands are today viewed very critically, whereas mixed stands are recommended for a variety of reasons. Mixed stands compared to monocultures stands cause a shift to a greater above-ground nutrient content, indicating an increase in the proportion of resources accumulated from a site (Richards et al. 2010) and sequestration of carbon (Jandl et al. 2007). Pretzsch et al. (2016) observed positive additive and multiplicative mixing effects on structural heterogeneity as well as stand productivity.

The objective of the study was to evaluate the effect of monocultures (beech and pine) and mixed-species stands (pine-beech) on soil properties, particularly accumulation of soil organic carbon. We aim to demonstrate how different vegetation types influence soil properties in surfaces horizons of soil. The study included different tree stands pine (*P. sylvestris* L.), European beech (*Fagus sylvatica* L.), and mixed-species stand with Scots pine (*P. sylvestris* L.) plus European beech (*F. sylvatica* L.). The following hypotheses were tested: (1) beech stands and mixed-species stands have a positive effect on the stabilization and quality of organic matter than pine stands; (2) beech stands and mixed-species stands decrease soil acidification.

Materials and methods

Study sites

The study sites are located in Germany and Central Poland under different tree stands pine (*Pinus sylvestris* L.), European beech (*F. sylvatica* L.), and mixed-species stand with Scots pine (*P. sylvestris* L.) plus European beech (*F. sylvatica* L.). Such sets with three stands will be referred to as triplets. The triplets were established by members of the COST Action FP 1206 EuMiXFOR. In Poland, the study sites, set as one triplet, are located in Niepołomice Forest District (Figure 1 and Table 1). The local soils are derived from sandy glacial deposits. The soils were classified as Cambisols (WRB 2014). In Germany, the study sites are located in two triplets in Alzenau and Schrobenhausen (Figure 1 and Table 1). On each of the nine research plots (three triplets), five soil samples were taken. We sampled the O, A, and B horizons according to the observed depths. In total, 135 soil samples were collected (45 for each triplet). Silvicultural characteristics of forest stands were presented in Table 2.

Laboratory analysis

For the laboratory analysis, soil samples were air-dried at room temperature and passed through a sieve (Ø 2 mm). In the samples, soil texture was determined using the laser diffraction (Analysette 22, Fritsch, Idar-Oberstein, Germany), and soil pH was analyzed in distilled water (in 1:5 soil-to-water suspension) using the potentiometric method. The content of total nitrogen (Nt) and organic

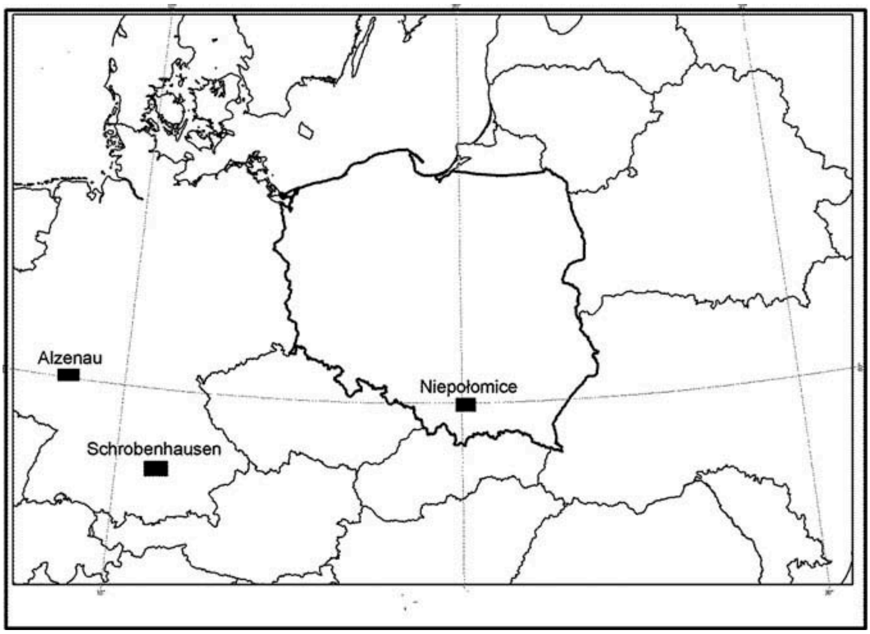

Figure 1. Localization of study area in Germany and Poland.

Table 1. Characteristics of the study area.

	Alzenau	Schrobenhausen	Niepołomice
Geographic location	50°06′48.74″ N 09° 03′54.36″E	48°34′57.95″ N 11° 14′12.49″ E	50°01′36.00″ N 20° 19′37.26″ E
E.a.s.l.	250	450	225
T	9	8.5	8.2
P	720	700	650
M	38	38	36
I	0	1	0
Exp	20	45	0
Age of stands	55	57	55

E.a.s.l – elevation above sea level (m); M – Martone index (annual precipitation (mm)/mean annual temperature (°C)); T - mean annual temperature (°C); P - annual precipitation (mm); I – inclination (°); Exp – exposition (°).

carbon (C_t) content were measured using LECO CNS True Mac Analyzer (Leco, St. Joseph, MI, USA), including the calculation of the carbon-to-nitrogen (C/N) ratio. Bulk densities (BD) were determined with the use of Kopecky rings of 100 cm^3 volume – with the dryer method (Ostrowska, Gawliński, and Szczubiałka 1991).

The obtained results were used to evaluate the carbon storage (CS) in soil under different tree species. CS in soil was determined from the thicknesses and BD of the O, A, and B horizons:

$$CS = Ct \cdot \ BD \cdot T \cdot S/100$$

where

CS – carbon storage in soil ($kg \cdot m^{-2}$)
Ct – carbon content in soil ($g \cdot kg^{-1}$)
BD – bulk density of soil ($g \cdot cm^{-3}$)
T – thicknesses of soil horizon (cm)
S - surface (1 m^2).

Table 2. Silvicultural characteristics of forest stands.

	Pure Scots pine					pure European beech					mixed Scots pine					mixed European beech			
	hq	dq	BA	V	N	hq	dq	BA	V	N	hq	dq	BA	V	N	hq	dq	BA	V	N
Alzenau	25.27	21.20	51.59	580.52	1461	22.38	16.45	43.00	474.3	2022	27.39	26.83	26.64	329.07	471	25.98	21.94	22.83	300.42	604
Schrobenhausen	26.20	33.15	24.66	296.48	286	25.86	16.96	23.32	304.19	1032	22.75	25.26	16.82	176.26	327	22.51	15.66	15.92	178.56	818
Niepołomice	24.75	30.44	33.00	374.82	453	26.15	25.44	24.15	324.12	475	24.32	27.88	16.28	180.42	267	22.59	25.73	15.89	186.91	306

hq – quadratic mean height (m); dq – quadratic mean diameter (cm); BA – stand basal area (m^2 ha^{-1}); V – standing volume (m^3 ha^{-1}); N – tree number (ha^{-1}).

Statistical analysis

Differences between the mean values of soil properties were evaluated with the nonparametric Kruskal–Wallis test. In order to reduce the number of variables in the statistical data set and to visualize the multivariate dataset as a set of coordinates in a high-dimensional data space, the Principal Component Analysis (PCA) method was used. The PCA method was also used in order to interpret other factors, depending on the type of dataset. The statistical significance of the results was verified at a significance level of $\alpha = 0.05$. All statistical analyses were performed with Statistica 10 software (2010).

Results

The texture of the investigated soils was dominated by sand (68–92%) with a minor admixture of silt and clay. The pH H_2O of soils ranged from 3.14 to 5.25. Soils of beech stands and mixed-species stands had the highest pH (Table 3). The highest pH was observed in the B and some O horizons while the lowest was usually observed in the mineral A horizon. The carbon content ranged from 0.7% to 45.5%. CS in the soils of mixed-species stands was higher than in the soils of pine stands and beech tree stands (Table 4). The highest accumulation of carbon was observed in organic (O) and subsoil (B) horizons. At the organic horizons, 48% of carbon from the growing stock up to 30 cm was accumulated. At the B horizon, the proportion from the growing stock up to 30 cm ranged from 24% to 40%. At humus and mineral horizon (A), 24% of carbon from the growing stock up to 30 cm on average was collected (Table 4). The best degree of decomposition of SOM, expressed as the C/N ratio, was attributed to beech stands. In soils of these stands, the highest C/N ratio was reported. The lowest rate of decomposition was observed in soils of pine stands for which the C/N ratio reached 30 and more. Statistically significant differences were reported for pH, carbon, nitrogen content, and the C/N ratio at each soil horizon between different types of stands. Most frequently, differences in the properties of soils between pine and beech stands were reported. Less frequently, differences in the properties of soils of pine and mixed-species stands and between soils of beech and mixed-species stands were observed (Table 3).

A projection of the variables on the factor-plane clearly demonstrated correlations between the soil properties and species. Two main factors had a significant total impact (52.6%) on the variance of the variables. Factor 1 explained 29.10% of the variance of the examined properties, and Factor 2 explained 23.52% of the variance (Figure 2). Soil of beech stands was connected with the highest pH of soil. Soil of pine stands was correlated with C/N ratio; in that soil, the highest C/N ratio was noted. The highest sand content and highest C/N ratio characterized Alzenau localization. Schrobenhausen localization was connected with high pH while Niepołomice localization with the highest nitrogen content.

Discussion

The studies conducted confirmed the positive effect of beech and mixed-species stands on acidification of surface soil horizons. We ordered the stands tested according to acidification effect on soils: pine stand > mixed-species stand (pine + beech) > beech stand, which is consistent with previous studies. Augusto et al. (2002) and Błońska, Lasota, and Gruba (2016) have demonstrated a beneficial effect on the properties of beech soils in comparison to pine soil. The beneficial effect of beech on surface soil horizons is explained by the ability of this species to collect nutrients, especially calcium from deep soil horizons. In the literature, there are data supporting these valuable properties of beech. In the studies conducted by Gruba (2004), it was confirmed that at the horizons of humus in soils of mixed-species stands with a high proportion of beech, calcium content increases proportionally to the content of this element in the bedrock. Berger et al. (2006) demonstrated that beech, when collecting large amounts of calcium from deep soil horizons, acts as a kind of specific “calcium

Table 3. The selected properties of soil (average ± standard deviation) in different research areas.

pH	C	N	C/N	Sand	Silt	Clay	BD	pH	C	N	C/N	Sand	Silt	Clay	BD
Alzenau								Schrobenhausen							
Pine stand															
O horizon															
^{b}4.02 ± 0.12	^{a}245.6 ± 63.5	^{ab}8.8 ± 2.6	^{a}28.1 ± 1.6	n.d.	n.d.	n.d.	^{a}0.38 ± 0.13	^{b}4.05 ± 0.22	^{a}288.3 ± 26.6	^{a}10.4 ± 1.1	^{a}27.7 ± 2.6	n.d.	n.d.	n.d.	^{a}0.29 ± 0.03
A Horizon															
^{b}3.90 ± 0.11	^{a}45.5 ± 13.9	^{a}1.5 ± 0.6	^{a}30.6 ± 3.1	^{a}92 ± 1.8	^{a}7 ± 1.6	^{a}1 ± 0.2	^{a}1.07 ± 0.08	^{a}3.93 ± 0.11	^{a}34.6 ± 4.6	^{a}1.4 ± 0.2	^{a}23.8 ± 2.1	^{a}85 ± 7.9	^{a}12 ± 6.2	^{a}2 ± 1.8	^{a}1.13 ± 0.03
B Horizon															
^{a}4.42 ± 0.32	^{b}10.1 ± 3.1	^{b}0.3 ± 0.1	^{a}39.8 ± 7.2	^{a}90 ± 1.6	^{a}8 ± 1.5	^{a}1 ± 0.2	^{b}1.30 ± 0.02	^{a}4.64 ± 0.21	^{a}11.9 ± 6.2	^{a}0.4 ± 0.2	^{a}27.1 ± 2.9	^{a}80 ± 7.1	^{b}16 ± 4.8	^{a}3 ± 2.4	^{a}1.29 ± 0.04
Beech stand															
O Horizon															
^{a}4.64 ± 0.28	^{b}95.8 ± 11.1	^{b}4.3 ± 0.8	^{b}22.2 ± 3.2	n.d.	n.d.	n.d.	^{b}0.81 ± 0.04	^{a}4.78 ± 0.34	^{b}166.5 ± 32.6	^{ab}8.2 ± 1.4	^{b}20.2 ± 1.31	n.d.	n.d.	n.d.	^{b}0.56 ± 0.09
A Horizon															
^{a}4.29 ± 0.28	^{a}32.7 ± 12.2	^{a}1.6 ± 0.6	^{b}19.9 ± 0.64	^{a}90 ± 3.7	^{a}8 ± 3.2	^{a}1 ± 0.51	^{a}1.15 ± 0.07	^{a}4.07 ± 0.09	^{a}47.4 ± 14.1	^{a}2.4 ± 0.4	^{b}19.2 ± 1.9	^{a}79 ± 3.1	^{a}19 ± 2.4	^{a}2 ± 0.7	^{a}1.06 ± 0.08
B Horizon															
^{a}4.60 ± 0.16	^{ab}12.8 ± 3.3	^{ab}0.5 ± 0.2	^{b}24.7 ± 3.6	^{a}87 ± 1.9	^{a}11 ± 1.6	^{a}2 ± 0.4	^{ab}1.28 ± 0.02	^{a}4.72 ± 0.39	^{a}16.1 ± 5.1	^{a}0.7 ± 0.2	^{a}22.5 ± 5.1	^{b}68 ± 2.9	^{a}27 ± 2.4	^{a}5 ± 0.9	^{a}1.26 ± 0.03
Mixed-species stand															
O horizon															
^{ab}4.26 ± 0.21	^{a}265.7 ± 100.6	^{a}9.4 ± 1.7	^{ab}27.4 ± 5.6	n.d.	n.d.	n.d.	^{a}0.36 ± 0.15	^{ab}4.71 ± 0.28	^{ab}204.9 ± 29.5	^{b}7.8 ± 1.0	^{ab}26.2 ± 1.7	n.d.	n.d.	n.d.	^{ab}0.45 ± 0.07
A Horizon															
^{ab}4.16 ± 0.13	^{a}48.4 ± 12.1	^{a}1.9 ± 0.5	^{ab}25.4 ± 2.8	^{a}91 ± 1.8	^{a}8 ± 1.8	^{a}1 ± 1.8	^{a}1.05 ± 0.07	^{a}4.16 ± 0.22	^{a}49.2 ± 15.1	^{a}2.3 ± 0.7	^{ab}20.8 ± 0.5	^{a}87 ± 7.7	^{a}11 ± 5.9	^{a}2 ± 1.7	^{a}1.05 ± 0.08
B Horizon															
^{a}4.65 ± 0.11	^{a}17.5 ± 3.7	^{a}0.7 ± 0.1	^{ab}25.6 ± 1.1	^{a}88 ± 1.8	^{a}11 ± 1.7	^{a}1 ± 0.2	^{a}1.25 ± 0.02	^{a}4.54 ± 0.22	^{a}14.8 ± 4.3	^{a}0.6 ± 0.2	^{a}22.4 ± 2.1	^{ab}74 ± 5.3	^{b}21 ± 3.8	^{a}5 ± 1.4	^{a}1.27 ± 0.03

pH	C	N	C/N	Sand	Silt	Clay	BD
			Niepołomice				
Pine stand							
O horizon							
^{a}3.56 ± 0.27	^{a}36.84 ± 10.06	^{a}13.4 ± 3.4	^{a}27.45 ± 0.34	n.d.	n.d.	n.d.	^{a}0.21 ± 0.13
A Horizon							
^{b}3.66 ± 0.27	^{a}9.45 ± 5.37	^{a}3.7 ± 2.2	^{a}25.69 ± 5.6	^{b}79 ± 5.1	^{a}19 ± 4.3	^{a}2 ± 1.1	^{a}0.84 ± 0.24
B Horizon							
^{b}3.85 ± 0.13	^{a}3.93 ± 2.03	^{a}1.4 ± 0.7	^{a}28.1 ± 1.8	^{b}82 ± 6.1	^{a}16 ± 4.9	^{a}2 ± 1.1	^{a}1.11 ± 0.12
Beech stand							
O Horizon							
^{a}3.89 ± 0.27	^{a}27.16 ± 10.03	^{a}11.3 ± 3.1	^{a}23.6 ± 2.9	n.d.	n.d.	n.d.	^{a}0.35 ± 0.15
A Horizon							
^{a}4.10 ± 0.09	^{b}2.87 ± 0.81	^{b}1.3 ± 0.3	^{b}21.2 ± 1.5	^{ab}89 ± 0.6	^{ab}9 ± 0.5	^{a}1 ± 0.2	^{b}1.17 ± 0.05
B Horizon							
^{a}4.38 ± 0.13	^{b}1.05 ± 0.10	^{b}0.4 ± 0.1	^{b}23.3 ± 2.3	^{ab}88 ± 1.7	^{ab}10 ± 1.4	^{a}1 ± 0.35	^{b}1.30 ± 0.01
Mixed-species stand							
O horizon							
^{a}3.76 ± 0.22	^{a}22.32 ± 10.28	^{a}8.8 ± 3.6	^{a}24.7 ± 2.1	n.d.	n.d.	n.d.	^{a}0.45 ± 0.23
A Horizon							
^{b}3.83 ± 0.10	^{ab}5.59 ± 2.23	^{ab}2.4 ± 1.0	^{ab}22.6 ± 1.9	^{a}89 ± 4.9	^{b}10 ± 4.5	^{a}1 ± 0.4	^{ab}1.02 ± 0.12
B Horizon							
^{ab}4.12 ± 0.11	^{ab}1.54 ± 0.41	^{ab}0.6 ± 0.1	^{ab}24.7 ± 2.6	^{a}92 ± 1.1	^{b}7 ± 0.9	^{a}1 ± 0.2	^{ab}1.26 ± 0.02

C – carbon content (g kg^{-1}); N – nitrogen content (g kg^{-1}); sand, silt. and clay fraction content (%); different lowercase letters in the upper index of the mean values mean significant differences of soil properties between different forest stands; n.d. – not determined.

Table 4. Percentage accumulation of carbon (%) in different soil horizons (O, A, and B) and carbon storage (kg·m^{-2}) in O, A, and B horizon summary under different tree stands.

Horizon	Alzenau	Schrobenhausen	Niepołomice
		Pine stand	
O	46	45	37
A	26	22	39
B	28	33	24
CS	*9.34*	*9.09*	*8.94*
		Beech stand	
O	44	41	48
A	20	22	20
B	36	37	32
CS	*9.03*	*11.05*	*8.49*
		Mixed-species stand	
O	37	42	39
A	23	23	25
B	40	35	36
CS	*11.01*	*10.85*	*10.81*

CS – carbon storage.

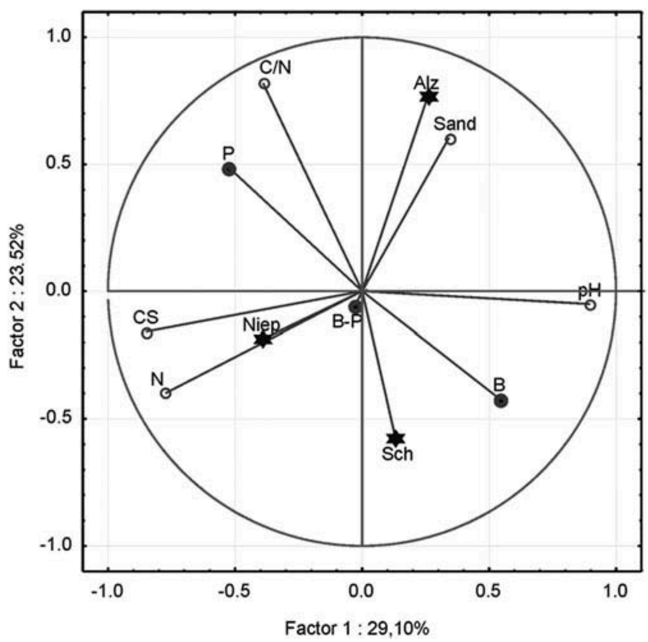

Figure 2. The projection of variables on a plane of the first and second factor in soil of different species (CS – carbon storage (kg·m^{-2}); P – pine stands B – beech stands, B-P - mixed-species stand (pine (*Pinus sylvestris* L.) plus European beech (*Fagus sylvatica* L.); Alz – Alzenau, Sch – Schrobenchausen, Niep - Niepołomice).

pump" which surface horizons of soil are supplied by this cation. Lower pH values in soil solutions under the coniferous stands induce higher activity of potentially toxic forms of aluminum (Gruba and Mulder 2015). According to these authors, the positive impact of deciduous and mixed-species stands is reflected in the increased activity of Ca^{2+} and Mg^{2+}, especially when exceeding pH 4.5.

In the studies conducted, different effects of pine, beech, and mixed-species stand on the quantity and quality of SOM accumulated in the surface soil horizons were reported. The most beneficial impact on the accumulation of organic matter was observed in mixed-species stands in which beech and pine were found. Higher accumulation under the mixed-species stand can be explained by the complex structure of the stand and greater density of crowns and root systems. In mixture standing volume (+12%), stand density (+20%), basal area growth (+12%), and stand volume growth (+8%) were higher than the weighted mean of the neighboring pure stands (Pretzsch et al. 2015). In the mixed-species stand, the clear differences in the high of beech and pine trees were noted, which indicates better fill the space by the crown. The soil conditions are also affected by different amounts of water that reaches the forest floor, which largely depends on the morphology of tree crowns (Kowalkowski, Jóźwiak, and Kozłowski 2002). Spatial and seasonal variation characteristics for beech (Carlyle-Moses, Flores Laureano, and Price 2004; Fathizadeh et al. 2013), by Kozłowski (2003), referred as the "umbrella effect" were not reflected in pine stands. The mixed-species stands were characterized by higher standing volume (Table 2), which probably caused the increases of organic fallout, which supplies the soil surface horizons leading to increased C accumulation. The mixed-species stand compared to monocultures stands are characterized by a higher aboveground biomass at the same time by a higher belowground biomass. The roots are a key component of the underground part of the forest ecosystem and the primary source of SOM (Janssens et al. 2002). Organic matter supplied to the soil by litter and root secretions contains different components such as soluble sugars, organic acids, amino acids or starches, cellulose, and lignin (Baldrian and Šnajdr 2011). According to Tomczuk (1975), lignin content (as a percentage of dry weight) in beech leaves is estimated at 20.23%. In terms of coniferous species, e.g., spruce, the content of lignin exceeds 25%. Typically, conifers have higher lignin content (25–33% of dry weight) than broadleaf trees (20–25%) (Sjöström and Westermark 1999). Hobbie et al. (2007) and Vesterdal et al. (2012) suggest that tree species influence the decomposition rate by differing contents of lignin and nitrogen; species with high lignin content and low nitrogen content decompose more slowly, which has a long-term impact on the C/N ratio in soils. In our study, lower C/N ratio was reported in beech stands in comparison to pine stands. The C/N ratio is often used to describe the litter quality, and broadleaf species have lower C/N ratio than pine (Handsson et al. 2011). According to Cools et al. (2014), species of trees are a major factor explaining variation in the C/N ratio. This study shows that mixed-species stands were characterized by an intermediate degree of decomposition of organic matter. The C/N ratio at organic and mineral horizons showed a tendency to decrease in comparison to soils of pine stands; however, no statistically significant differences were reported. In addition, we found high accumulation of SOM at the B subsoil horizons. An important component affecting the stability of organic matter in the levels of these relatively poor clay-rich soil is the silt fraction. Błońska (2015) reports the importance of the silt in the formation of humus and mineral connections in beech stands. Cyle et al. (2016) illustrate a relationship between the quality of carbon inputs and quantity of silt and clay fraction SOM. In our research, the localizations on the west of Germany (Alzenau) were characterized by higher productivity of stands, which can be associated with a more favorable climate features. The average annual temperature is higher by approximately 1 °C compared to surface in Niepołomice in Poland. On the surface in Alzenau, beneficial effects of climate are not reflected in the quality and quantity of organic matter that can be associated with a sand texture. In sandy soils, the humus–mineral connections are not formed; moreover, these soils also poses a serious-leaching problem. Simultaneous beneficial effect of climate and particle size can be seen in Schrobenhausen localization. This effect is reflected in beech stand, where the silt fraction content is highest in relation to the other localizations and types of stand.

Our study has focused on the effect of the species composition on the soil fertility characteristics. The other way round soil characteristics such as humus condition, carbon content, or acidity may have a feedback on the stand and tree growth. The repeatedly reported overyielding of mixed-species stands versus monocultures (Liang et al. 2016; Pretzsch et al. 2015) may be caused by the improved soil conditions and complementary soil resources use, especially on poor sites. On more fertile sites where light is the limiting factor, the denser canopy space occupation and completer light interception may cause a superior productivity of mixed-species stands.

Conclusions

The studies conducted confirmed the positive effect of deciduous species, in this case – beech and mixed-species stands, on acidification of surface soil horizons. We ordered the stands tested according to acidification effect on soils: pine stand > mixed-species stand > beech stand. The mixed-species stand had the most beneficial impact on the accumulation of organic carbon in the soil. Higher accumulation under the mixed-species stand can be explained by the complex structure of the stand and greater density of crowns and root systems. The obtained results suggested that breeding of beech-pine stands improves the condition of the soil, especially quantity and quality of SOM. The forest soils will be better protected with the knowledge of the relation between soil properties and species composition of forest stands.

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