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Original article

Hazel improves soil quality of sloping oak stands in a German low mountain range

Dirk MOHR*, Werner TOPP

Universität zu Köln, Zoologisches Institut, Terrestrische Ökologie, Weyertal 119, 50923 Köln, Germany

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Abstract – We compared *Quercus petraea* monocultures with adjacent mixed oak-hazel (*Corylus avellana*) stands at gentle (14°) and steep (25°) slopes of the Ahr-Eifel. The influence of hazel on forest floor mass, soil nutrients, microbial properties and on the abundance of Lumbricidae was studied. Litter mass was greater in mixed stands than in oak monocultures, resulting in a thicker Ah-horizon. Additionally, the PO_4^{3-}, Ca^{2+}- and Mg^{2+}-contents were higher and the Al^{3+}-content lower in the upper soil of mixed stands. In contrast, the contents of organic carbon , total nitrogen and the C/N ratio did not differ between the two soils. Basal respiration, specific microbial activity (qCO_2) and carbon mineralisation (C_{min}) were higher in mixed stands than in oak monocultures. Lumbricidae showed low densities in three of the stands studied (15–21 ind./m^2) and were almost absent at the oak monoculture on the steep terrain (2 ind./m^2).

oak / hazel / decomposition / soil nutrients / Lumbricidae

Résumé – Le noisetier améliore la qualité du sol des peuplements de chênes de basse montagne en Allemagne. Nous avons comparé des monocultures de type *Quercus petraea* avec des cultures adjacentes mixtes composées de chênes et de noisetiers (*Corylus avellana)* situées sur des pentes (14°/25°) différentes. L'influence du noisetier sur la masse de litière, les substances nutritives du sol, les propriétés microbiennes et l'abondance de Lumbricidae at été étudiée. Cette étude a montré que la masse de litière est plus élevée dans les cultures mixtes que dans les monocultures de chênes ; il en résulte un épaississement de l'horizon Ah. En outre, les teneurs en PO_4^{3-}-P, Ca^{2+} - et Mg^{2+} - sont plus élevées et les teneurs en Al^{3+} -plus faibles dans les couches supérieures des sols de cultures mixtes. Par contre, la teneur en carbone organique, en azote total ainsi que la relation C/N ne diffèrent pas. La respiration de base, l'activité microbienne spécifique (qCO_2) et la minéralisation carbonique (C_{min}) sont plus élevées dans les cultures mixtes que dans les monocultures de chênes. Les Lumbricidae présentent des densités faibles dans trois des cultures étudiées (15–21 ind./m^2), tandis qu'ils sont pratiquement absents dans les monocultures de chênes en terrain escarpé (2 ind./m^2).

chêne / noisetier / décomposition / substances nutritives du sol / Lumbricidae

1. INTRODUCTION

Many oak stands (*Quercus petraea*) in the central European low mountain range were formerly used as simple coppice forests. Nowadays many stands are not commercially used and grow in association with other trees or shrubs. In the Ahr-Eifel hazel (*Corylus avellana*) is the most common species to form a dense shrub layer below the oak canopy. During the last decades many oak coppice forests were converted into monocultures, and hazel was cut down to enhance the growth of the target trees and to improve accessibility to the forests, especially for hunting.

However, we assume that hazel may improve the ecological sustainability in oak forests. Oak trees may even benefit from the presence of shrubs. The better palatability of hazel litter compared to oak litter [33] could promote decomposition processes by the soil biota and thus enhance nutrient accumulation in soils. Moreover, hazel leaves exhibit higher concentrations of base cations than oak leaves [16] and could therefore improve the buffering capacity of acidified soils as shown for other alkaline plant material [24, 31, 32]. Litter as a fuel for the nutrient cycles in upper soil horizons is particularly important in the nutrition of woodlands growing on soils of low nutrient status [10].

To find out if hazel influences soil quality in sloping oak stands we determined several soil physical, chemical and microbial properties and the abundance of Lumbricidae in mixed oak-hazel stands and adjacent oak monocultures.

* Corresponding author: D.Mohr@uni-koeln.de

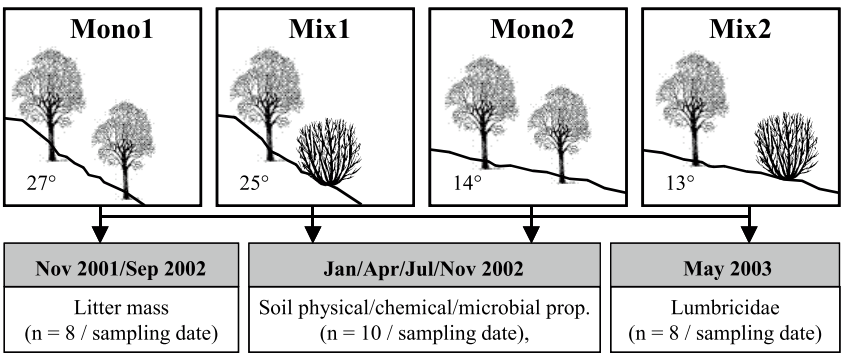

Figure 1. Illustration of the experimental design: Mono1 = oak monoculture, 27°; Mix1 = oak-hazel; 25°, Mono2 = oak monoculture, 13°; Mix2 = oak-hazel, 14°.

2. MATERIALS AND METHODS

2.1. Study area

The study was conducted in the Ahr-Eifel, Forestry District Adenau, in Rhineland-Palatinate. The Ahr-Eifel is an eastern part of the Eifel-mountains in the Central European low mountain range and is characterized by steep forested hills with elevations up to 700 m above sea level. The typical tree species at the dry windward hillsides (SW) is sessile oak (*Quercus petraea*) associated with hazel (*Corylus avellana*), hornbeam (*Carpinus betulus*), birch (*Betula pendula*) or, at very dry and nutrient poor sites, pine (*Pinus sylvestris*). The humid leeward hillslopes are dominated by oak and beech (*Fagus sylvatica*). The main bedrock is Devonic slate. The dominant wind direction is from the west/southwest, mean annual rainfall ranges from 675 to 800 mm and mean annual temperature from 6 to 8 °C. The latter two factors both depend on elevation and exposure. The abundant soil types vary depending on inclination, exposure and plant composition. Lithic Leptosol (Ranker) with shallow (< 5 cm) Ah-horizons predominates at steep and windward oak forests. At leeward sites with mixed cultures an Umbric Cambisol (acid brown earth) with Ah-horizons up to 10 cm is developed. The thickness of the B-horizon in such soils is highly variable and depends on the soil forming bedrock. Locally, loess layers of varying thickness cover the devonic basis. An important characteristic of the investigation area is the high game density. The population density of red deer was calculated to be 20 individuals per 100 ha. Densities of moufflons and wild boar are also high but there are no reliable calculations yet. Game produces extensive soil disturbances through grazing, trampling and rooting. Over large areas the herb layer is completely removed, soil layers mixed and organic soil horizons eroded.

2.2. Study sites

We selected two sites at which oak monocultures (*Quercus petraea*) were growing next to mixed stands of oak and hazel (*Corylus avellana*). The sites were 300 m apart and only differed in the slope gradient (13–14° vs. 25–27°, respectively). We used the following abbreviations for the investigated locations: Mono1 (= monoculture, 27°), Mix1 (= mixed stand, 25°), Mono2 (= 13°) and Mix2 (= 14°) (Fig. 1).

Bedrock type (Devonic slate), elevation (450 m) and exposure (W) were the same at all locations. The litter type at the observed forests is a moder. However, at steep and windward sites litter is often completely removed from the soil due to wind drift and downhill transport. The soil at the locations Mix1, Mono2 and Mix2 is an Umbric Cambisol. At the location Mono1 a Lithic Leptosol is formed. Thickness of the Ah-horizon is 2–10 cm and thickness of the B-horizon exceeds 20 cm (Tab. I). The study sites have remained unmanaged for at least 80 years. The present species composition is the result of land use dating back to the beginning of the nineteenth century. At that time coppice management was practised throughout the region. Oak is the dominant tree species at all sites. The height of the oak trees ranged from 10 to 20 m, crown closure of trees varied between 0.5 and 0.6 at the mixed stands and between 0.7–0.9 at the monocultures. Crown closure of hazel at the mixed stands ranged from 0.4 to 0.6. The herb layer covered 1.4 to 8.8% of the soil area of the investigated forest stands.

2.3. Soil chemical analyses

Soil samples (n = 10) were taken at random from the Ah-horizon in January, April, July and November of 2002 to reach a total number of 40 replicates per location and year. Soil samples were sieved at a mesh size of 2 mm. Soil pH was determined according to Schlichting and Blume [41] with a microprocessor pH-meter (pH 320, WTW) after extraction with 1 M KCl. All other chemical analyses were conducted with air-dried soil. Content of organic carbon (C_{org}) was calculated from CO_2 measurements (Total Organic Carbon Analyser, Ströhlein Instruments) after combustion at 550 °C. Total nitrogen (N_t) content was analysed using the Kjeldahl method. The analysis of extractable phosphate-ions in the soil was performed colorimetrically with the Vanadate-method as described in Steubing and Fangmeyer [43]. Plant available contents of calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^+) were extracted from 10 g soil with 50 mL 1M NH_4NO_3 solution [17, 49] by homogenisation (horizontal shaker for 2 h) and filtration. The ion contents in the suspension were analysed with an Atomic Absorbance Spectrophotometer (AAS, PERKIN-ELMER GmbH). Al^{3+}-analysis was performed reflectometrically with MERCK test-strips after extraction with 2 M KCl.

2.4. Soil microbial analyses

Soil samples were taken as described for the soil chemical analyses. The maximum water retention capacity (WRC_{max}) of the sieved soil (2 mm) and the soil moisture were measured gravimetrically as described in Alef [2]. For microbial analyses the moist soils were, if necessary, adjusted to 40–60% of the maximum water retention capacity of the sieved soils by adding distilled water and incubated at 20 °C for two days. Potential microbial activity was determined using the method of Skambracks and Zimmer [42], modified for soil samples. Soil is incubated in CO_2-free glass vessels for 24 h at 25 °C and the release of microbial CO_2 measured with a TOC-analyser (Ströhlein Instruments). Microbial biomass (C_{mic}) was analysed using the fumigation-extraction method as according to Vance et al. [47]. The carbon

Table I. Selected soil properties of the investigation sites Mono1, Mix1, Mono2 and Mix2 (Mono = oak monoculture; Mix = oak-hazel; 1 = 25–27°, 2 = 13–14°). For soil physical, chemical and microbial properties the median and median absolute deviation of all sampling dates (n = 8–40) are presented.

Site	n	Mono1	Mix1	Mono2	Mix2
Soil type (FAO)		Lithic Leptosol	Umbric Cambisol	Umbric Cambisol	Umbric Cambisol
Ah-horizon (cm)		2–5	5–10	3–5	5–10
B-horizon		> 20	> 20	> 20	> 20
WRC_{max} (%)	40	63.7 ± 3.1a	65.3 ± 1.4a	65.5 ± 2.7a	73.7 ± 4.0b
Soil moisture (%)	40	32.6 ± 6.2a	37.9 ± 4.4a	37.9 ± 4.2a	46.2 ± 7.0b
pH (1 M KCl)	40	3.4 ± 0.1a	3.5 ± 0.1a	3.5 ± 0.1a	3.4 ± 0.1a
C/N	40	18.6 ± 1.8a	18.1 ± 2.2a	19.5 ± 2.3a	18.4 ± 2.1a
C_{org} (%)	40	13.9 ± 3.2ab	11.8 ± 2.1b	15.3 ± 3.1ac	19.1 ± 5.0c
N_t (µg/g)	40	7.3 ± 1.6a	6.8 ± 0.7a	8.2 ± 1.8b	11.3 ± 3.2c
PO_4^{3-} (µg/g)	40	24.4 ± 4.8a	27.2 ± 4.6a	30.3 ± 7.1a	64.2 ± 13.9b
Ca^{2+} (mg/g)	40	0.5 ± 0.2a	1.4 ± 0.5b	1.4 ± 0.5b	2.6 ± 0.8c
Mg^{2+} (µg/g)	40	130 ± 45a	226 ± 82b	194 ± 46b	391 ± 110c
K^+ (µg/g)	40	416 ± 77a	456 ± 114ab	431 ± 62ab	469 ± 97b
Al^{3+} (µg/g)	40	606 ± 156a	402 ± 114b	357 ± 132b	221 ± 125c
Microbial activity (μgCO_2–C/g × h)	40	4.4 ± 1.4a	4.5 ± 0.7a	4.5 ± 1.3a	7.4 ± 2.2b
Microbial biomass (mgC/g)	40	4.8 ± 0.5a	3.5 ± 1.3b	4.7 ± 0.5a	4.5 ± 0.9a
Litter mass (g/m^2)					
Nov. 2001	8	393 ± 44b	457 ± 36b	410 ± 19b	507 ± 38a
Sept. 2002	8	0 ± 0b	287 ± 36a	92 ± 23b	327 ± 19a
Disappearance (%)		100	37	78	36

Differences between the plots are indicated by different letters ($p \leq 0.05$; Mann Whitney U-test).

content of the extracts (C_{mic}) were measured with the TOC-analyser. Specific microbial respiration (qCO_2) was calculated as microbial activity in mg CO_2-C per hour and g C_{mic}-C. The C-mineralisation (C_{min}) was calculated as microbial activity in mg CO_2-C per g C_{org} and day.

2.5. Litter sampling and extraction of Lumbricidae

Litter was sampled at random in areas of 300 cm^2 (n = 8) in November 2001 after litter fall and ten months later in September 2002 before litter fall. The litter was dried, weighed, and the results multiplied by 33.3 to calculate the amount of litter in g/m^2.

Earthworm abundance was determined for an area of 1/8 m^2 by hand selection from the litter and a consecutive formalin extraction [36]. Eight 1/8 m^2 circles per site were chosen at random and sampled in May 2003. The number of individuals per m² was calculated by summing up the number of earthworms of each single replicate per site.

2.6. Statistical analyses

Normal distribution of data was tested with the Kolmogoroff-Smirnoff-test, modified after Lillefors. Because not all data sets were normally distributed, we present the median values with the median absolute deviation and used the nonparametric Kruskal-Wallis-H-test and the Mann Whitney U-test in succession to test for differences between data sets. The limit of significance was set at $p \leq 0.05$. Two factorial analysis of variance (ANOVA) was conducted to specify the effect of species composition (oak mono/oak-hazel) and inclination (flat/steep) on soil chemical and microbial properties. Each factor appeared in a replicate number of n = 2 and therefore the degree of freedom of the single factors was d.f. = 1. The investigation was set up as a two factor randomised complete block design (RCBD). The soil characteristics used for analysis of variance appeared in a replicate number of 80 per factor. To avoid pseudoreplication repeated sampling never occurred at the same positions within the locations. All data were log (x + 1) transformed to minimize violation of normal distribution. The limit of significance was set at $p \leq 0.001$ to reduce the influence of heterogeneity of variance [39]. In the ANOVA result table the F-value, the significance-level and the R^2-value is presented. The R^2-value indicates the contribution of a specific factor to the total variance of the analysis. If a parameter's distribution is exclusively influenced by the chosen factors then the R^2-value of the model is 1.0. All statistical analyses were conducted with the computer programm SPSS 11.0.

Table II. Two-factorial ANOVA on the effects of species composition (oak monoculture/oak-hazel) and slope gradient (steep/gentle) on selected soil properties (C_{org}, N_t, PO_4^{3-}-P, K^+, Mg^{2+}, Ca^{2+}, Al^{3+}, qCO_2, C_{min}) at the investigation sites.

ANOVA two-way	Species composition			Slope gradient			Interaction			Model		
d.f.	1			1			1			7		
	F		R^2	F		R^2	F		R^2	F		R^2
C_{org}	0.2	ns		**15.3**	***	**0.09**	1.2	ns		**5.6**	***	**0.10**
N_t	3.8	ns		**54.1**	***	**0.23**	10.4	ns		**22.8**	***	**0.31**
PO_4^{3-}-P	**83.3**	***	**0.21**	**101.6**	***	**0.26**	**53.9**	***	**0.14**	**80.0**	***	**0.61**
K^+	4.3	ns		1.3	ns		0.5	ns		2.0	ns	
Mg^{2+}	**37.5**	***	**0.17**	**33.3**	***	**0.15**	0.3	ns		**23.7**	***	**0.31**
Ca^{2+}	**113.1**	***	**0.30**	**100.8**	***	**0.26**	11.6	ns		**75.2**	***	**0.59**
Al^{3+}	**34.6**	***	**0.14**	**53.5**	***	**0.22**	0.2	ns		**29.5**	***	**0.36**
qCO_2	**42.8**	***	**0.21**	5.6	ns		0.2	ns		**16.2**	***	**0.24**
C_{min}	**19.1**	***	**0.11**	1.8	ns		1.4	ns		**7.4**	***	**0.13**

*** $p \leq 0.001$; ns: no significance.

3. RESULTS

3.1. Organic matter

At the mixed cultures and at the monoculture with low inclination (Mono2), acidic brown earth (Cambisol) was formed (Tab. I). At the site Mono1 the soil type was a Lithic Leptosol. There were clear differences in the thickness of the Ah-horizon between monocultures and mixed cultures (Tab. I). The thickness of the Ah-horizons was about twice as high at the mixed stands (5–10 cm) than at the monocultures (2–5 cm).

WRC_{max} and soil moisture was significantly highest ($p \leq 0.05$) at the at the mixed stand of low inclination (Mix2) but did not differ between the sites Mono1, Mix1 and Mono2 (Tab. I). The C/N ratio ranged from 18.1 to 19.5 and did not differ significantly between the sites.

The forest floor mass after litter fall (Nov. 2001) ranged from 393–507 g/m^2 and did not statistically differ among the sites except for the site Mix2 which exhibited a significantly higher value (Tab. I). Ten months later, shortly before the next litter fall, the amounts of litter were substantially lower at all sites. Particularly high amounts of litter (78–100%) disappeared from the oak monocultures. At the mixed stands the amount of litter decreased by 37% (Mix1) and 36% (Mix2). The amounts of litter found at Mix1 (287 g/m^2) and Mix2 (327 g/m^2) were significantly higher ($p \leq 0.05$) than those found at the monocultures (Mono1: 0 g/m^2; Mono2: 92 g/m^2).

The contents of C_{org} and N_t were generally higher at the sites of low inclination than at the steep sites (Tab. I), but the difference in the content of organic carbon between the monocultures was not significant. Differences between monocultures and mixed stands did not occur except for the gentle slope which had a significantly higher nitrogen content at the mixed stand ($p \leq 0.001$). Accordingly, the factor "species composition" did not significantly influence C_{org} and N_t contents in a two-way ANOVA (Tab. II). The factor "inclination" explained the variances at 9% (C_{org}) and 23% (N_t).

3.2. Soil acidity and exchangeable soil nutrients

The soil pH was almost identical at all sites (3.4–3.5; Tab. I), and the contents of extractable potassium only differed marginally among the sites (416–469 mg/kg) (Tab. I). Only the sites Mono1 and Mix2 differed significantly from each other ($p = 0.024$). In respect to the contents of extractable calcium and magnesium there were strong differences between the sites (Tab. I). They reached the highest values at site Mix2 (Ca^{2+}: 2.6 ± 0.8 mg/g; Mg^{2+}: 391 ± 110 µg/g) and the lowest values at site Mono1 (Ca^{2+}: 0.5 ± 0.2 mg/g; Mg^{2+}: 130 ± 45 µg/g). Differences to the other sites were highly significant ($p \leq 0.001$); only between the sites Mix1 and Mono2 were there no significant differences in the contents of Ca^{2+} and Mg^{2+}.

The contents of Al^{3+} ions exhibited opposite tendencies to those found for the base cations Ca^{2+}, Mg^{2+} and K^+ (Tab. I). The significantly highest value was obtained at the site Mono1 (606 ± 156 mg/kg), the significantly lowest value at the site Mix2 (221 ± 125 mg/kg). The Al^{3+} contents at the sites Mono2 (357 ± 132) and Mix1 (402 ± 114) did not differ significantly from each other.

The content of extractable phosphate was more than twice as high ($p < 0.001$) at the flat mixed stand (Mix2; 64.2 ± 13.9 mg/kg) than at all the other sites (24.4–30.3 mg/kg) which did not differ significantly from each other (Tab. I).

Two factorial analyses of variance delivered highly significant model explanations for the contents of PO_4^{3-}-P, Ca^{2+}, Mg^{2+}, and Al^{3+} in the soil (Tab. II). The factors "species composition" (oak-hazel/oak monoculture) and "inclination" (flat/steep) both

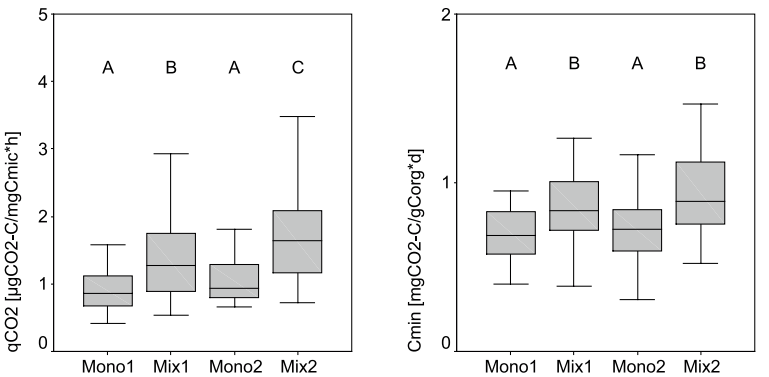

Figure 2. Specific microbial activity and carbon mineralisation (C_{min}) in the topsoil of the investigation sites Mono1, Mix1, Mono2 and Mix2 (Mono = oak monoculture; Mix = oak-hazel; 1 = 25–27°, 2 = 13–14°). Presented are Box-Whisker-plots. The letters above the box-plots represent the results of Mann-Whitney U-tests. Different letters indicate significant differences between the sites ($p \leq 0.05$).

Table III. Abundance of Lumbricidae at the sites Mono1, Mix1, Mono2 and Mix2 (Mono = oak monoculture; Mix = oak-hazel; 1 = 25–27°, 2 = 13–14°). Presented are median values of individuals per m^2 ($n = 8$) and values in ind./m^2.

Sites	Mono1	Mix1	Mono2	Mix2
Individuals per m^2 (median values; $n = 8$)	0 ± 0	1 ± 1	1 ± 1	2 ± 1
Individuals per m^2	2 (all juv.)	16 (all juv.)	21 (10 juv./11 ad.)	15 (7 juv./8 ad.)
Dendrodrilus rubidus	0	0	8	8
Lumbricus rubellus	0	0	3	0
Dendrobaena sp.	0	3	3	2
Lumbricus sp.	2	13	7	5

contributed to the model explanation for the elements P, Ca, Mg and Al with high R^2-values.

3.3. Soil biota

3.3.1. Lumbricidae

In total, 54 individuals were found in the litter and extracted from the soils of the investigation sites, 19 of which were adult (Tab. III). Adults were exclusively found at the flat sites: eight of them at Mix2 and eleven at Mono2. The species were *Dendrodrilus rubidus* and *Lumbricus rubellus.* Juveniles were only determined to the genus but very likely belonged to the same species. The low total number of individuals per m^2 (15 at Mix2, 21 at Mono2, 16 at Mix1 and 2 at Mono1) did not permit us to compare sites statistically.

3.3.2. Soil microbial properties

The potential microbial activity was significantly higher at the site Mix2 (7.4 µgCO_2-C/g × h) compared to all the other sites (4.4–4.5 mg CO_2-C/g × h) which did not significantly differ from each other (Tab. I). The microbial biomass was almost identical at the sites Mono1, Mono2 and Mix2 (4.5–4.8 mg C_{mic}-C/g) but significantly lower ($p \leq 0.001$) at site Mix1 (3.5 ± 1.3 mg C_{mic}-C/g) (Tab. I). The specific microbial respiration (qCO_2) was significantly higher ($p \leq 0.05$) at the oak-hazel sites than at the oak monocultures, independent of inclination (Fig. 2). While there was no significant difference between the flat and steep oak monocultures, the specific respiration was significantly higher at the flat hazel site (Mix2) than at the steep hazel site (Mix1).

The carbon mineralisation was generally higher at the mixed stands than at the oak monocultures ($p \leq 0.05$) (Fig. 2). The highest value was obtained for the mixed stand at low slope gradient (0.89 ± 0.21 mgCO_2-C/gC_{org} × d) and the lowest value for the steep monoculture (0.69 ± 0.11 mgCO_2-C/gC_{org} × d). There were no statistical differences between steep and gentle slopes when comparing sites of the same plant composition (monoculture/mixed stand).

Two factorial analysis of variance revealed a highly significant ($p < 0.001$) influence of the factor "species composition" (oak mono/oak-hazel) on the specific microbial respiration and the carbon mineralisation in the soil (Tab. II). Inclination did not affect microbial properties.

4. DISCUSSION

4.1. Organic matter

Soils of many simple oak coppice forests in the investigation area are extensively degraded by erosion. Usually, soil erosion is mostly affected by water and wind [27] and removes the finest and most fertile soil particles [9]. In our investigation area a high population density of red deer (20 ind./100 ha) enhances soil erosion processes through grazing and trampling. As a result we observed a significant reduction in the organic matter content and the activity of the soil biota in such degraded soils in a previous study [28]. The impact of red deer was pronounced at windward sites and high slope gradients (> 25°).

In the present study soil organic carbon and total nitrogen contents were mostly higher ($p \leq 0.01$) in the stands of low slope gradient than in the stands at the steep slope (Tab. I), a fact which points to increased erosion and run-off of soluble C- and N-compounds at high slope gradients [21, 22].

We assumed that hazel reduces the wind velocity close to the soil surface at windward forest sites. This would prevent the drift of litter and fertile soil from the ground and therefore reduce organic matter loss and nutrient depletion. As oak leaves decompose slowly due to the high concentration of phenolic compounds the huge reduction (78–100%) in forest floor mass between November 2001 and September 2002 in oak-monocultures was mainly evoked by wind drift and downhill transport. On forest paths, in troughs or at foot slopes we generally found thick layers of oak litter accumulating from downhill transport. In the mixed stands litter remained on the ground and its decomposition contributed to the formation of thicker Ah-layers compared to the monocultures (Tab. I). However, the higher aboveground organic matter mass (O-horizon) in mixed stands compared to monocultures was not reflected by differences in the contents of organic carbon and total nitrogen and the C/N ratio in the mineral soil (A-layer) (Tab. I).

4.2. Soil acidity and exchangeable soil nutrients

Litterfall is a major component of nutrient cycles in forest ecosystems [35]. Hazel leaves as well as leaves of other phaenerophytes like lime (*Tilia chordata*) and cherry (*Prunus avium*) are rich in base cations (Ca^{2+}, Mg^{2+}, K^{+}) [16]. It is known that the addition of alkaline plant material to acidic soils can appreciably increase the soil pH and the content of exchangeable soil nutrient status [14, 30, 45]. In our study, contents of exchangeable Ca^{2+} and Mg^{2+} were significantly higher ($p \leq 0.001$) in soils under mixed stands than in monocultures (Tab. I). However, the soil pH was not affected when hazel litter contributed to litter decomposition (Tab. I). In contrast, the content of Al^{3+} was significantly lower ($p \leq 0.001$) in soils of the mixed stands (Tab. I). Soil conditions beneath hazel seem to have favored the complexation of Al^{3+} ions to organic compounds in the Ah-horizon as already described in previous studies [15, 18]. Al^{3+} ions are also known to complex with phosphate ions in the soil and thus to prevent P-uptake by plant roots [6, 8]. Consequently, we assume that the higher content of plant-available phosphate beneath hazel (Tab. I) resulted from a lower Al^{3+} content in soils of mixed stands compared to soils from monocultures. Potassium contents did not differ between the sites (Tab. I), possibly due to the high mobility of K^{+} ions in soils [37].

4.3. Soil biota

Decomposers are known to be influenced by nutrient availability, substrate quality and microclimatic conditions [1, 26, 34]. Hazel litter is highly degradable because of the lower concentrations of polyphenolic substances in comparison to oak and beech leaves [33, 40]. Many studies suggest that the chemical composition and the species composition of the leaf litter influence its decomposition [20, 44, 50] and that these factors prevail over others controlling litter decomposition under favourable climatic conditions [11]. We therefore hypothesized that lumbricids and microorganisms would be favoured in mixed oak-hazel stands compared to oak monocultures.

Microbial respiration is supposed to be higher in tree leaf litter mixtures than in single-species litters [25]. Such a relationship was found for the low inclination site but differences at the steep site were marginal (Tab. I). The microbial biomass was even lower in soils of mixed stands than in the monocultures which conflicts with relationships found in earlier studies [7, 20, 34]. The specific microbial respiration (qCO_2) evaluates the efficiency of soil microbial populations in utilizing organic C-compounds [13]. Increases in qCO_2 are often interpreted as a result of unfavourable conditions ("stress") for the microbiota [3, 4]. In contrast to the potential microbial activity we generally found increased values for the specific microbial respiration in our mixed stands (Fig. 2). "Stress" can be excluded as a reason for higher qCO_2-values because pH, soil texture, humidity and carbon and nitrogen availability were similar or even higher in soils of the mixed stands than in monocultures. Here, the qCO_2 could have been influenced by density-dependant interactions, nutrient availability and top-down effects [5, 29, 46]. For example, selective arthropod grazing may reduce the microbial biomass without reducing the microbial activity [19, 20, 51]. Significantly higher carbon mineralisation (Fig. 2) at the mixed stands of this study also point to a stress-independent effect and suggest that conditions for decomposition processes are better in mixed stands than in oak monocultures.

Compared to other studies [12, 48], the abundance and diversity of Lumbricidae found here was very low (Tab. III), too low to compare sites statistically. This may be due to the low soil pH at all sites, which is known to reduce hatching success, enhance weight loss of aging adults and to hamper juvenile growth of lumbricids [8, 23, 38]. The absence of mature individuals at the steep sites and the virtually absence of individuals at the steep oak monoculture (Tab. III) suggest that the conditions at the steep sites might be even less favourable for lumbricids.

5. CONCLUSION

Hazel positively affects nutrient cycling in degraded oak forests. It reduces the wind velocity on the ground and traps litter to allow for accumulation of organic matter. Moreover, decomposition of hazel or oak/hazel-litter mixtures increases the content of plant-available calcium, magnesium and phosphate and supports the complexation of toxic aluminium ions.

Consequently, sustainable forest management in oak forests should include the growth of hazel and further base-rich shrubs and trees.

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