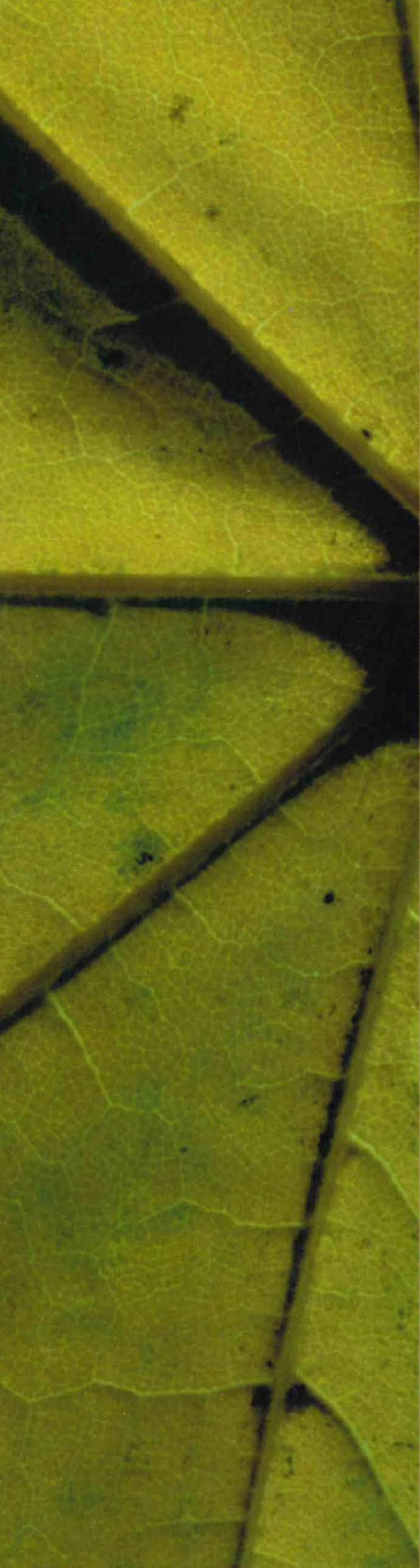

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ACTA SILVATICA ET LIGNARIA HUNGARICA

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Tartalomjegyzék

Management of *Robinia pseudoacacia cv. 'Üllői'* – 'Üllői' locust

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Abstract – Black locust (*Robinia pseudoacacia* L.) is the most widespread introduced tree species in Hungary. Though it covers 24% of the country's total forest area, the wood industry has difficulties processing large quantities of this poor quality wood. To address this issue, the Hungarian Forest Research Institute (FRI) initiated a selective breeding program designed to improve black locust wood quality. The breeding was based mainly on the small, elite breeding populations of the so called "ship mast" locust, which possess solid, straight, fork-free stems. Mono- and multi-clonal cultivars were developed and cultivar comparative and growing trials were established. Among the selected cultivars, the cultivar 'Üllői' locust (*Robinia pseudoacacia cv. 'Üllői'*) proved one of the best. As a result, a comprehensive review on the management of 'Üllői' locust in Hungary was compiled. This study provides a contribution to the improvement of growing technology used for selected black locust cultivars.

Robinia pseudoacacia / 'Üllői' locust / selection / growing

Kivonat – Az 'Üllői' akác (*Robinia pseudoacacia cv. 'Üllői'*) termesztése: áttekintés. Magyarországon a fehér akác (*Robinia pseudoacacia* L.) az egyik legelterjedtebb exóta fafaj. Az ország erdőterületéinek 24%-át foglalja el, azonban a faipar nem képes az alacsony minőségű akác faanyagot nagy mennyiségben feldolgozni. Ebből következően, a honi Erdészeti Tudományos Intézet (ERTI) egy szelekciós nemesítési programot indított néhány évtizeddel ezelőtt a faminőség javítása érdekében. Egy- és többklónú fajtákat hoztak létre, valamint fajtaösszehasonlító és termesztési kísérleteket létesítettek. A kiválasztott fajták közül az 'Üllői' akác (*Robinia pseudoacacia cv. 'Üllői'*) fajta bizonyult az egyik legjobbnak. Ezt a tényt figyelembe véve, átfogó áttekintés készült az 'Üllői' akác magyarországi termesztéséről. A tanulmány hézagpótlólag járulhat hozzá a szelektált akácfajták termesztési technológiájának fejlesztéséhez.

Robinia pseudoacacia / 'Üllői' akác / szelekció / termesztés

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1 INTRODUCTION

Selecting new clones and cultivars able to provide industrial wood of good quality and volume were the main objectives of the first black locust breeding programme in Hungary in the 1960s. Superior tree groups have been identified in some seed origin stands. Graft material was taken from the plus trees and planted in test plots at Gödöllő (the experimental station of Forest Research Institute (FRI)). *Mono- and breeding populations* were developed and a seed orchard was established from the selections (Keresztesi 1983, Rédei et.al. 2001, 2002).

FRI coordinated the research programme. Results showed the *'Jászkiséri', 'Kiscsalai', 'Nyírségi', 'Üllői'* and *'Szajki'* cultivars proved the best in terms of volume expected at felling age (Keresztesi 1988).

Several countries have also started research programmes to improve black locust wood quality and/or increase the production of biomass for energy purposes. Black locust has also been considered a promising tree for animal feed, nectar production, and the re-cultivation of dry and devastated lands. At present, black locust breeding and improvement research is being undertaken in the United States (Bongarten et al. 1991), Greece (Dini-Papanastasi – Panetsos 2000), Germany (Liesebach et al. 2004), Poland (Kraszkiewicz 2013), Turkey (Dengiz et al. 2010), India (Sharma et. al. 2006), China (Dunlun et al. 1995), and South Korea (Lee et al. 2007). Countries are increasingly interested in black locust improvement and management with a focus on the species' response to climate change effects.

The main goals of this paper are as follows:

- Bringing together researchers and forestry professionals who are interested in all aspects of black locust improvement.
- Documenting available knowledge about 'Üllői' black locust.
- Facilitating future information exchanges on black locust clones and cultivars.

2 ORIGIN AND TREE CHARACTERISTICS OF THE EXPERIMENTS

'Üllői' locust (*Robinia pseudoacacia cv. 'Üllői'*) was bred by B. Keresztesi and his co-workers Z. Marjai, J. Fila, and Z. Bujtás at FRI in the middle of the 20th century (Keresztesi 1983, 1988). The cultivar was registered in 1982. The origin of 'Üllői' locust is related to J. Fila who called the attention to the occurrence of this cultivar. In March 1966, plus trees were selected from the forest sub-compartment Üllő 10D on rusty-brown forest soil developed on sand, deposited on meadow forest soil. Collecting scions was difficult because climbers could not establish a safety station on the tree due to their tapering stem and narrow crown (Keresztesi 1988).

The characteristics of 'Üllői' locust are as follows: Pinnata type, trunk is vigorous, cylindrical and straight to the top of the crown. A greenish-brown field with many light brown lenticels between two linear stripes are visible on its bark. We noticed many bark plates on old trees. Spines are tiny; circa 10 mm long. The foliage is erect and the short leaf-stalk has 17–19 leaflets. These are oval-shaped and widest in the middle part, while the tips are blunt at the end with small awns. Leaflets on the underside are glaucous. The largest leaflets are in the middle part of the compound leaf. The tree has short-bodied white flowers that produce variable amounts of bloom that follow the same blossom period as common black locust. It has average nectar production and very poor seed-binding; moreover, it provides a medium to low value bee pasture (Keresztesi 1988).

'Üllői' black locust is susceptible to late and early frosts; therefore, it is not recommended for sites in higher hilly zones and in areas where frost hollows are present.

Good results can be attained in regions where the mean annual temperature is above 8°C. Fine sands and light loamy soil types are good for these black locust cultivars, provided sufficient soil depth. Shallow soils, soils with a poor water regime and coarse sand, or soil containing many stones are unfavourable. Clay texture is also unfavourable due to its poor aeration and compact condition.

3 STUDY SITES

The first experimental stand of the 'Üllői' cultivar was established in 1967 at the FRI Gödöllő Arboretum. Successful vegetative propagation led to further field cultivation experiments with this cultivar, experiments which have been conducted in various parts of the country ever since. This study executed evaluations in 21 experimental forest subcompartments. These are located at Tét, Gödöllő, Isaszeg, Pusztavacs, Helvécia, and Szentkirály. The trial plots are located in either a Turkey oak -sessile oak forest climate or a Forest-steppe climate (according to the Hungarian climate classification categories). The ages of the 'Üllői' black locust stands range from 6 to 35 years. Research site locations are presented in *Figure 1*.

Figure 1. Location of the research sites

Table 1 lists the site description including location (forest subcompartment), site type, and the most important dendrometric characteristics (age, H, DBH, V, N, G, mean tree volume).

Table 1. Location, site type, and stand characteristics

Location, subcompartment	Climate	Hydrology	Genetic soil type	Depth of productive layer	Soil texture	Age (yr)	H (m)	DBH (cm)	DBH/H*100 (%)	V (m^3/ha)	N (tree/ha)	G (m^2/ha)	Mean tree volume (dm^3)	Yield class (Rédei, 1984)
Isaszeg 7D	3	1	46	4	3	6	5.5	4.9	89.09	23.00	2555	4.82	9.00	III.
Gödöllő, Arboretum	3	1	46	4	3	10	13.3	10.4	78.20	100.03	1672	14.20	60.25	I.
Szentkirály 40 F	3	1	15	3	3	14	14.9	12.2	81.88	133.52	1320	15.43	101.15	III.
Gödöllő, Arboretum	3	1	46	4	3	15	15.6	12.7	81.41	171.18	1672	21.18	102.38	I.
Helvécia 67B	4	1	15	4	3	19	17	18.7	110.00	283.10	950	26.09	298	III.
Gödöllő, Arboretum	3	1	46	4	3	20	19.7	19.7	100.00	182.34	1095	33.38	166.52	I.
Szentkirály 46 G	4	1	15	3	3	20	18.5	15.4	83.42	218.00	1200	22.32	181.67	III.
Szentkirály 47 H	4	1	15	3	3	20	17.5	15.3	87.27	225.10	1300	23.85	173.15	III.
Tét 16 K-I	3	1	46	3	3	21	17	17	100.00	162.27	752	17.07	215.78	III.
Tét 16 K-II	3	1	46	3	3	21	17.7	17.3	97.74	131.39	573	13.47	229.3	III.
Tét 16 K-III	3	1	46	3	3	21	17.5	18	102.86	149.67	606	15.42	246.98	III.
Pusztavacs 212 A	4	1	15	3	3	31	15.5	15.7	101.90	169.03	930	18.10	181.75	V.
Pusztavacs 213 B	4	1	15	3	3	33	18	20.6	114.85	196.95	540	18.03	364.72	IV.
Pusztavacs 213 C	4	1	15	3	3	33	18	18.2	100.90	164.99	620	16.04	266.12	IV.
Gödöllő 5G (137D) - 5/26	3	1	46	3	4	35	22	21.6	98.18	199.80	448	16.42	445.98	II.
Gödöllő 5G (137D) - 5/32	3	1	46	3	4	35	19.4	20.6	106.19	229.80	674	22.46	340.95	III.
Gödöllő 5G (137D) - 5/48	3	1	46	3	4	35	20.4	22	107.84	218.90	546	20.76	400.92	III.
Gödöllő 5G (137D) - 5/44	3	1	46	3	4	35	22.4	23.4	104.46	335.40	690	29.67	486.09	II.
Gödöllő 7 B-I	3	1	46	4	3	35	18.9	21.6	114.29	235.46	625	22.90	376.74	IV.
Gödöllő 7 B-II	3	1	46	4	3	35	20.7	22.1	106.76	237.15	567	21.75	418.25	III.
Gödöllő 7 B-III	3	1	46	4	3	35	20.8	22.2	106.73	192.75	451	17.46	427.38	III.
Gödöllő 7 B-IV	3	1	46	4	3	35	18.4	22.3	121.20	235.81	596	23.28	395.65	IV.

Climate: **3** Turkey oak – sessile oak, **4** Forest steppe.
Hydrology: **1** No additional water supply.
Genetic soil type: **15** Sand with humus, **46** Rusty brown forest soil.
Depth of productive layer: **2** shallow, **3** medium deep, **4** deep.
Soil texture: **3** sand, **4** sandy loam.

Distribution of the sample plots in the site index curves of the black locust yield table are presented in *Figure 2*. As the figure shows, most plantations belong to yield class I to III. This means 'Üllői' black locust can produce relatively high volume on good sites where the objective is the production of sawlogs. A high proportion of poles and props can be expected from yield IV plantations.

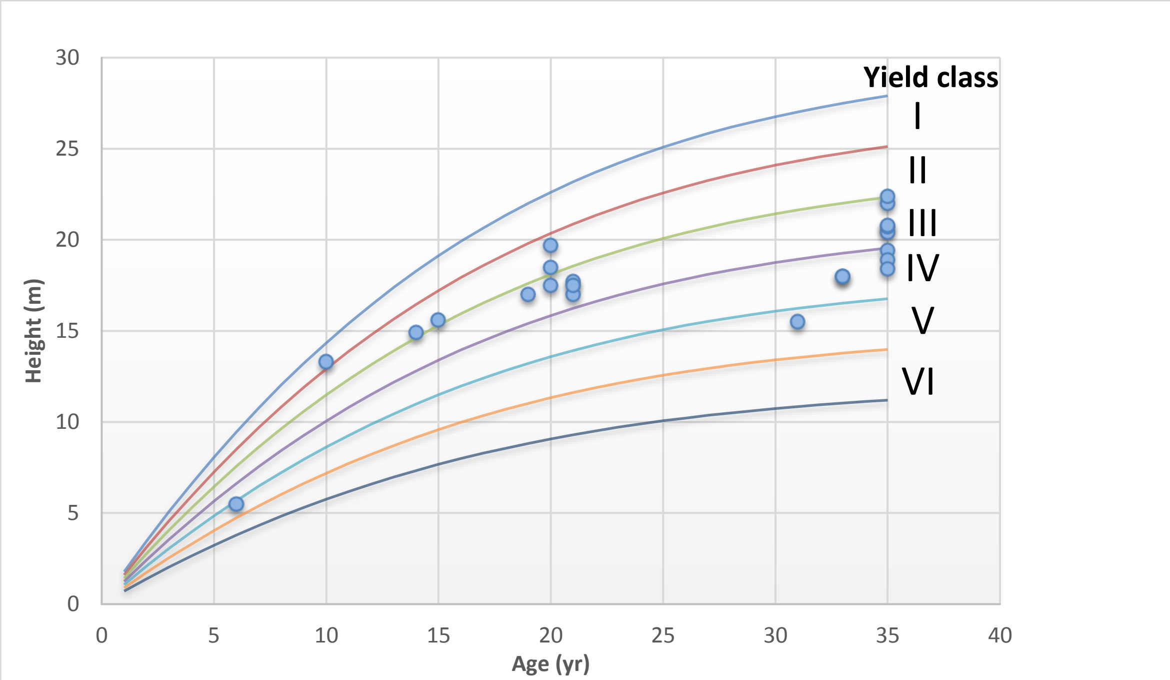

Figure 2. Experimental plots in the site index curves of black locust yield table (Rédei, 1984)

4 VOLUME EQUATIONS

Volume equations based on a single variable of DBH may be constructed from existing multiple-entry volume tables or from the scaled measure of standing or felled trees. Such equations are particularly useful for quick timber inventories because height and form estimates are not required and trees can be tallied by species and DBH only.

Volume equations based on DBH alone are sometimes compiled for inventories of relatively small areas, but this is not an essential condition; in some instances, "local" equations may be as widely applicable as "standard" equations. From 30 to 100 samples are usually considered a minimum number for small tracts, depending on the range of diameter classes to be included in the equation.

Figure 3-1 and *3-2* provide relationships of tree volume to DBH, and the same relationship transformed to a straight line, based on measurements of 55 'Üllői' trees at Pusztavacs region. The tree volume equations are subsequently used to estimate the average tree volume in each diameter class.

Figure 4 provides the relationship of mean tree volume (v) and DBH based on measurements of 22 'Üllői' black locust plantations (see *Table 1*). Multiply the mean tree volume by the number of trees per hectare to give the total volume per hectare. Multiply the volume per hectare by the stocked area of the plantation to obtain the total volume of the plantation.

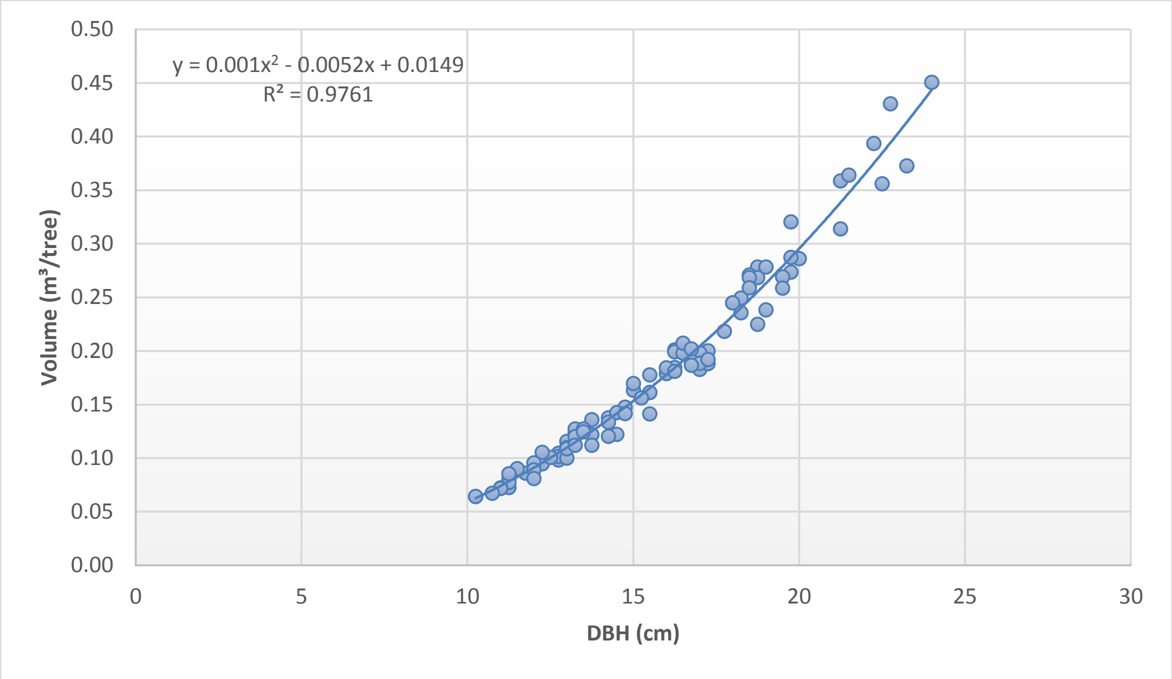

Figure 3-1. Curvilinear relationship of tree volume to DBH (based on measurements of 31 years old 'Üllői' black locust trees in Pusztavacs 212 A)

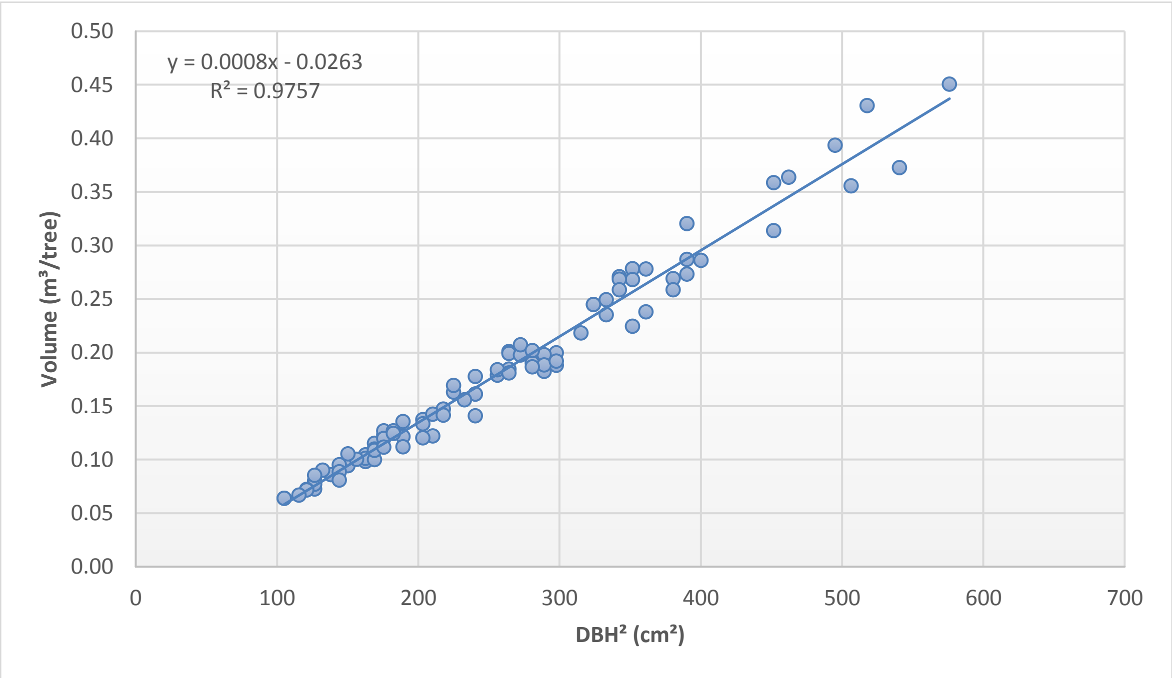

Figure 3-2. Straight line relationship of tree volume to single tree basal area of single trees (based on measurements of 31 year old 'Üllői' black locust trees in Pusztavacs 212 A)

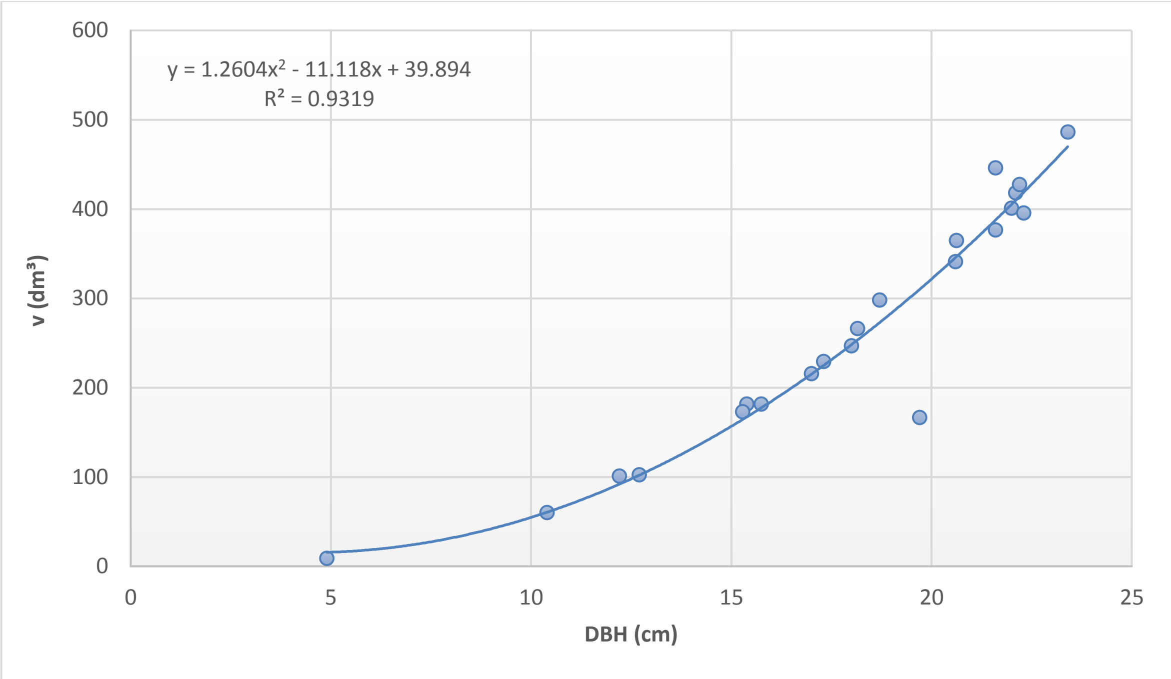

Figure 4. Curvilinear relationship of mean tree volume to DBH (based on measurements of 22 'Üllői' black locust plantations)

5 TENDING CUTTING MODELS

Tending techniques for black locust have been developed as a result of both advances in research and practical experience. A grouping of forest tending operations to form a tending regime can be made on the basis of results of long-term stand structure and forest yield trials. This is a great help for planning, prescribing, and controlling tending operations. The number of forest tending operations can be reduced by an effective forest tending regime and, at the same time, cleaning and thinning intensity can be increased. Introducing new cultivars as an alternative to commercial black locust growing has opened new perspectives for further development.

Tending principles for black locust stands established with cultivars are in some ways different from those established with common black locust seedlings or regenerated by coppicing. As in this case where stands are established with genetically uniform plants, initial spacing can be wider theoretically if there is no risk of game damage. Instead of a number of selective tending cuttings, a single comprehensive operation could rationalize the whole growing process (Rédei 2013).

Recommendations for tending cuts (enlargement of growing space) for 'Üllői' black locust plantations

Tending guidelines of stands established with selected black locust cultivars are different from stands established by seedlings or regenerated by coppicing. Tending phases typical for multiclonal common black locust stands with similar growth conditions (cleaning, thinning) are more difficult to separate for the "Üllői" black locust because the growth properties of monoclonal cultivars are theoretically identical. The particular aim of tending cuttings is to form the growing space for the optimal growth of the trees. When designing the ages and intensities of cutting, we relied on both the results of thinning experiments and the experience of forest managers working with this specific clone.

On good and excellent sites, altogether two enlargements of growing space are applicable to produce raw material for the sawmilling industry in stands planted in a 2.5×2.0 m spacing (5 m^2/tree growing space) (*Table 2.*). During the first enlargement of growing space (at the age of 9-10), tree number reduction is approximately 50%, so spacing will be 2.5×4.0 m (10 m^2/tree growing space) after the tending. The second enlargement of growing space (at the age of 16–17) also reduces the number of stems by 50%. During this process, the greater part of the yield is already suitable for industrial utilization. Hence, this growing technology can be considered economically profitable.

Prospective tree plantations of selected black locust cultivars tended according to the demonstrated model in *Table 3* are profitable only on excellent and good sites. If reduction of the rotation ages (20–25 years) is planned, the growing aims can be the production of poles, or saw logs of a lower size limit.

Table 2. Models of enlargement of growing space of selected black locust cultivars. Aim of growing: sawlog. Initial spacing: 2.5 x 2.0 m. Initial number of seedlings: 2000 plants/ha.

Label	Age	Height	Diameter at breast height	Number of trees	Expected total volume
		H	DBH	N	V
	(yr)	(m)	(cm)	(tree/ha)	(m^3/ha)
Yield Class I					
1. Enlargement of growing space	9–10	14	13	1000	90
2. Enlargement of growing space	16–17	20	18	500	130
3. Harvest cutting	30	25	25	450	270
Yield Class II					
1. Enlargement of growing space	9–10	13	11	1000	90
2. Enlargement of growing space	16–17	18	16	500	120
3. Harvest cutting	30	23	23	450	220
Yield Class III					
1. Enlargement of growing space	9–10	12	10	1000	55
2. Enlargement of growing space	16–17	17	15	500	80
3. Harvest cutting	30	21	21	450	170

It is also important that *pruning* should be done on time and with skill in stands established with 'Üllői' cultivars. At a mean crop height of 2.5–3.0 m, all branches in the first 1 m of stem should be removed as well as any others that reach into the space between rows and hinder cultivation. Form pruning of the crown should also be done at this time. The second pruning is carried out when height is 5–6 m. Only rows remaining after the first cleaning need be pruned. The third pruning, to a height of 3–4 m, is due after the cleaning and is limited to final crop trees. The final pruning, up to a height of 5–6 m, is done after thinning.

Table 3. Models of enlargement of growing space of plantations established by selected black locust cultivars. Aim of growing: poles, prospectively sawlogs. Initial spacing: 3.0 x 3.0 m. Initial number of seedlings: 1100 pieces/ha

Label	Age	Mean height	Mean diameter	Number of trees	Expected volume
		H	DBH	N	V
	(yr)	(m)	(cm)	(tree/ha)	(m^3/ha)
Model I					
Before enlargement of growing space	10	13	10	1100	60
After enlargement of growing space	10	14	11	700	50
Harvest cutting	20	20	18	700	180
Model II					
Before enlargement of growing space	8	10	8	1100	35
After enlargement of growing space	8	11	9	750	30
Before enlargement of growing space	15	17	14	750	105
After enlargement of growing space	15	18	15	500	85
Harvest cutting	25	22	20	500	180

6 CONCLUSIONS

Common black locust may – to varying degrees – have negative properties such as warping and twisting, forked stems, and low industrial wood yield, which are all disadvantageous for cultivation.

Therefore, from the second half of the 20th century, the staff of the Hungarian Forestry Research Institute (FRI) has been engaged in the improvement of black locust cultivation technology, including the selection and cultivation of selected black locust cultivars. The primary purpose of these initiatives is to improve stem quality and increase wood and nectar yields. In the case of 'Üllői' black locust, the aim was to improve stem quality (Keresztesi 1988).

Even though black locust cultivars possess better qualities than common black locust, they are not widespread in the afforestation practice of forest enterprises. The reason is the relatively high costs of cultivar propagating material. Consequently, it is cheaper for forest managers to apply common black locust instead of cultivars. Hopefully, EU subsidies and local/national funding for the forest sector will change this situation in the future. The 'Üllői' cultivar is one of the most cultivated varieties, having about 15 thousand rooted cuttings at the Nyírerdő State Forest Shareholders Company in Nyíregyháza.

For some decades black locust has garnered greater attention in an increasing number of countries due to global climate change and the energy crisis, which have stimulated research on relatively rapid growing, nitrogen-fixing trees such as black locust. This short review posits the following conclusions:

(1) selected black locust cultivars like 'Üllői' can be grown well under semi-marginal site condition as well;
(2) vegetative propagation method – root cuttings – have proved to be as a suitable means in black locust clonal selection;
(3) by growing selected black locust cultivars, it is possible to increase the stem quality significantly by 12–25% on average (Rédei et. al. 2017).

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The Multifunctional Role of Shelterbelts in Intensively Managed Agricultural Land – Silvoarable Agroforestry in Hungary

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Abstract – The use of shelterbelts as windbreaks to protect and increase field productivity has a long history in Hungary. Nevertheless, when shelterbelts began to wane, many environmental problems such as soil drying, deflation, and erosion began to occur, which in turn led to economic difficulties. Earlier field experience supported by new results indicates that shelterbelts are beneficial for intensively-treated fields, this despite the space shelterbelts require. Our research study aims to summarize the information available in Hungarian and international literature regarding the most effective shelterbelt structure. In addition, the study supports the design of multipurpose tree plantations with recommendations to mitigate climate change impacts and minimize the negative effects of intensive agricultural technology. In this article we would like to draw attention to the fact that shelterbelts can serve as effective tools in agroforestry and can be regarded as a means of ensuring economically and environmentally sustainable methods for agriculture. Below, we summarize how shelterbelts can help with adaptation to coming global and local challenges; we also describe why and how shelterbelts can be renewed and implemented in a reasonable way.

shelterbelt / productivity / green infrastructure

Kivonat – Az erdősávok szerepe intenzíven művelt mezőgazdasági területeken - szántóföldi agrárerdészet Magyarországon. Egyes európai országokban komoly hagyományokkal rendelkezik a mezővédő erdősávok telepítése az épített környezet, a szántóföldek védelme, a termelékenység növelése érdekében, a szélerősség csökkentése és a klíma szabályzása által. Ahol ezeket az erdősávokat felszámolták, komoly környezeti problémák merültek fel, mint például erózió, a talaj kiszáradása, defláció, amelyek gazdálkodási nehézségeket okoznak. A korábbi szakirodalom és jelenlegi európai kutatási eredmények alapján úgy tűnik, a területfoglalással együttvéve is előnyösek az erdősávok az intenzíven művelt területeken. Kutatásunk célja, hogy a magyar és nemzetközi szakirodalom alapján összefoglaljuk a mezővédő erdősávok leghatékonyabb felépítéséről rendelkezésre álló információkat, és ajánlásokkal támogassuk a többcélú erdősáv rendszerek tervezését a klímaváltozáshoz való alkalmazkodás és az intenzív mezőgazdasági technológiák kedvezőtlen hatásainak csökkentése érdekében.

erdősáv / termelékenység / zöld infrastruktúra

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1 INTRODUCTION

Extreme weather, droughts, and the increased frequency of flooding have negative impacts on natural vegetation as well as the quantitative and qualitative parameters and safety of agricultural production (Akpoti et al. 2019, Luetzenburg et al. 2019, Wiréhn 2018). Erosion, pollution, snowdrift, frost, and drought can all cause problems for infrastructural facilities (e.g. roads), and for quality of life as well. (Echavarren et al. 2019, Khavarian-Garmsir 2019). Natural or anthropogenic impacts can be reduced through technological solutions, but living plant organisms may replace these or increase their efficiency when biologically active areas are developing, which can favourably affect the quality of the environment (e.g. protecting species and soils, climate conditioning.) Targeted usage of appropriately planted vegetation (including non-forest plantations[1] as well) can significantly contribute to the supportable execution of ecological needs, and the requirements of environmental management and nature protection. In that way, the development of shelterbelt systems could strongly contribute to the EU Strategy on Green Infrastructures (GIs), which promotes the deployment of GIs across Europe (EC 2013).

The first shelterbelt data in Hungary is connected to a windbreak established in 1802. The aim of planting 10 rows of willow trees was to settle drifting sand and facilitate agricultural production (Danszky 1972). The first purposeful establishment of forests were in the 1950s, which resulted in the shelterbelts reaching their maximum length in Hungary in this period (Négyesi 2018). Agricultural techniques developed by leaps and bounds until the 1970s, causing a demand for large-scale farming. This in turn led to a decrease in shelterbelts as the space reserved for them were absorbed into farming (Takács – Frank 2008). In addition to this, shelterbelt ownership became unclear after communism ended; therefore, many remaining plantations were simply abandoned. Nowadays, the common European Union agricultural policy supports establishment of shelterbelts, and they are intensively researched alongside economic interests and ecosystem services.

The significance of this study is that it evaluates the effects of shelterbelts in a multifunctional way based on the results of studies from different perspectives accumulated over decades. The collected data indicates that, aside from their land requirements, the most significant disadvantage of shelterbelts is the decrease in yield caused by competition. A properly planned and planted shelterbelt comprises a very small portion of agricultural land, and its advantages are many times greater than its disadvantages (Mize et al. 2008). Moreover, root pruning effectively reduces the competition with the crop (Kort 1988, Kowalchuk et al. 1995).

2 THE EXTENT OF SHELTERBELT SYSTEMS IN EUROPE

Hedgerows and shelterbelts are grouped together as windbreak tree plantations in European surveys and project reports; therefore, separate data for each is currently unavailable. These agricultural protection plantations in some European countries are examples of the integration of trees with farming systems. Herzog (2000) defines hedgerows as structures comprised of trees or bushes that separate land parcels of different owners. Data from 2001 estimated the area of hedges to be 117,174 ha for England, Scotland, and Wales (den Herder et al. 2015). Hedgerows and windbreaks cover about 12,400 ha in Belgium (den Herder et al. 2017, based on Etat de l'Environnement en Wallonie 2010). In Hungary, a shelterbelt system of around 16,400 ha could be found in 2001 (Takács – Frank 2008), which is only half of the area occupied

[1] non-forest plantation: planting trees on areas, on which agriculture is unprofitable, or along streets, irrigation canals, cisterns, watercourses, or in the surroundings of settlements or monuments (Gál et al. 1960).

by these agroforestry systems in the 90s. According to the estimation, between 40-80% of the hedgerows have disappeared in Europe since the end of 1960s (Herzog 2000). The policy in itself was not the only cause; the use of land solely for production was also a factor (Baundry et al. 2000).

Though many traditional agroforestry systems have disappeared with the intensification of agriculture since the 1960s, a revived interest in integrating trees with agricultural production systems has occurred. “This interest comes from farmers who can see benefits in terms of increased and more diversified production” (den Herder et al. 2015).

The authors of this article would like to draw attention to shelterbelts as effective instruments for agroforestry and for economically and environmentally sustainable agriculture. The study provides a summary of how shelterbelts can help the adaptation to coming global and local challenges through ecosystem services, and offers clear guidelines on the reasonable implementation of shelterbelts.

3 WINDBREAKS

Shelterbelts decrease harmful effects mainly by reducing wind speed. The reduction of wind speed through shelterbelts of appropriate structure and direction may generate micro and mezzo climate changes that are advantageous for cultivated crops. Furthermore, these plantations can reduce accident risk on motorways by eliminating snowdrifts caused by crosswinds along roads, as well as limit the spread of pollution, dust, and erosion on bare surfaces. They can also reduce the spread of foul smells. The establishment of a shelterbelt is a relatively cheap solution for protecting agricultural land. The efficiency of reducing wind speed is about 10–15% on the windward side, and can reach 60% on the leeward side (Boskovic et al 2010).

The effectiveness of shelterbelts as wind speed reducers can be best described by the openness factor, which is the ratio of wind speeds measured on the protected side behind the belt and those measured in open areas. The openness factor depends on the “porousness” of the shelterbelt’s structure measured in its leafy condition. The most effective are the so-called fretwork or porous-structured shelterbelts. In these belts, the gaps that let the moving air through add up to 10 to 30% to the lateral surface, creating an openness factor of between 0.35 and 0.70. This means the wind speed on the protected side of the shelterbelt will generally be reduced by 50%. Behind closed plantations (without gaps or at less than 10% of the lateral surface), turbulence, heat pockets, and frost corners may develop. Open belts (with a gap ratio of more than 30%) are ineffective at reducing winds and may even increase wind speed through the so-called echelon-effect (Dömsödi 2010, Gál 1972).

Regarding the widths of shelterbelts, these can be categorized into three main groups. Narrow belts are 6 to 11 meters wide and contain 3 to 7 rows. Medium belts are 12 to 20 meters wide containing 8 to 13 rows, while wide belts with widths of 20 to 30 meters and 14 to 20 rows belong to the category of protecting forests (Gál 1972).

The results of Gál (1961), which assessed the wind-reducing effects of different shelterbelt structures in relation to their height, are summarized in the chart below (the extension of protective effects is given by a multiplier to the height of the trees).
At lower wind speeds, the effectiveness of dense shelterbelts decreases, whereas that of porous ones increases.

Based on research results and economic aspects that were also taken into consideration, the deployment of mainly narrow – 12 to 15 meter wide and 7 to 9 row – porous belts is recommended (Gál 1961).

Recent researches have introduced the concept of total area density (Ad), which is obtained by dividing projected area of leaf, branch, and stem per unit ground area, by the average crown length, because most of the total area of vegetation is in the crown mainly. Ad multiplied with the width of the shelterbelt (Ad × W) is considered to be a measure of the total surface area per unit length of the shelterbelt obstacle. Torita-Satou (2007) found a significant positive correlation between the sheltered area and W × Ad.

Table 1. Efficiency of different shelterbelt structures, h = tree height (based on Gál 1961)

Effect		Distance		
		closed	porous	open
Windbreak	front side	5 – 22h	3 – 17h	5 – 10h
	behind/protected side	15 – 49h	15 – 51h	11 – 20h
Highest protection		1 – 5h	1 – 5h	1 – 10h
Practically important (min 50%) wind decrease		10h	10h	–

Curiously, Hungarian experiments showed that snow stopping properties of shelterbelts are not influenced by porousness, but rather by tree height, the geographic structure of the belt, and the surrounding surfaces (Takács 2008). The more complex the obstacle we set up perpendicularly to the wind direction is, the better the expected result should be. A complex 4-row plantation alongside the road at a minimum distance of 20 meters, where the line of trees is combined with an edge of shrubs (e.g. articulated in two parts), can be more effective than a conventional 8 to 10 row protective belt. The reason may be that the articulated structure of the 4 row belt and the turbulence created by it can change the direction of the wind vectors and the energy of the particles conveyed by the wind. Thus, the particles settle along the wind-exposed side of the belt in a strip about 20 meters wide in the uncovered area between the belt and the line of trees (shrub) as well as on the embankment between the road and the line of trees.

As described above, in addition to appropriate orientation, the most important factor is to shape the structure so that it is suitable for the purpose of protection. Experience shows that it is unnecessary to plant 15 to 20 row-wide shelterbelts since the first couple of rows of trees can break the strength of winds insofar as it does not endanger the protected area or project.

Model experiments show that the length, height, width, and cross-sectional shape have an effect on the aerodynamic features of the shelterbelt, as well as on the internal structural components, such as the amount and arrangement of its vegetative surface area and volume, as well as the geometric shape of individual vegetative elements (Brandle et al. 2004, Zhou et al. 2004).

4 MITIGATION, CLIMATE ADAPTATION AND PRODUCTIVITY

Transpiration and assimilation are much higher in forests than in other forms of vegetation due to the high leaf-surface index, which has a cooling effect on the environment. Thus, the carbon sequestration of the forested areas coupled with agricultural systems may dampen global warming, while enhancing productivity (Amichev et al. 2016, Mátyás (ed.) 2005).

The effects of shelterbelts that influence the micro-climate (e.g. windbreak, increasing the relative moisture of air, decreasing evaporation, promoting the formation of dew and homogeneous blankets of snow), manifest themselves in increasing agricultural productivity.

Decreased air movements help reduce plant and soil evaporation. This leads to an improved water balance and hydration and, thereby, lower energy requirements to compensate dehydration. Stomas do not close in lighter winds, enabling undisturbed ventilation. Reduced air movement reduces the chilling of the environment; thus, soil and air temperatures increase, which is favourable for germination, the function of plant cells, and soil microbes, too (Szarvas

2010). The physical damage (twisting by the wind or sandblasting by eroding particles is smaller in the protection of a shelterbelt (Boskovic et al 2010).

Summarizing the results of several researchers (Kölüs 1979, Takács 2008, Abdalla – Fangama 2015, Zheng et al. 2016), we can conclude that a 10–12m wide, articulated and at least 20m high, but young shelterbelt, supplemented with a shrub zone to break wind and snow, can have a positive effect on crop yield up to a distance of 300 m for a wide range of crops: groundnuts, cotton, vegetables, cereals, maize.

A statistically evaluated yield analysis was carried out in the 1960s for the seven most important crops (winter wheat, winter and spring barley, alfalfa, maize, carrot, pasture grass) in 18 selected areas in Hungary (Gál 1963). The conclusion was that the production-increasing effect is demonstrable on both sides of the shelterbelt, regardless of their compass orientation. The best result is achieved if shelterbelts are situated perpendicularly to the typical direction of wind. In Hungary, shelterbelts positioned in an east-west direction are the most effective since protection against wild northerly winds and dry southerly winds is extremely important. The danger of drought occurs mainly with winds with a temperature higher than 25 ^{o}C / 77 ^{0}F, and relative moisture lower than 35%.

Concerning the wind-breaking and snow-catching properties of shelterbelts, the width of the protected zone for increased yield is influenced mostly by the height and structure of the shelterbelt; the width has no significant influence.

The width of the effective zone can be 6 to15 times bigger than the height of trees on the northern and southern side of the shelterbelt, while on the eastern and western side, this is limited to 8–10 times. The biggest rise in crop yield has been experienced in a strip 3-10 times wider than the height of the trees.

The favourable effects on climate and yield are more apparent in shelterbelt sites situated in locations that experience weather extremes and drought; the more extreme the conditions, the more apparent the favourable effects become.

Table 2 shows the extra yield on shelterbelt-protected areas, compared to samples taken from unprotected control plots.

Table 2. Extra yield in shelterbelt-protected plots (Based on Gál 1963)

Plant species	Extra yield (%)
winter wheat	9.8 – 26.8
winter barley	1.7
spring barley	6.1 – 33.5
alfalfa	20.3 – 22
maize	2.9 – 28.7
carrot	6.2
pasture grass	15.3

In comparison, Nuberg (1998) found similar values of the weighted mean yield increase except for alfalfa, which reached 99% in Australia.

However, as stated in both research studies, somewhat weaker crop yield has been found in areas close to the shelterbelts –a distance ranging from 5–60 m –than in the middle of the plot. In Hungary on the southern edge of the shelterbelt, this negative effect is less significant.

The effect of shelterbelts on crop yield depends on the sensitivity of the crop against wind (Gál 1963).

Nevertheless, shelterbelts increase the overall safety of yield due to the protection they offer against drought and wind damage.

5 SOIL PROTECTION

In agricultural plant producing systems, irrigation alone cannot prevent drought or solve water supply needs; this is particularly true on sites stricken by extreme weather. Irrigation influences soil water balance only. Combating atmospheric drought requires the reduction of dry winds. In the absence of this, the wind continuously replaces the moist air layers that result from evaporation and transpiration. As a result, the need for irrigation increases, and the requirement of secondary salinization in soil occurs. The favourable micro-meteorological effects of shelterbelts result not only in improved productivity of non-irrigated agricultural sites, but also play an important role in increasing irrigation efficiency and soil protection. Beyond that, based on an examination of microflora and microfauna in soil profiles, 8–10-year-old shelterbelts also have a favourable effect on deeper soil layers. Beside soil ventilation, life in the soil is also positively influenced by plantations of mixed stands. Deeper soil layers also have the opportunity to unfold nutrients, which is beneficial for tree growth (Gál et al. 1960, Carnovale et al. 2019). Regarding carbon sequestration, several research studies (Saha et al. 2009, Nair et al. 2010, Lorenz – Lal 2014) reveal that tree plantations on agricultural land can significantly increase soil organic carbon (SOC) content. Long term managed plantations such as shelterbelts can store SOC in the upper soil level similar to adjacent semi-natural forests (Lorenz – Lal 2014). Tree species richness increases the amount of stored SOC.

Establishing shelterbelts can provide solutions for damaged areas such as industrial sites, landfills, and sludge reservoirs that cannot be afforested due to their toxicity. In such cases, the area surrounding the contaminated site should be afforested in the interests of environmental protection. Over a longer time period, conditions at these contaminated sites can improve through the benefits shelterbelts provide (windbreak, flue-dust, lixiviation of toxic material), which first enables the settling of natural grass and, later, the growth bushes and trees (Dömsödi 2010).

Shelterbelts also can be a solution for gully erosion, as mentioned in Deng et al. (2015). They recommend an optimal planting density of farmland shelterbelts for the prevention of gully erosion at 1100–1300 m/km^2.

Examining the annual water budget on soils, well-shelterbelts can lead to a favorable process in protected areas: atmospheric precipitation rises, physical evaporation from the soil surface decreases, and the accumulation of considerable water reserves in the soils occurs (Lazarev 2006).

6 NOISE AND AIR PROTECTION

Due to their effectiveness and limited space requirements, technological solutions are the most commonly used methods for noise reduction near motorways. Nevertheless, building noise barriers can be disproportionately expensive in cases involving longer road sections or a diffuse noise source with a large extension. In addition to their windbreak function, shelterbelts can also serve as effective noise reducers when the distance of the sound traversing the plantation (so the width of the belt) is a minimum 30–50m. In this case, noise is reduced up to 3–4 m height from the surface, but the noise reduction is not more than 10-15 dB (Islam et al. 2012). However, the literature also refers to the so-called screen-noise created by the whispering leaves of trees, which can have a soothing, relaxing effect.

Plant usage, mainly with sufficiently wide tree or bush rows, has many additional favourable aspects that artificial technical solutions do not provide. For example, in contrast to walls, plants absorb the sound of vehicles rather than reverberate and increase the noise. In addition, they also provide all the added benefits green spaces provide, ranging from carbon sequestration to making a microclimate more pleasant (Palotás 1985, Barótfi 2000).

The many problems associated with air pollution validate the air-purifying function of shelterbelts. Tree stands increase the roughness of the surface and cause vortexes in streaming air. The leaves catch not only the precipitation, but also filter out dust, heavy metal, sulphur-dioxide, freon, etc. As well as improving the CO_2 balance of our atmosphere, forests stands have a significant filter effect against trace gases and aerosols; however, this environmental influence can be fatal for tree stands in extremely polluted areas. Under the effect of vortexes, the transported particles deposit on the surface of leaves, herbaceous plants, and soil (Heath et al. 1999, Islam et al. 2012). The scale of turbulence depends principally on scragginess of crown storey, while adhesion of aerosol particles is influenced by leaf area index (LAI), leaf surface features, and crown structure (Mátyás (ed) 2005). Prominently high deposition values were measured in spruce (*Picea*) stands, with high surface roughness (Takács 2008).

According to the measurements of Kölüs (1979), the 15–25 ppm CO concentration near the motorway is not demonstrable at the opposite side of the shelterbelt, while 11ppm concentration in areas without shelterbelts decreases only to 1.2ppm at a distance of 50m from the motorway. A consistent tree plantation at a width of 10–12m can catch the deposition of smut as well as gaseous, small-sized particles that may be harmful to respiratory organs. An increasing number of researchers agree (Fórián – Hagymássy 2009, Chen et al. 2015, Amadi et al. 2016, Amadi et al. 2017) that wayside hedgerows or tree plantations can play a significant role in suspending air pollution and salty sprinkle, the contaminated rainwater sprayed by vehicles. Another point of view is that tree stands act as complex "filters" and play an important role in the natural accumulation of pollutants. The typical air drifts connected to afforestation work very much like a conveyor belt as they transport the air moisture, carbon-dioxide, and other gaseous components of metabolism (Willis et al. 2017). The relatively lower temperature in the forest processes an intensive air transport between the atmosphere of the forest and the layer above, which dissolves pollutants into the stand. Forest stands also have their own air circulation, and this helps the pollution engaging effect of the forest.

7 ECOLOGY

The wildlife of many areas is affected by human establishment and activity. Human activity and construction alters natural areas, disrupting the contacts between certain wildlife populations, migration opportunities for some individual wildlife species and, finally, affecting the sum of natural living conditions for wildlife. Coherent non-forest tree stands, for example shelterbelts, which can serve as ecological corridors, are suitable for limiting the impacts human activities can have on a landscape (Barna 2004). These ecological corridors, together with protected areas and other semi-natural sites, can create a network of biotope systems, and as "green corridors" can ensure the variegation of sites, life circumstances, communication, and the spread of interconnected plant and animal species. In addition, shelterbelts are ecological systems that can contain significant wildlife; several species within these are natural predators of pests, which can have a beneficial impact on agriculture through pest reduction (Szarvas 2010, Todd et al. 2018, Gontijo 2019). Furthermore, by reducing wind speed, shelterbelts can significantly prevent the spread of some wind-carried pests and aphid-transmitted viruses (Mize et al. 2008).

Though farmers generally consider ecological issues to be of lesser importance than economic factors, they do experience and appreciate the strong correspondence between ecology and crop productivity and sustainability. The influence that the presence of pollinators has on different production systems is a good example of the relationship between ecological and economic factors.

For example, bees not only directly create food by converting nectar to honey, but more importantly support agriculture through their pollination activity. According to URL1, it is commonly understood that bees are responsible for at least one-third of all global food supplies and billions of dollars of agricultural production. Bee-dependent crops include the majority of tree fruits and berries, several vegetables, and some important forage species such as alfalfa, clovers, and legumes. Having a diverse population of pollinators is even better as this can ensure crops receive some pollination and fruiting even if honeybee populations fail.

Bee keeping is promoted by CAP Pillar II in the European Union, which is the world's second largest honey producer. (Santiago-Freijanes et al. 2016). By providing pollens and nectars for bees, shelterbelts can play a significant role in domestic honey production as well (Donkersley 2019). The wind speed reducing effect of shelterbelts causes a higher amount of pollinating insects on the protected field compared to the open areas. Honey bee (*Apis mellifera*) flight is inhibited at wind speeds of 6.7–8.9 m/s (Mize et al. 2008). By providing pollen and nesting resources for honey and wild bees, shelterbelts positively affect the diversity of the pollinator fauna (Hass et al. 2018). The intensity of the management – both for shelterbelts and adjacent crops – also affects bee diversity (Wu et al. 2019) and total gamma diversity (Duflot et al. 2015).

The changes in agricultural practices and the movement away from diverse landscapes in the past 50 years, has caused a significant decline in pollinator species (Odanaka – Rehan 2019). Multi-canopy layouts with permanent herbaceous soil cover provide year-round benefits to bees and agricultural systems as a whole by lengthening the available term of pollen starting early in the year with willow (*Salix sp*.) and hazel (*Corylus sp*.) and then ending with chestnut (*Castanea sp*.) and English ivy (*Hedera helix*). Other species are a source of nectar, including maple (*Acer sp*.), mountain ash (*Sorbus sp*.), blackthorn (*Prunus spinosa*), quince (*Cydonia oblonga*), and elderberry (*Sambucus sp*.), or honeydew, e.g. poplar (*Populus sp*.), beech (*Fagus sp.)* or propolis, as oak (*Quercus sp*.) and certain conifers. These effects can nearly double honey harvest volumes (Clément et al. 2016). Though honey bees are a focus of research because of their dominance in pollinator communities, wild bees and other pollinators can actually be more effective pollinators due to their higher frequency of contact with the flowers (Földesi et al. 2016).

Hundreds of useful wild bee species and subspecies are unique pollinators of many seed crops, including rapeseed for oil, legumes as secondary crops, cultivated fruit plants etc. Open areas may be left inside or on warm margins of larger patches in net nodes when designing shelterbelts to make feeding or nesting areas for game and thermophilous wild bees, spiders, and other insects (Zajączkowski 2016, Morrison et al. 2017).

Semi-natural habitats like shelterbelts also promote the appearance of generally forest-related spider (Araneae) and beetle (Staphylinidae) species that do not occur or are only occasionally found in intensive cultivation areas (Szél – Kádár 2012, Li et al. 2018). Similarly, the species richness and diversity of springtails (Collembola) also highlights the importance of shelterbelts in agricultural environment (Winkler – Traser 2012, 2017). With bird communities, species specific to agricultural fields and specific to forests appear and nest in the shelterbelt system. Also, species that rarely nest in closed forests can often be found in shelterbelts (Jánoska 2011). Similarly, special temporary mammal communities appear in shelterbelt-protected agricultural areas. In addition to the common rodent species and communities of cultivated areas, there is a steady population of generalist rodents of European temperate forests (Németh 2014).

Although amphibians and reptiles are not typical animal communities on farmland, species occurring only in wooded areas also occur in shelterbelts. This underlines the role of such tree plantations as an ecological corridor by facilitating the migration and spread of amphibians (Winkler 2012).

8 SOCIO-ECONOMIC ASPECTS

In recent years, the role of landscapes has significantly changed. Attention is mainly directed to those areas that have been attributed to a single destination such as conventional monoculture agricultural areas. Nowadays, the process of transformation into multifunctional landscapes, where people living in a region rely on a higher variety of resources, can be observed (Schaller et al. 2018). In a multifunctional landscape a typically agricultural area is not only the scene of agricultural production, but also a biological and social living space. Agroforestry systems, including windbreaks and shelterbelts, are necessarily part of these multifunctional landscapes due to their complexity, diversity, and valuable ecosystem services. These services bring benefits to both landowners and society. Landowners benefit from shelterbelts in several ways. While most environmental services such as soil improvement and increased biodiversity effects cannot be estimated due to a lack of information and data, other benefits such as yield increment and energy conservation are measured private benefits of shelterbelts supported by a number of evidences. Society as a whole also benefits from shelterbelts in terms of climate regulation through carbon sequestered in the system, and improvements in water quality and biodiversity (Grala 2004, Kulshreshtha et al. 2018). In addition, the utilization of locally produced biomass brings significant energy savings at the regional or national level and contributes to the achievement of renewable energy targets.

Even though they offer many benefits for farmers, landowners, and society as a whole, shelterbelts have been removed from many livestock farms, croplands and farmsteads worldwide. The reasons for their removal include the following (Grala 2004, Tyndall 2009, Pisanelli et al. 2012, Kulshreshtha et al. 2018, Amichev et al. 2020):

- space needed for buildings, equipment and other infrastructure
- weather damage (flood, storm, fire, etc.)
- damage by human activity (chemical or mechanical effects)
- age of shelterbelt (tree degradation, structure disintegration)
- change of land size and technology (intensification, larger machines, aerial spraying etc.)
- poor market facilities
- labour and time requirements for planting and maintaining trees and shrubs
- the economic consequences of all aspects listed above
- less experience and/or lack of knowledge on behalf of land users and landowners

The use of other agro-ecologically advantageous microclimate and soil improvement land use methods (e.g. no tillage or reduced tillage, mulching, growing cover crops) is another possible factor; the farmers may not perceive the benefits of shelterbelts and thus remove them.

According to some research examining farmer motivations, farmers who decided to maintain or establish shelterbelts did so for a variety of reasons including snowdrift control; dust, sand, noise, spraying, and wind protection; yield increment; livestock protection; firewood production; aesthetic reasons; wildlife habitat; product diversification; and the mitigation of livestock emissions (Dix 1976, Brandle et al. 1984, Vernon et al. 1991, Mertia et al. 2006, Tyndall 2009, Kulshreshtha et al. 2018, Rois-Díaz et al. 2018). Having shelterbelts in arid and environmentally sensitive areas is even more important as shelterbelts play a significant role in optimising yield; furthermore, in certain places and growing seasons, shelterbelts are essential for crop production (Mertia et al. 2006, El Amain – El Madina 2014, Li et al. 2020).

Kulshreshtha et al. (2018), points out that the decisive factors in decisions to remove shelterbelts are the educational attainment long-term planning of landowners.

A number of estimates have been calculated to examine whether it is worth keeping shelterbelts and similar green linear infrastructure elements. The results are wide-ranging; some show little benefit while others estimate a significant impact (Dix 1976, Vernon et al. 1991, Mertia et al. 2006, Tyndall 2009, Kulshreshtha et al. 2018, Pisanelli et al. 2019). In a U.S. survey Brandle et al. (1992) concluded that windbreaks are an economically attractive investment over a wide range of conditions. Analysis by Grala (2004) reveals that additional crop yields necessary to break even vary significantly across windbreak scenarios, lifespans and lengths of the protected zone. According to Tyndall (2009), 75 % of Iowa hog producers who believe shelterbelts help to physically and social-psychologically mitigate odours would be willing to pay to plant and maintain shelterbelts. Livestock farmers likely see more direct benefits of shelterbelts than crop producers do, primarily from the social-psychological aspects stemming from public relations related to matters of odour control.

The economic and social value of natural assets can be measured by the sum of all the benefits provided by their ecosystem functions. However, when examining economic aspects, it is very important to emphasize that the large number of factors makes each system special; hence, judging the benefits of maintaining shelterbelts requires a unique calculation tailored to local circumstances. No universal method has been developed to calculate the value of positive externalities due to positive environmental effects, which may be significant. Therefore, the benefits shelterbelts extend to society are not considered by most producers in their management decisions as they offer no compensation for the producers themselves. In contrast, Rempel et al. (2017) found that producer costs were easily identifiable and that these strongly influenced management decisions. Shelterbelt timeframes also complicate the issue. The economic benefits of shelterbelts are only realized after 10-15 years, which is beyond the annual timeframe by which agricultural producers typically operate. This contributes to increased uncertainty that further discourages agricultural producers (Grala, 2004). Moreover, in many cases, available subsidies provide little motivation for farmers to install or maintain shelterbelts.

The positive perception of farmers is a very important step in the adoption of agroforestry practices (Mertia et al. 2006, Pisanelli et al. 2012, Kulshreshtha et al. 2018). Results of a survey undertaken to determine farmers' perceptions of silvoarable agroforestry across Europe in 2003 and 2004 suggest silvoarable agroforestry would become a more common feature of the European landscape if it were provided with appropriate promotion and support (Rigueiro-Rodríguez et al. 2009). CAP should support this type of farming by mutually reinforcing measures rather than through exclusive measures, which should also be thoroughly explained and encouraged by experts. Due to the lack of awareness and practical knowledge, Pisanelli et al. (2012) and Rois-Díaz et al. (2018) highlights the importance of promotion at the institutional level through training and extension activities with the aim of raising awareness of available support in addition to practical knowledge of farming and alternatives. In order to promote agroforestry, it is also essential to draw consumer attention to the quality of agroforestry products and the ecosystem services provided by agroforestry systems.

9 POSSIBLE NEGATIVE EFFECTS OF SHELTERBELTS ON ADJACENT CROP

Though shelterbelts have many advantages, they do have some disadvantages as well. The shade of the trees, the competition, and the spread of invasive plants have a negative effect on crop yield. The most common mentioned handicap of the plantations in agricultural land is the competition between woody vegetation and the adjacent crops, especially under conditions of limited moisture (Brandle, et al. 2004, Jørgensen 2009). Generally, the competitive zone is 1-2 h (h is the height of the trees), where the yield loss can reach 49% (Nuberg 1998). Although competition is mainly for soil water content (Kowalchuk et al. 1995), tree shade reduces opportunities for photosynthesis, and the roots increase demand on soil nutrients. The allelopathic effect of litter also causes yield loss (Nuberg 1998). Theoretically, without wind, the effects of shelterbelts would be negative; on the other hand, the trees reduce evaporation and maintain moisture by decreasing wind, which is a positive effect for crop yield (Vandermeer 1989).

Shelterbelt competition can be decreased by root-pruning. The effectiveness of this depends on the rooting characteristics of the trees/shrubs. A root cut in the top 60 cm of the soil at 0.5 h distance from the trees eliminates the crop yield reduction for three years (Kort 1988, Kowachuk et al. 1995).

The sensitivity of different crops for competition is various. While wheat and oats show a larger loss in the shade of shelterbelts, the reduction in alfalfa and other perennial hay crop yields is smaller. Corn showed no apparent yield loss due to competition (Brandle et al. (ed) 1988).

Although shelterbelts can provide habitat for wildlife, they may also promote the spread of undesirable, for example invasive plant and animal species. The role of valuable or desirable species also can be disadvantageous, particularly when they feed on crops rather than on pests and weeds (Mize et al. 2008).

In addition to the disadvantages of the shelterbelts, the lack of theoretical knowledge and practical experience about managing tree plantations is a great limiting factor for farmers (Stancheva et al. 2006). Based on crop yield measurements, the installation of a shelterbelt will pay off in the long run (Easterling et al. 1997). The protection effect appears after the trees are 6 years old and increases yearly, reaching the full efficiency at the age of 20 (Garrett – Buck 1997).

10 GUIDELINES FOR THE ESTABLISHMENT AND MAINTENANCE OF SHELTERBELTS

The positive effects of shelterbelts will only prevail with well-prepared planning, appropriate installation, and targeted usage (Yang et al. 2018). Therefore, some guidelines for the structure and choice of tree species should be taken into consideration during installation. Takács (2008) determines the ideal shelterbelt structure as the following (*Figure 1*):

- an additional line of trees or shrubs should be settled on the windward side, 12-20 meters from the edge of the shelterbelt,
- the windward side of the shelterbelt should be permeable and higher than the accompanying shrub or tree line
- an open area between the shelterbelt and shrub line should be left
- trunk density should be high on windward side and thinning dense towards the leeward side
- tree heights in the interior lines should be diverse (two-storey stands)
- the shape of the protected (leeward) side should be slope or stepped
- leeward edge does not extend beyond the crown projection of the outer tree-line

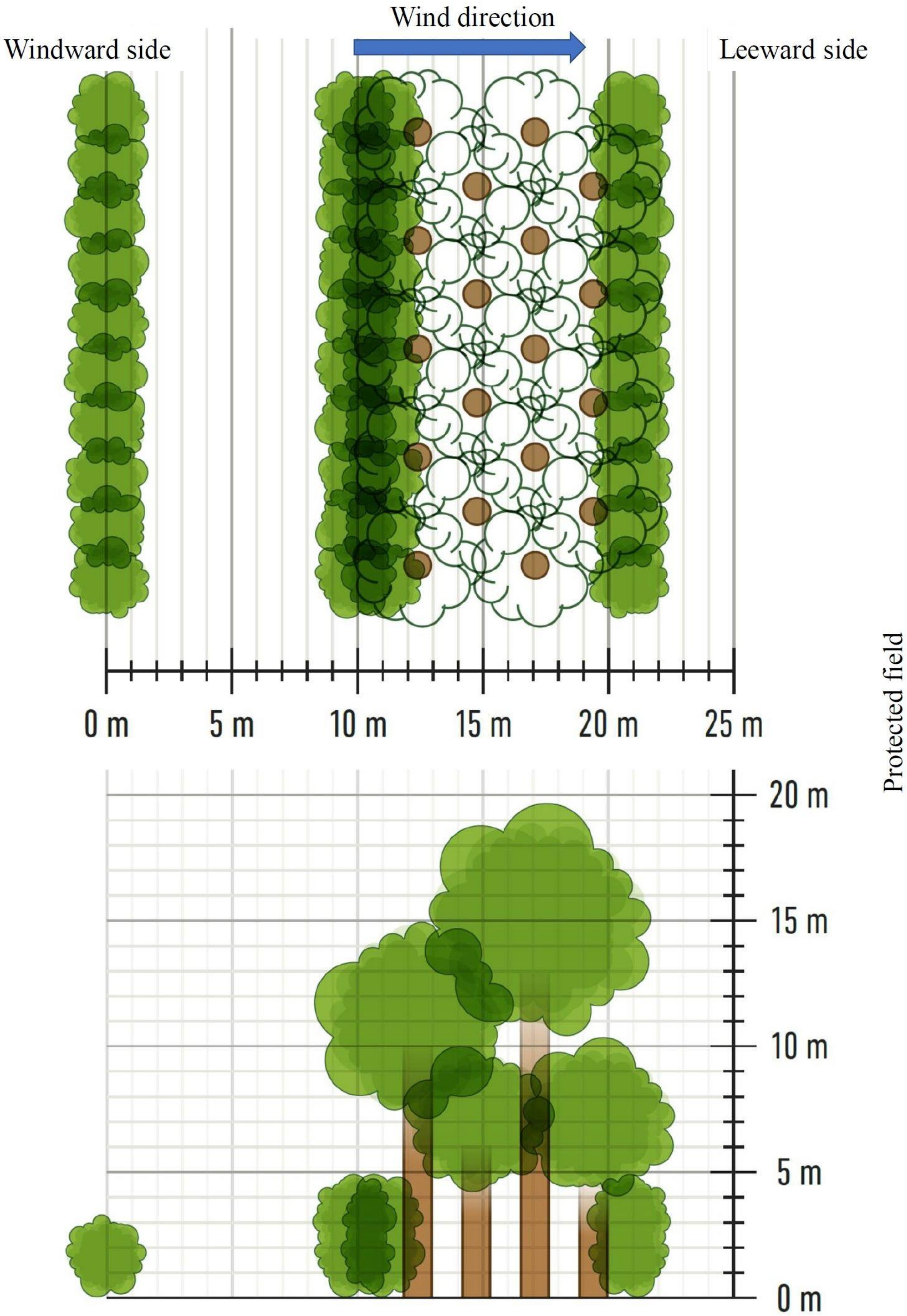

Figure 1. Ideal shelterbelt structure

Starting from the protected site, a two-meter-high bushy strip is settled at 10 meters from the belt. The edge of the belt is 3–4 meters wide and 5–6 meters high; 2 lines, 1 meter line spacing, extending into the trunk space. Distances between the rows of trees are 1–1.5 meters long, the trees are offset from each other. The height of the first line of trees is 15–16 meters, line 2 is 10–12 meters, line 3 is 18–20 meters and line 4 is 10–12 meters high. The edge on the protected side has a more simple structure and reaches into the stand by 2–3 meters. In this way, the bandwidth can be maximized to 10–12 meters.

When using forest belt to protect against snow drifts the distance from the traffic lane border should be at least 7 meters (10 meters without borders), but should not exceed 20 meters. For this purpose, the use of two lines of shrubs and 2–3 tree lines on the exposed side while one shrub-line on the protected side of the belt is sufficient.

Road

Besides forming a harmonic relationship between the artificial lines of traffic and landscape, the aim of roadside afforestation is to improve traffic safety. Afforestation is used with the goal of drawing attention to the road, accident prevention (forewarning of dangerous points, end of road, slip road), and as an “optical stopper” effect. Other functions connected with this are optical lead, shadowing the road, and protection against snow and wind. Furthermore, afforestation plays a role in improving aesthetic and landscape values (fine view) (Takács 2008).

Species

Tree and shrub species that primarily develop the appropriate belt structure providing suitable protective effects are recommended for instillation in shelterbelts. In the site conditions of the protected area, these species are able to grow quickly, form plant communities, and contribute to the preservation of soil fertility. They are resistant to disease and weeds, and less sensitive to chemicals used in agriculture. In addition to giving wood and fruits, they also serve as bee-pastures. Wind resistance is also an important factor of selection *(Table 3).*

Table 3. Classification of tree species according to their wind resistance (based on Barna 2004)

Wind resistant species	poplars (Polulus sp.), pedunculate oak (*Quercus robur*), lime (*Tilia cordata*), elm (*Ulmus minor*), alder (*Alnus glutinosa*), black locust (*Robinia pseudoacacia*)
Moderately wind resistant species	Hungarian ash (Fraxinus angustifolia), larch (*Larix sp*.), beech (*Fagus sp*.), maple (*Acer platanoides*), bigleaf lime (*Tilia platyphyllos*)
Physiologically wind-sensitive species	hornbeam (*Carpinus betulus*), birch (*Betula pendula*), pine (*Pinus sylvestris*), red oak (*Quercus rubra*), aspen (*Populus tremula*), spruce (*Picea abies*), white pine (*Pinus strobus*), and common fir (*Abies alba*)

In order to design the optimal structure of the upper canopy, main tree species should be selected in line with the specific site conditions. By using the proper species, the maintenance of the shelterbelt will be sustainable for a long time. It is also important that a resistant tree community with spread crown can be developed. The upper level is complemented by filling tree species of the second level. These may already be shade-tolerant tree species, but utilizing the given habitat conditions in the best possible way is necessary to help the growth of trees in the upper level. The shrub layer is also a structuring element whose main task is to protect the soil of the shelterbelt beyond forming its edge. Evergreen pines, juniper, thuja, and thick-branched shrubs can be considered for the purpose of protection against winter and spring winds. Thus, forest belts will not become open in winter; their snow-retaining ability will grow and they may serve as winter shelter for wild animals.

The design of shelterbelts requires simplicity. Excellent combinations can be developed by the use of one or two main tree species, one to two complementary tree species, and one-to-three shrub species. By contrast, the aim in the proximity of protected areas is to develop a diverse combination of species providing stability. Tree and shrub species having advanced root systems that can compete with agricultural crops e.g. *Salix alba*, *Tilia cordata, Fraxinus pennsylvanica* (Gencsi – Vancsura 1992) are not recommended for installation. In addition, those species that have strong root-shooting abilities, are wind or frost sensitive, and are less resistant to disease or potential intermediate hosts of insects damaging crops, should also be avoided *(Table 4)* (Gál – Káldy, 1977).

Table 4. Attributes of shelterbelt types (Gál – Káldy, 1977)

Type	Complementary tree species	No. of rows	Width (m)	Soil condition
giant poplar (*Populus x canadensis “Robusta*”)	maple (*Acer platanoides*)	5	9	loamy agricultural soil, alluvial soil, peat soil, sandy soil
Italian poplar (*Populus italica*)	bigleaf lime (*Tilia platyphyllos*)	4	7,5	farmland with good nutrition supply, peat soil of better quality
giant poplar (*Populus x canadensis “Robusta*”) + pedunculate oak (*Quercus robur*)	large leaved lime (*Tilia platyphyllos*)	8	12,5	nutrient-rich alluvial soils, heavy clay soil, humus sand, improved saline soil
black locust (*Robinia pseudoacacia*)	oleaster (*Elaeagnus angustifolia*)	7	11	sandy soils (not applicable in heavy soils)
pine (*Pinus sylvestris*), red oak (*Quercus rubra*)	–	5	8	not too heavy clay, loamy- or nutrient-dense sandy soil
lime (*Tilia cordata*) + sessile oak (*Quercus petraea*)	maple (*Acer sp*.), elm (*Ulmus sp*.), alder (*Alnus glutinosa*)	10	15,5	dry, slightly acidic soil with thin topsoil

Beyond planning and creating the structure, proper maintenance is critical to keeping the integrity of the shelterbelt spatially and through time. This is more difficult in systems where all the individual trees and shrub components have been planted at the same time. However, the management techniques of shelterbelts can be similar to general forest management, the purpose is different. In case of shelterbelts, the aim of the management is to maintain their effectiveness. The activities begin soon after planting with weed control till the canopy layer closure (Zhu 2008). Later, the goal of management is to maintain the diverse structure and porosity of the shelterbelt (Takács 2008).

Consequently, in the absence of regeneration, effectiveness will decrease due to natural mortality. It is therefore important to use a diversity of species in protective plantations and inspect them regularly in order to identify and restore vulnerable parts of shelterbelts (Xie et al. 2018, URL2). A properly planned and planted shelterbelt comprises a very small portion of the agricultural land, and their advantages are many times greater than their negative effects (Mize et al. 2008).

The current Hungarian support system does not give detailed guidelines for implementing a shelterbelt. The number of trees in an agroforestry system is limited to 200–250 pieces/ha. The width of the shelterbelt is defined from 15 to 20 m, and a 1 m wide shrub belt must be planted in both sides. In order to reach the maximum efficiency and ecological benefits, the available research results on the appropriate structure and species composition should be taken into account in the future support regulation.

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Comparative Local Case Study of Coniferous Forest Litter of the "*Pinus halepensis* Mill" in Arid and Semi-arid Areas of Western Algeria

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Abstract – Forest tree species produce litter, which is the plant/soil interface that ensures the maintenance of soil fertility whose properties depend on the botanical species considered. The differences of properties are marked in the nature of the decomposition processes and the forms of humus which result from it. In this study, the physicochemical characteristics and biological activity of litter were compared in coniferous plots located in the semi-arid and the arid zones of western Algeria. The objective of this work was to characterize and compare the physical-chemical properties and microbiological characteristics of softwood forest litter in the semi-arid and arid areas of western Algeria. We analyzed the properties of 50 samples of Aleppo pine litter collected from five stations in each zone. Analysis results show a highly significant difference ($p<0.05$) in the physical-chemical properties between the semi-arid and arid zone: humidity (20.7% – 6.51%), pH (5.98 – 6.14), conductivity (0.42 mS/cm – 0.65 mS/cm), carbon (45.74% – 73.42%), nitrogen (1.17% - 0.86%) and C/N ratio (37.47 – 73.42). A comparison of the mean of microbial biomass and their efficacy reveals what is homogeneous in both zones, with a small difference in basal respiration.

The heterogeneity of these results indicates that such observations still need to be made in other forests of the Algerian territory in order to better understand the functioning of forest ecosystems and the effect of climate on these compartments, especially soil.

decomposition / physicochemical properties / biological parameters /aridity / Aleppo pine

Kivonat – Az Aleppó-fenyő erdei avarjának összehasonlító vizsgálata Nyugat-Algéria száraz és félszáraz területein. Az erdővel borított területek talaj/növény rendszerében a talaj termékenységének fenntartását az erdei fafajok avarprodukciója biztosítja. A termőrétegképződés folyamatának tulajdonságai jelentősen függenek a fajfajösszetételtől, ebből eredően pedig különbségek jellemzik a bomlási folyamatokat és a keletkező humuszformákat. Jelen tanulmányban avarminták fizikai-kémiai tulajdonságait, valamint a bennük lezajló biológiai aktivitást hasonlítottuk össze nyugat-Algéria félszáraz és száraz övezeteiben fekvő tűlevelű állományokban. A vizsgálat fő célja a kutatási területekről származó fenyőavar fizikai-kémiai és mikrobiológiai tulajdonságainak jellemzése és összehasonlítása volt. A kutatás során 50 Aleppó-fenyő avarminta tulajdonságait vizsgáltuk minden mintaterületről 5 mintát gyűjtve. Az eredmények szignifikáns ($p < 0{,}05$) eltérést mutatnak a félszáraz és száraz övezetek mintáinak fizikai-kémiai tulajdonságai között: nedvességtartalom (20,7% – 6,51%),

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pH (5,98 – 6,14), vezetőképesség (0,42 mS/cm – 0,65 mS/cm), szén (45,74% – 73,42%), nitrogén (1,17% – 0,86%) és C/N arány (37,47 – 73,42). A mikrobiális biomassza átlagának és hatékonyságának összehasonlítása azt mutatja, hogy mindkét zónában homogének a folyamatok, csak kis különbség van az alaplégzésben. Az eredmények alapján Algéria egyéb erdeiben is vizsgálatokat kell végezni az erdei ökoszisztémák működésének és az éghajlati hatások jobb megértése érdekében, különösen a talajra nézve.

lebontás / fizikai-kémiai tulajdonságok / biológiai aktivitás / szárazság / Aleppó-fenyő

1 INTRODUCTION

Considering the bioclimatic criteria, Algeria includes all the Mediterranean bioclimates from moist to dry. Forest formations are found on virtually all bioclimatic stages. This allows the presence of a great diversity of biotopes occupied by an important floristic richness especially in the forest ecosystems that are found at almost all stages of bioclimatics. Today the Forestry Directorate-General (DGF 2018) estimates this forest heritage at 4.1 million ha, of which 1.420.000 ha consists of forests, 2.410.000 ha of Maquis shrubland, and 280.000 ha of young reforestation. The main tree species are Aleppo pine (*Pinus halepensis*) (69%) and cork oak (*Quercus suber*) (21%). In smaller areas, cedar (*Cedrus satlantica*), maritime pine (*Pinus pinaster*), oak species (*Quercus ilex, Q. faginea, Q. suberet Q. afares*), and eucalyptus are predominant (DGF 2018).

The Aleppo pine forests are mostly present at the semi-arid level, content with 350 mm of annual precipitation, and adapting to any type of soil. Occupying the highest area in Algeria, they are essentially confined to the east and west of the country. The areas of Aleppo pine are found on the coastline, the Tell, the Saharan Atlas, and the Aures Nememcha. In Algeria, the forest has social and scientific functions and, to a lesser degree, an economic function especially in relation to cork oak (*Quercus suber*) (Louni 1994). Algeria is characterized by very diverse and fragile forest ecosystems, incumbent on its geographical position and the significant variations of its climate.

In Algeria, conifers include the majority of forest and pre-forest formations. These are very important economically and ecologically, particularly through their role of protecting the soil from the processes of desertification and erosion, which are very dynamic in the semi-arid and arid regions (Benabadji et al. 2007). These areas are among the most fragile ecosystems in the world due to recurrent droughts and the growing overexploitation of scarce resources. Arid and semi-arid areas occupy about one-third of the earth's land surface and account for roughly one billion human inhabitants, who are often among the poorest in the world (Malagnoux et al. 2007). Forests, trees, and herbaceous plants are essential components of arid-zone ecosystems. At the level of these semi-arid and arid areas, vegetation is continually struggling against harsh climatic factors, and nutrient-poor soil and organic matter (Borsali 2013).

Among various factors, forest/soil relationships can be addressed through the impact of litter on fertility (Dupuy 1998). Litter is the superficial layer that covers the soil. It constitutes the vegetal mass from the leaves (70 to 94%), branches, and stems and forms all the organic matter (Rapp 1969, Mangenot 1980). Many factors may be involved in litter decomposition; physicochemical properties play an especially important role (Lossaint 1959). Indeed, litter plays an important role in soil protection, the storage of mineral elements, and the restitution of these minerals to the soil. The disappearance or destruction of litter is accompanied by a sudden fall in the stock of available mineral elements, which may be a limiting factor for plant growth (Dupuy 1998). The suppression or decrease of protective layers represented by litter and vegetation after a fire subjects the ground to direct sunlight and raises its general temperature (Raison et al. 1986) because litter plays the role of a sponge that protects the ground and keeps it moist (Faurie 2011).

Through temperature and humidity, the climate directly influences the decomposition of plant debris; however, the climate can also affect the physicochemical and biological properties of litter through its influence on plant community composition and litter quality (Lavelle et al. 1993, Aerts 2006, Pérez et al. 2007). Our objective was to characterize and compare the physical-chemical and microbiological properties of softwood forest litter in semi-arid and arid areas of western Algeria to see if the arid gradient has an effect on these characteristics in order to better anticipate the future of litter in the semi-arid zone due to climate change. The sites were chosen to cover the panel of pedoclimatic conditions corresponding to the semi-arid and arid climates of the western Algeria.

2 MATERIALS AND METHODS

2.1 Study areas

2.1.1 Semi-arid area

The Jebel Sid Ahmed Zeggai forest is located 4.5 km west of Saida province; it is part of the mountains of Saida, which are the eastern extension of the mountains of Dhaya, which belong to the Atlas Tellian *(Figure 1)*. This forest covers an area of 2232 hectares on a limestone brown soil dominated by 90% Aleppo pine. Other plant species present are: are lentisk (*Pistacia lentiscus* L), cade juniper (*Juniperus oxycedrus*), evergreen oak (*Quercus ilex*), and esparto grass (*Stipa tenacissima*). This forest is extremely dense (2000 plant ha^{-1}) and has significant regeneration. Aleppo pine has an average age of 50 years with an average height of 6 to 8 m. From a climatic point of view, the forest benefits from a semi-arid climate (T min = 3 °C, P = 344.6 mm) located on superior stage of the Mediterranean vegetation (T min > 3 °C, 200 < P < 400 mm); the seasonal regime of the zone is of the HAPE type (Winter, Autumn, Spring, Summer) and has 6 months of drought (Zouidi et al. 2019).

2.1.2 Arid area

The Jebel Antar Forest is located in the commune of Mecheria in the east of Naama province *(Figure 1)*. This forest is a piedmont area of Jebel that plays a protective role against the desertification of the area. It is a mass afforestation with an area of 1000 ha on a calcimagnesic soils. Aleppo pine is used as the main species at a rate of 95% with a density of 1600 plant/ha. Cepressus *(Cupressus)*, betoum (*Pistacia antlantica*), white retem *(Retama raetam)*, esparto grass (*Stipa tenacissima*), and white wormwood *(Artemisia herba-alba)* are also found in this forest. Today, Aleppo pine trees have an average height of between 3 and 5 m. The area has recently encountered several factors of degradation due to desertification and urbanization with the consequence of a radical transformation of the affected plant formations. The forest benefits from an arid climate (T min = 2 °C, P = 203.5 mm) located on a superior stage of the Mediterranean vegetation (T min > 2 °C, 100 < P < 300 mm). The seasonal regime is type APHE (autumn, spring, winter, summer) with 8 months of drought (Zouidi et al. 2018).

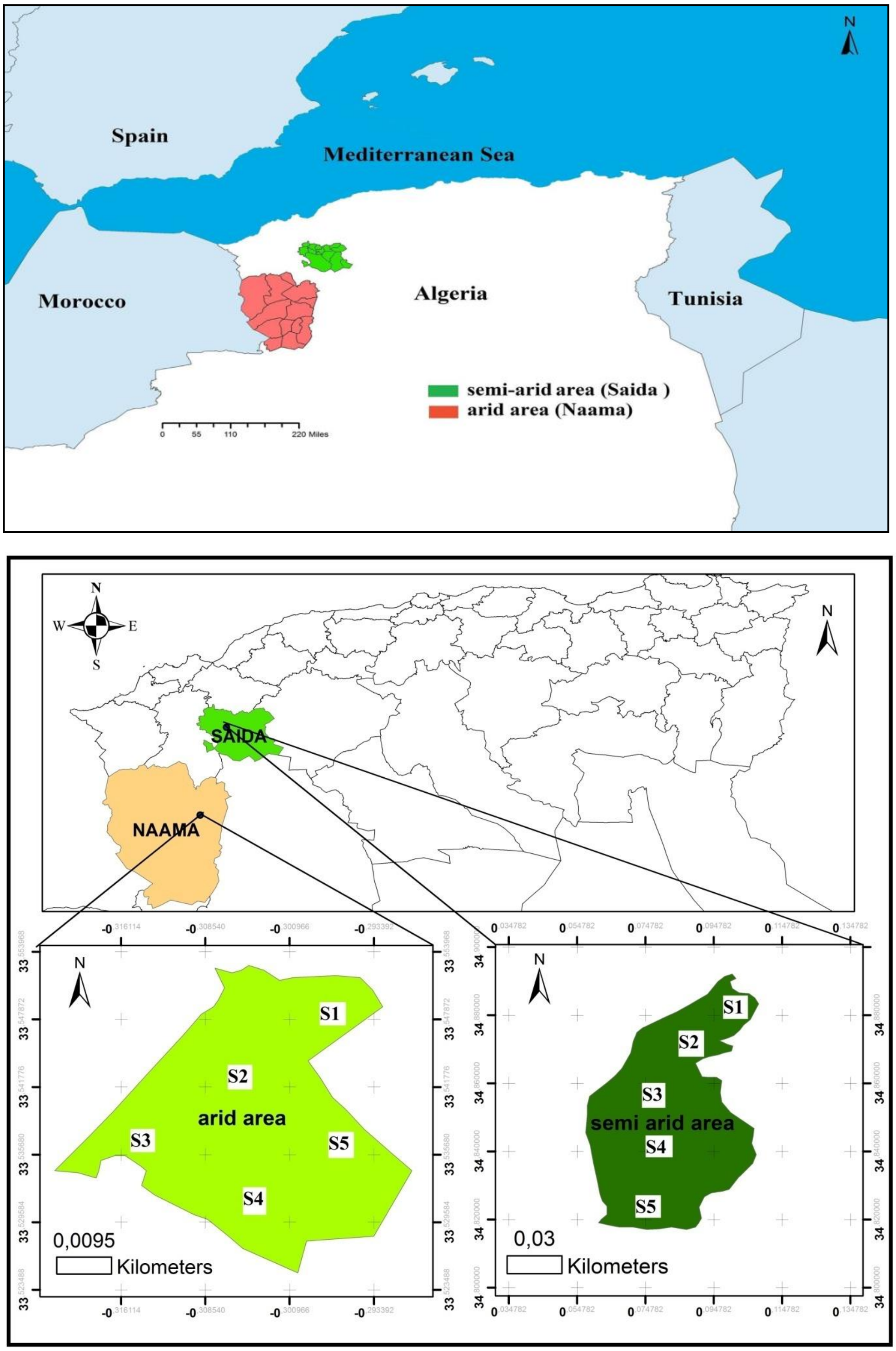

Figure 1. Geographical situations of study areas

2.2 Litter Sampling

Five sampling stations were selected for each zone *(Table 1)*. Five samples were randomly collected at each station. All stations are located at altitudes between 970 and 1280 m with a similar exposure (N). Samples of approximately 1kg of litter (OL horizon) were collected under the canopy of *Pinus halepensis.* Mill. in March 2016. Each sample was sorted manually to remove any shellfish shells, pebbles, or twigs.

Table 1. Geographical and characterizations of the study stations

Areas	Station	Altitude (m)	Latitude	Longitude
semi-arid area	S 01	975	34°52'13.7" N	00°05'09.5" E
	S 02	1067	34°51'22.3" N	00°04'40.9" E
	S 03	1146	34°50'29.5" N	00°04'57.6" E
	S 04	1160	34°49'31.8" N	00°05'22.6" E
	S 05	1081	34°49'23.7" N	00°04'33.8" E
arid area	S 01	1080	33°32'02.3" N	00°19'13.1" W
	S 02	1140	33°32'23.7" N	00°18'25.1" W
	S 03	1119	33°32'51.6" N	00°17'55.0" W
	S 04	1085	33°31'52.7" N	00°17'55.3" W
	S 05	1108	33°31'52.7" N	00°18'25.6" W

2.3 Physicochemical Analyses

Litter water content was determined by measuring fresh weights and weights after oven-drying (80°C) for 24h (Alarcón-Gutiérrez 2007). The pH and conductivity of the samples were measured on a litter suspension obtained by mixing 5 g of litter with 100 mL of distilled water. The measurement was carried out 2 h after using a pH meter (Métrohm, Herisau, Switzerland) (Alarcón-Gutiérrez 2007). Total organic carbon (COT) and total nitrogen (TN) were measured as follows: kiln-dried initial litter subsamples and each microcosm litter were sprayed in a ceramic mortar and analyzed by combustion in an analyzer Elemental, FlashEA 1112, Thermo Fisher; the calculated C/N ratio then presents a chemical character that may show the decay rate of plant debris (Gloaguen –Touffet 1982).

2.4 Biological analysis

Basal respiration (µg C-CO_2/g dry litter) was measured according to the protocol described by Anderson and Domsch (1978) to assess the physiological state of the microbial communities of litter; 3 grams (dry equivalent) of fresh litter stored at 4 °C were weighed in a glass vial (117 ml). The vials were closed with a hermetically sealed plug immediately after the replacement (4 minutes) of their internal atmosphere via a stable CO_2 concentration atmosphere, and incubated 4 hours at 25°C. After incubation, an aliquot of atmosphere of the vial (1 ml) was injected using a syringe into a gas chromatograph (Chrompack CHROM 3 – CP 9001). The chromatograph was equipped with a TCD detector and a filled column (Porapack) in which helium circulates at a flux of 60 mL/h. The values obtained were adjusted to 22°C according to the law of the gases perfect at Q10 = 2. Ambient CO_2 concentrations were subtracted from the CO_2 concentrations measured after incubation to obtain the amount of CO_2 produced by the heterotrophic microorganisms contained in the sample. Microbial biomass was estimated by the glucose-induced respiration method (Anderson – Domsch, 1978). A mixture of talc and glucose (1 000 µg carbon/g of litter) was added to the three grams (dry equivalent) of litter. An incubation of 100 minutes was performed to achieve a maximum rate of induced respiration. The vials were closed with an airtight stopper immediately after the replacement (4 minutes) of their internal atmosphere by an atmosphere of stable CO_2 concentration, and then incubated for 90 minutes at 22°C. The CO_2 concentration of the vials was analyzed with gas chromatography and corrected in the same way as previously described for basal respiration. Induced respiration rates were converted to microbial biomass values using the equation given by Beare et al. (1990). The metabolic quotient (qCO_2) was calculated as the ratio of basal respiration/microbial biomass to Anderson and Domsch (1985).

2.5 Data analysis

The student *t-test* was used to compare the results of the physicochemical and microbiological properties of litter between the semi-arid and the arid areas using Sigmaplot 14 software.

3 RESULTS

3.1 Physicocemical characteristics

The evaluation of litter quantities of Aleppo pine litter taken from one square meter shows a good production of litter with high moisture in the semi-arid zone (1493 gr/m^2; 20.70%) compared to the litter in our arid zone, which presents quantities (906.4 gr/m^2) with low moisture (6.51%). The comparison of the averages reveals this difference is significantly high between the two zones ($p < 0.001$). Conductivity and pH are elevated in the arid zone (6.14 for the pH and 0.65 mS/cm for the conductivity). The pH is low acid (pH greater than 5) in our semi-arid zone with a low conductivity (0.42 mS/cm) and presents a significant difference between the two zones ($p < 0.001$). On the basis of the results, a carbon concentration and a high C/N ratio were recorded in the arid zone (73 for the C/N ratio; 73.42% for the carbon) in contrast to the concentration of nitrogen, which presents a significant average in our semi-arid zone (1.17%) more than the arid zone (0.86%). The statistical study based on the comparison of the means (student's t test) shows a highly significant difference ($P < 0.001$) of these parameters *(Figure 2).*

3.2 Microbial properties of litters

The microbial parameter averages of litters are recorded in table 02. Based on the comparison of biological parameter averages of litter, we recorded a high basal respiration in the semi-arid zone (97.78 µg de C-CO_2 /h/g) compared to the arid zone, which presents an average of 85.42 µg of C-CO_2 /h/g. Statistical analysis of the results shows a notably small difference ($t = 2.14$; $p < 0.05$) of this microbial basal respiration (BR) between these two zones. It should be noted that the average of microbial biomass (BM) and metabolic quotient (qCO_2) are high in our semi-arid zone (BM - 4.31 µg of carbon microbial/g ; qCO_2 - 23.67 µg of C-CO_2/h/g). However, the bacterial biomass and the metabolic quotient did not show any noteworthy difference between the two zones ($p > 0.05$).

Table 2. Microbiological properties of forest litter in arid and semi-arid areas.

Microbial analysis	Student *test-t*	Semi-arid area	Arid area
Basal respiration at 22°C (µg of C-CO_2/h/g)	2.14*	97.78 ± 17.39	85.42 ± 22.98
Microbial biomass (µg of Carbon microbial/g)	1.73ns	4.31 ± 0.90	3.94 ± 0.54
Metabolic quotient (qCO2) (µg of C-CO2/h/g)	0.753ns	23.67 ± 6.51	22.17 ± 7.57

This table records the average values ± deviation; Microbial properties of soils; the p value of independent test is presented with its threshold of significance (*: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$; ns: not significant).

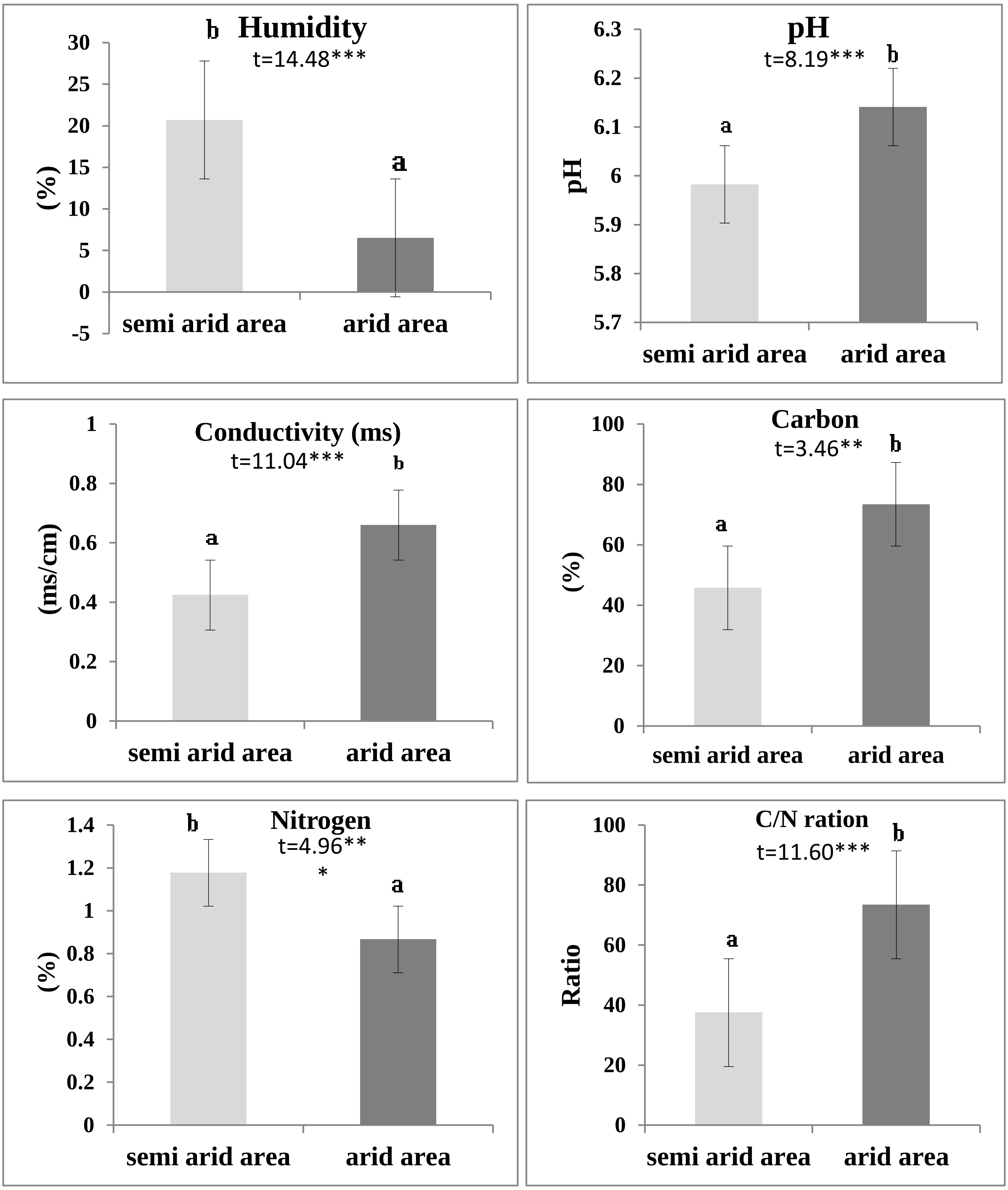

Figure 2. Physicochemical parameters of litter in semi-arid and arid areas. Averages ± standard deviations. The t-value of the Student's test is presented with its significance threshold (: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$, ns: not significant)*

4 DISCUSSION

Forest litter is mainly composed of softwood leaves, needles, and dead wood. It forms a source of energy and essential elements for the metabolism of microbial communities. Our study reveals there is an effect of the arid gradient on the production of *pinus halepensis* litter, which is more important in the semi-arid zone compared to the arid zone. This is certainly due to forest density as well as climatic and edaphic conditions specific to each area. Several scientists have shown that litter production is controlled by climatic and edaphic factors that regulate production and forest stand density (Puig – Delobelle 1988, Mutabesha 2009). Litter in arid forests is susceptible to winds, and according to Kumada et al. (2008), it is natural that this weather effect removes a significant amount of litter.

The work presented in this research concerns the quality of litter in two areas on two different bioclimatic stages (arid and semi-arid). The moisture measurements highlight the footprint of the climatic stage on each zone. In fact, litter in the semi-arid zone has a more significant proportion of moisture than litter in the arid zone, which indicates that the wilted leaves of *Pinus halepensis* retain more water in the semi-arid zone. Air and rainfall are more important in this area when it comes to soil moisture (344 mm/year) than it is in the arid area where there is less rain (203 mm/year) and, therefore, less water in the soil and litter (Zouidi et al. 2018, Zouidi et al. 2019). It should also be stressed that water evaporation of leaves in the semi-arid zone is low as it is in the arid zone where temperatures and periods of drought are longer and more pronounced. In addition, the low density of species trees and herbaceous species are non-existent in the arid zone, which facilitates the loss of water from the litter and soil. Consequently, the water content of the litter and the dead plants depend solely on physical phenomena such as exchange by capillarity with the soil and in equilibrium with the moisture content (in vapor form) of the atmosphere located in immediate contact with the litter (Trabaud 1976). High temperatures with reduced plant cover in the arid zone also reduce soil moisture by increasing evaporation (soil and litter) and perspiration (Tardif 2013).

The pH of litter in both the semi-arid zone (5.98) and the arid zone (6.14) are low in acid (pH>5). Softwoods, and especially pine, are considered acidifying species (Gobat et al. 2003, Lagacé 2009); in fact, the litter acidifies during decomposition and its pH gradually rises to 6 after 3 months (Lossaint 1959). The pH is more acidic in the semi-arid zone because there is less leaching that will limit the pluviolessivats loaded with phenols (which can deproton and therefore generate a higher acidity) (Bernhard-Reversat 1972). On the other hand, this is also probably due to the higher $CaCO_3$ content in the arid zone, which acts like a 'tampon' and, therefore, causes a small increase the pH (Zouidi et al. 2018). Litter in the arid zone may remain saline compared to litter in semi-arid areas. This result is probably related to the nature of soil and the presence of minerals in soils in this arid zone (Zouidi et al. 2018). The difference in carbon levels between the two zones can be explained in the following manner: the high percentage in the arid zone can be explained by the pedoclimatic variation between the two study areas, which influences the significant photosynthetic activity of the conifers, especially in the presence of solar radiation in the arid zone that lasts all year as shown by Puig and Delobelle (1988). Changes in carbon levels, therefore, reflect the climatic or edaphic variations of an annual cycle with a lag of a few months. Forest litter fallout and decomposition are key processes in the formation of carbon (C) and nutrient cycling in terrestrial ecosystems. These processes determine the amount of carbon stored in the humus (Berg et al. 2001, Sabine et al. 2014). Carbon stocks will increase if litter production (carbon input) increases. With regard to litter production, it is closely related to the rainfall regime. The lack of rainfall in the arid zone (8 months dry) is accompanied by falling leaves, which translates into increased litter production (Paul – Clark 1996, Dupuy 1998). This also explains the significant amount of carbon in the arid zone, which has a seasonal rainfall regime that is less than that of the semi-arid zone. This causes pine trees to shed their needles and increases litter production. The accumulation of organic carbon in the humus of the closed conifer formation can be explained by the quality of the litter composed of recalcitrant materials to the microbial decomposition such as tannins and polyphenols (Berg 2000, Prescott et al. 2000). Nitrogen levels remain low, especially in arid zones. This can be explained by the very slow decomposition of the Aleppo pine litter; indeed, several studies have confirmed that decomposition is influenced by the initial concentrations of mineral nitrogen (Aerts 1997, Kaspari et al. 2008, Wieder et al. 2009) and total litter nitrogen, which decreases with decomposition (Gloaguen – Touffet 1982, Qasemian et al. 2012). According to Salleles (2014), the source of nitrogen for plants in low-input (unfertilized) ecosystems such as arid zones is mainly derived from litter decomposition and the mineralization of soil organic matter. As a result, litter plays an essential role in the recycling of nitrogen in the forest ecosystem (Salleles 2014). When litter is subjected to favorable climatic conditions (temperature and humidity), it has a high initial nitrogen content (Kurz-Besson 2000). This is one of the key factors that regulate the decay rate of plant debris, as pointed out recently (Taylor et al. 1989). Conifers are characterized by acidifying litter which, due to their composition, cause a slowing of the biodegradation of humification with a C/N ratio generally greater than 50 (Duchaufour, 1980). The C/N ratio in the semi-arid zone translates into the capacity of a litter to be decomposed more or less rapidly in the arid zone. This shows a very slow decay. This report is only a general indication of the potential of litter to decay (Taylor et al. 1989). A strong C/N ratio of the initial litter was correlated with a low rate of decay and increased with the age of the needles in place, corresponding to nitrogen depletion and lignin enrichment (Gloaguen – Touffet 1982, Lagacé 2009).

The results showed that microbial biomass remains homogeneous and low in both the arid and semi-arid zones as a result of lack of water and high temperatures. As some authors have reported in their work (Sabaté et al. 2002, Papa et al. 2008), the most important factors affecting soil microbial biomass are precipitation and temperature. In addition, studies on forest ecosystems have shown significant decreases in fungal and bacterial biomass during drought periods (Krivtsov et al. 2006, Borsali et al. 2017). Salinity is a factor influencing the activities of microorganisms, particularly in arid and semi-arid areas (Toberman et al. 2008). Basal respiration remains weakly variable between the two zones and depends on water availability, temperature, and biochemical composition of litters such as lignin, cellulose, hemicellulose, and C/N ratio (Arunachalam et al. 1998).

5 CONCLUSION

Forest litter is the plant-like interface in the forest that protects the soil and ensures that fertility is maintained through the production of nutrients. The aim of this study was to demonstrate the differences between litters in semi-arid and arid areas and to determine any imprint of exposure to bioclimatic stages on the physicochemical and biological properties of resin litter. The results showed a significant difference in all physicochemical parameters ($p < 0.05$) and particularly in moisture where a 14.19% difference between the two areas was recorded. The differences for carbon and nitrogen, both of which promote decomposition and ensure the life of decomposing organisms, were 27.68% and 0.49%, respectively. The pH of the two semi-arid and arid zones shows that acidifying litters are mull or mild humus ($pH > 5$); this acidity is a character of conifers and in particular Aleppo pine. The decrease in the moisture content of the arid forest litter (6.51%) caused an increase in carbon (73.42%) content and, consequently, the elevation of the C/N ratio (73%) and the slow decay of the litter. Litter degradation in the arid zone is slower than in the semi-arid zone. This is due to the pedoclimatic factors of the arid zone (mother rock nature, precipitation erosion, drought, and salinity). The forests dominated by Aleppo pine from both zones produce poor quality litters that are difficult to degrade. In these zones litter possess low activity and low microbial biomass, with an average of 4.12 μg of carbon microbial/ g.

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Comparison of Physical, Chemical and Biological Soil Properties under Norway Spruce, European Beech and Sessile Oak – a Case Study

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Abstract – This study examined the interaction of tree species and soil development in litter and the 0-10 cm mineral topsoil layer in European beech, Norway spruce, and sessile oak forests. It also compared the main soil chemical, physical, and selected microbiological indicators as well as the microbial biomass, basal and substrate induced respiration, lipid phosphate content, phospholipid fatty acid profiles (PLFA), and respiratory quinones (RQ). With Norway spruce, soil pH, clay, and silt content were significantly lower, while exchangeable acidity was higher. This leads to a major loss of exchangeable cations of the upper soil layer resulting in lower base saturation. The microbial metabolic activity and microbial biomass of deciduous forest soils were significantly higher. The respiratory quotient (q) was highest in spruce, indicating disadvantageous circumstances for microbial activity. Our results demonstrate the importance of a complex study of physicochemical and biological soil parameters when investigating the impact of forest management on soil by, for example, providing data for the development of forest condition monitoring activities.

tree-soil interaction / soil acidification / microbial soil indicators

Kivonat – Fafajok erdőtalajra gyakorolt hatásának összehasonlítása fizikai, kémiai és biológiai talajtulajdonságok alapján. A fafajok és a talajképződés összefüggését vizsgáltuk az avarszintben és a 0-10 cm-es felső ásványi talajrétegben európai bükk (*Fagus sylvatica*), közönséges lucfenyő (*Picea abies*) és kocsánytalan tölgy (*Quercus petraea*) főfafajú erdőkben. Összehasonlítottuk a talaj fő kémiai, fizikai és egyes mikrobiológiai paramétereit, a mikrobiális biomasszát, az alap- és szubsztrát-indukált légzést, lipid-foszfát tartalmat, foszfo-lipid zsírsav profilokat (PLFA) és a respirációs kinonokat (RQ). A talaj pH, az agyag- és iszap% szignifikánsan alacsonyabb volt, a kicserélhető savasság magasabb volt a lucfenyő esetében, ami a kicserélhető kationok nagymértékű kimosódását mutatja a felső talajrétegben, alacsony bázistelítettséget eredményezve. A mikrobiális metabolikus aktivitás és a mikrobiális biomassza értéke a lomblevelű erdők talajában szignifikánsan magasabb volt. A respirációs kvóciens (q) értéke a legmagasabb a lucfenyő alatt volt, a mikrobiális lebontás kedvezőtlen feltételeire utalva. Eredményeink bizonyítják a fiziko-kémiai és biológiai talaj-paraméterek komplex vizsgálatának fontosságát az erdőgazdálkodás talajra gyakorolt hatásának vizsgálatában, adatokat szolgáltatva például az erdőállapot-monitoring tevékenységek fejlesztéséhez.

fa-talaj kölcsönhatás / talajsavanyodás / mikrobiális talajparaméterek

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1 INTRODUCTION

Climate change and forest management impacts present severe challenges for forestry. The decline in vitality of important tree species such as Norway spruce has accelerated in recent decades (Mátyás et al. 2010). Site conditions essentially limit the range of tree species used in forestry. Climate, hydrology, and soil together determine the development of the soil-plant system. Expected climate change induced shifts of forest communities will also be linked to soil indicators, emphasizing the importance of the interaction between tree species composition and soil indicators (Führer et al. 2010, Bartha et al. 2018).

Slowing microbial degradation processes can disrupt forest ecosystems with severely-reduced buffer capacities caused by (partly anthropogenic) acidification and nutrient cycles (Ca, Mg, and K). This leads to a gradual loss of biodiversity, which can lead to the reduction of several important ecosystem processes in the soil (Borken – Brumme 1997).

Katayouan and Kooch (2019) compared four different forest types with respect to the effects of tree species composition on nutrient-cycling and soil-related processes. Their results proved that changes in litter quality had subsequent negative effects on soil fertility, as described by physicochemical and biological soil indicators, thereby emphasizing the importance of soil quality maintenance in silviculture.

Recognizing the factors that influence soil microbial communities is important for understanding how human activities, such as forest management and tree species selection, may impact ecosystem functioning (Bahnmann et al. 2018). Numerous methods to assess biological processes in soils exist. Oxygen-based respiration is a common way to measure the *metabolic activity of microbes*. This measurement effectively quantifies the respiratory activity of microbes living in soils (Anderson – Domsch 1978, Dilly 2003). In situ measurements of the biochemical determination of microbial cell components (e.g. phospholipids) can *determine the microbial biomass*. The structure of the *microbial community* is also of great importance: analysis of specific biochemical cell components, the so-called *signature molecules*, can provide important information (Hiraishi 1999, Kandeler 2007, da Costa et al. 2011, Birgander et al. 2014).

Our former site investigations around the research area in the Sopron Mountains revealed that high litter accumulation, surface soil acidity, and the presence of a leached upper E-horizon was connected to spruce monoculture forest stands. These findings suggest that replacing ancient broadleaved species with conifers can affect the physicochemical and biological soil properties of the upper layers.

Our case study investigated the roles of three different forest types including European beech (*Fagus sylvatica*), sessile oak (*Quercus robur*), and Norway spruce (*Picea abies*) on an O and A horizon quality, described by physicochemical and biological indicators. Under natural conditions in Hungary, these tree species often compete with each other to occupy sites. The currently unfavourable ecological conditions for spruce are deteriorating further due to climate change. In addition, the expected processes are also endangering the living conditions of beech. That is why it is crucial to study the forest-scale replacement of one tree species for another and how these species replacements interact with soil processes and nutrient cycles.

We hypothesized that Norway spruce forest cover is less favourable for soil biological activity than broadleaved tree species forests are, and that this results in differences of soil biological activity. Our objectives were, therefore, to find and assess soil physicochemical and biological indicator differences between conifer and broadleaved stands.

2 MATERIALS AND METHODS

2.1 Study area

The chosen study areas were a European beech (*Fagus sylvatica* L.; 41 years old; Lat: 47°39'19.7"N; Lon: 16°27'16.9"E, Sopron 171/G forest comp.) stand, a Norway spruce (*Picea abies* L.; 54 years old; 47°39'26.1"N; 16°27'16.1"E, Sopron 171/F forest comp.) stand, and a sessile oak (*Quercus petrea* Liebl.; 46 years old; 47°39'33.4"N; 16°28'14.3"E, Sopron 163/D forest comp.) stand in the Sopron Mountains near the Hungarian-Austrian border. The region is located in the warm temperate forest zone (yearly average temperature 9.5-9.8 °C), and is dominated by deciduous broadleaf tree species. Elevation is between 500-550 m; average yearly precipitation is about 800-850 mm. The yield classes of all three stands are similar, measured as 4 (on a scale with decreasing quality from 1 towards 6).

According to the Hungarian forest climate classification, the climate of the area is beech because the 50-year (1961-2010) average of the Forestry Aridity Index (FAI) interpolated to the area is 3.65, which is the typical value of a beech climate, i.e. 3.5 and 4.75 (Führer 2010, Führer et al. 2011). Conditions below an FAI value of 3.5 are more favourable for spruce and those above an FAI value of 4.75 are more favourable for sessile oak. Further description of the area is provided by Gribovszki et al. (2006).

Parent material is unclassified tertiary (Miocene) fluvial sediment, on which a loamy soil containing coarse gravel formed. The soils in all three sampling areas belong to the WRB soil reference group *cutanic luvisols* and possess similar basic reference group properties.

2.2 Sampling and measurements

A soil pit was opened in all three stands and soil samples in 6 replicates were taken from each horizon respectively. These replicates were immediately transported to laboratory for storage at 4 °C until analysis. Soil microbial investigations were completed for litter samples and mineral soil samples from 0-10 cm depth. Laboratory analyses of physical and chemical soil characteristics were measured according to the Hungarian standards (MSZ-08-0205-2: 1978; MSZ-08-0206-2: 1978; MSZ-08-0215: 1978; MSZ-08-0452: 1980; MSZ-08-0480-2: 1982), summarized by Buzás et al. (1993). Soil microbial investigations: soil and litter samples were divided into subsamples to perform parallel microbial activity and microbial biomass measurements.

Microbial metabolic activity: the mineralization rate of dead organic matter accumulated at soil surface (litter layer and 0-10 cm layer of the mineral soil) was determined with 6 replicate measurements via the “basal respiration” (BAS) method (Heilmann – Beese 1992).

Microbial biomass:

a) Substrate-induced respiration (SIR) method SIR tests were conducted in 6 replicates of soil samples from each stand to determine the microbial biomass. The SIR tests were performed according to the modified method of Anderson – Domsch (1978) as described by Heilmann – Beese (1992). From the basal respiration and the microbial biomass, the respiratory quotient (q) was calculated as a simple quotient. This value provides information on the effectiveness of the decay.

b) Lipid phosphate measurements: Soil samples taken from the 0–10 cm mineral soil layer were placed into a Bligh and Dyer's solution (Bligh – Dyer 1959) in sterilized glass jars, and cooled and stored at –20 °C until processed. Further processing included the chemotaxonomic measurements completed by the modified method of Findlay by Tóth et al. (2004).

Respiratory quotient (q-CO_2): From the basal respiration and the microbial biomass, the respiratory quotient (q) was calculated as a simple quotient of basal respiration divided by microbial biomass. This value provides information on the effectiveness of the decay (Dilly, 2003).

Comparison of microbial communities: Cultivation independent chemotaxonomic methods were applied to study microbial communities.

Examination of the respiratory quinones (RQ): The organic components cleaned from mineral soil particles were evaporated under vacuum, and the lipid soluble materials (PLFA and RQ) were solved with chloroform. A silica-based octadecyl column was employed to separate lipid soluble components. The purification of the chloroform fraction containing quinones was performed with thin-layer silica gel. High pressure liquid chromatography was used for the instrumental analyses of the purified filtrate of quinones. Detection is based on specific light absorption observed at 270-nm wavelength. Test samples were compared with quinone profiles of pure cultures of bacterial strains.

Determination of phospholipid fatty acids (PLFA): Glyco-and phospholipids were washed from the chromatographic column using acetone and methanol, respectively. The methanol-phase was – likely to the preceding – concentrated in vacuum evaporation at 37 °C. The dried phospholipid content was dissolved in 0.5 ml methanol: toluol (1:1) mixture. After separation of the two phases, the fatty acid analysis was performed by gas chromatograph (Tóth et al. 2004).

2.3 Statistical analysis

For data analysis, we used standard statistical tools (Statistica and Syntax 2000 statistical programs): quantitative data of physicochemical and microbial soil indicators were expressed with mean values and standard deviation. Paired sample t-tests were applied to compare physical and chemical soil indicators. Principal component analysis was used to describe the microbial community differences in the studied stands via chemotaxonomic markers (PLFA and RQ). Differences were considered significant at $P<0.05$.

3 RESULTS AND DISCUSSION

3.1 Soil physical and chemical indicators

The mean values of physicochemical test results of the upper 0–10 cm mineral soil layer of the three forest stands are shown in *Table 1.*

Soil pH (H_2O) and exchangeable acidity values (y_2) were significantly lower for spruce when compared to both deciduous stands, while hydrolytic acidity values (y_1) were significantly higher for spruce only in comparison to oak.

In reaction to the alkaline hydrolysis (in case of y_1), all three stands soil colloids showed an acidic-highly acidic nature. For soils – under agricultural use – having hydrolytic acidity values (y_1) greater than 8, liming is classified as unconditional (Buzás et al. 1993).

Humus- and nitrogen contents were significantly higher under sessile oak, compared to the other stands. The nitrogen content of the oak forest's soil was medium, and the other two had a low nitrogen supply. In contrast, plant-available phosphorus and potassium were both lowest in the soil of the spruce stand.

The Carbon/nitrogen ratio of soil organic matter was 18, 15, and 14 for oak, beech and spruce, respectively. All three values – which are favourable in terms of degradability – were lower than C/N values detected by Joergensen and Scheu (1999) in a beech and spruce forest in the Solling Mountains in Lower Saxony. Similar to their findings, the difference of C/N ratios between deciduous and coniferous stands was also small in our study. The C/N rates are generally believed to be inversely proportional to the breakdown intensity, but some studies have shown that microbial degradation in forest soils cannot be described as a function of this single parameter, as other factors have an influence on their context (Spohn – Chodak 2015).

Table 1. Physical and chemical soil indicators in 0-10 cm depth of the mineral soil of three forest stands (Standard deviation in parentheses).

Main tree species	*Quercus robur*	*Fagus sylvatica*	*Picea abies*
pH (H_2O)	4.9 (0.18)	4.6 (0.11)	4.3 (0.08)
pH (KCl)	4.0 (0.22)	3.6 (0.07)	3.4 (0.09)
y_1 (hydrolytic acidity)	28 (2.6)	36 (3.0)	35 (1.9)
y_2 (exchangeable acidity)	3 (1.4)	9 (1.0)	13 (0.6)
Humus content (%)	4.85 (0.20)	2.26 (0.06)	2.43 (0.14)
N_{total} (%)	0.16 (0.02)	0.09 (0.02)	0.10 (0.03)
C / N	18 (1.15)	15 (3.98)	14 (5.79)
AL-soluble P_2O_5 (mg * 100 g^{-1} d.s.)	13.2 (2.32)	22.5 (3.08)	11.4 (2.34)
AL-soluble K_2O (mg * 100 g^{-1} d.s.)	16.1 (2.48)	19.8 (2.32)	9.9 (1.83)
Cation Exchange Capacity = T-value (mmol IE * 100 g^{-1} d.s.)	30.0 (3.16)	41.5 (3.33)	39.3 (3.72)
exchangeable Ca^{2+}, Mg^{2+}, K^+ és Na^+ = S-value (mmol IE * 100 g^{-1} d.s.)	5.5 (1.64)	7.0 (2.10)	6.3 (0.52)
Base saturation% (V%)	18 (6.6)	17 (4.29)	16 (1.63)
hy% (higroscopicity)	1.99 (0.09)	2.04 (0.18)	1.83 (0.24)
K_A (plasticity index acc. to Arany)	54 (3.25)	55 (3.95)	50 (2.80)
5 hours capillary rise (mm)	150 (7.73)	113 (9.68)	141 (5.56)
Particle size distribution			
Sceletts (>2 mm)%	0 (0)	0 (0)	0 (0)
cS% (coarse Sand% 2-0.2 mm)	31 (2.79)	24 (5.35)	21 (5.13)
fS% (fine Sand% 0.2-0.02 mm)	23 (3.37)	33 (2.94)	54 (2.59)
Si% (Silt% 0.02-0.002 mm)	26 (3.13)	21 (3.01)	7 (2.07)
CL% (clay% <0.002 mm)	20 (5.61)	22 (6.02)	18 (4.76)

Total adsorption capacity of the soil (T-value according to the modified method of Mehlich MSZ-08-0215: 1978 = CEC_t) was lowest in the oak forest soil; slightly higher quantities were obtained under spruce and beech. The latter two are average values found in Cutanic Luvisol soils in Hungary, but the value under oak is below average.

S-values (sum of "basic" or "alkaline forming" cation in Eq according to the modified method of Mehlich) and *V-values* (base saturation in %) all displayed low base saturation for oak, beech, and spruce respectively. This indicates that negative surface charges of soil particles are mostly neutralized with Al^{3+} and H^+ ions. Even if differences were not significant, the soil of the spruce stand once again had the most unfavourable properties (V=15%), increasing the risk of clay-mineral destruction with negative effects on nutrient and hydrological cycles of the ecosystem.

The oak and beech forest soils had a loamy texture according to the *particle size distribution* (Si+Cl=46%, 43%) (*Table 1*), while the texture of the spruce stand is a poorer (Si+Cl=25%) sandy or sandy loam texture, which could possibly indicate the removal of clay from this horizon, resulting in a weaker expression of structure, reduced pore space, and water holding capacity of the upper mineral soil over a longer term. Nevertheless, this would need to be proved by an additional texture analyses of underlying B-horizons.

3.2 Soil biological indicators

The results of metabolic activity measurements are shown in *Figure 1*. Microbial respiration intensity of the beech litter was the highest. The basal respiration of spruce litter was significantly ($p = 0.05$) less. Values of oak leaf litter did not differ significantly from that of the other two stands.

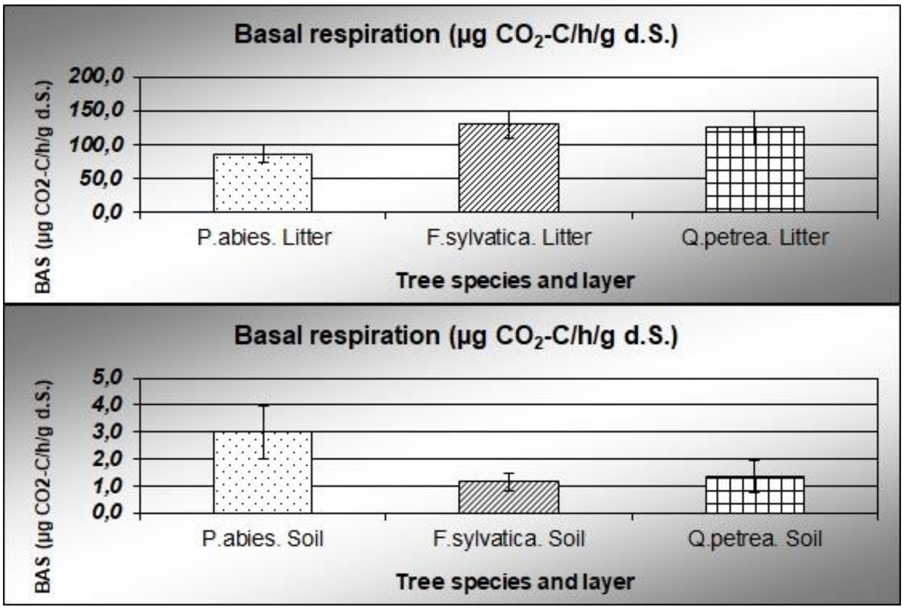

Figure 1. Basal respiration (with standard deviation) in the litter and the 0–10 cm mineral soil layers in the spruce (P. abies), beech (F. sylvatica) and sessile oak (Q. petrea) forests

We detected a reversed situation regarding the microbial respiration of the uppermost 0-10 cm mineral soil layer: soil carbon mineralization was highest under spruce. The two deciduous stands did not differ from each other in this respect.

Microbial biomass from substrate induced respiration (SIR): the SIR-value was lowest under spruce (*Figure 2*), while microbial biomass stocks were more than twice as high in deciduous leaf litters. The highest microbial biomass in the mineral soil was found under spruce. The microbial carbon stock of the upper mineral soil layer of the beech forest was significantly lower. The value under oak is very similar to this, but due to the high standard deviation, it is not significantly different from the other two stands.

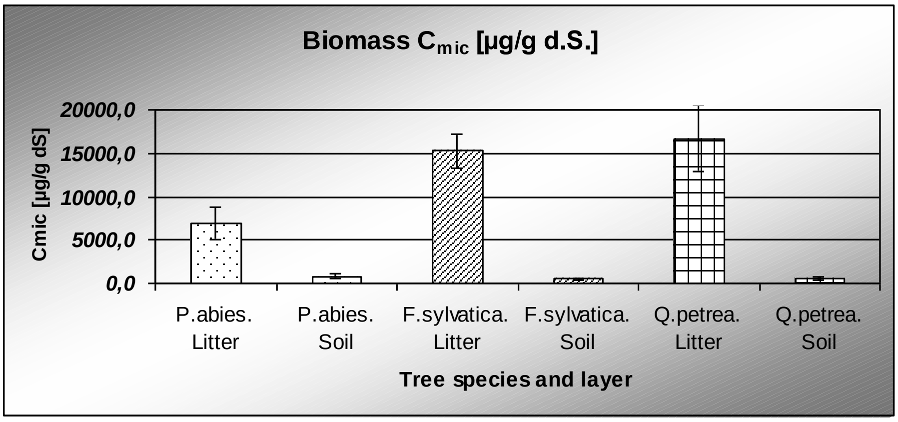

Figure 2. Microbial biomass (C_{mic}) (with standard deviation) measured with the SIR method in the litter and the 0–10 cm mineral soil layers in the spruce (P. abies), beech (F. sylvatica) and sessile oak (Q. petrea) forests

In the end, the microbial biomass concentration found in the litter and upper mineral soil was largest in the oak forest. The concentration was only slightly smaller in the beech forest, but it was only half of the level under spruce.

Similar to microbial biomass values derived from SIR, according to lipid-PO_4 measurements, the soil under spruce had the highest microbial biomass (*Table 2.)* and were roughly equally low in the soils of the two deciduous stands. Values found were only about 1/3 of those measured with the SIR method.

Table 2. Microbial biomass calculated from the lipid phosphate content of the 0–10 cm mineral soil layer in the spruce (*P. abies*), beech (*F. sylvatica*) and sessile oak (*Q. petrea*)

Forest stand	*P. abies*	*F. sylvatica*	*Q. robur*
Microbial biomass µg C_{mic} * g^{-1} d.s.	291	166	157

The respiratory quotient for each of the three stands is significantly lower in the mineral soil than in the leaf litter (*Figure 3*). The value of both layers of spruce was significantly higher compared to the deciduous stands.

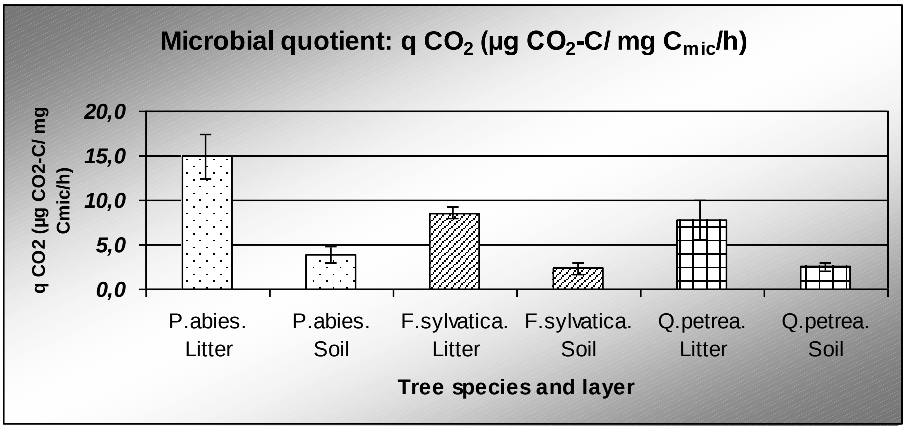

Figure 3. Respiratory quotient (q-CO_2) (with standard deviation) in the litter and the 0–10 cm mineral soil layers in the spruce (P. abies), beech (F. sylvatica) and sessile oak (Q. petrea) forests

In the soil microbial community investigations, the fatty acid patterns of each sample contained compound (C16: 0, C14: 0, Q10), which can be found in a wide range of microbes. In all samples, the highest amounts found were of plant fatty acids (C18:1 t9c11, C18: 2 c9-12) and of the very common Q-10 molecules (main or secondary quinones of numerous bacteria, occurring in the mitochondria of many eukaryotic cells, in plants and protists as well). MK-7 occurred in all three stands, branched iso-, anteiso-, 16–19 carbon atoms containing fatty acids, these compounds formed the dominant fraction of the compounds in each case.

Compounds characteristic for micro-fungi occurred in larger quantities (Q-11H_2, Q-10H_2); these did not emerge in the beech stand under oak and under spruce. In addition, these samples contained higher amounts of poly-unsaturated menaquinones (MK10H4, MK10H6). C20:2 and C22:3 fatty acids were also found.

Figure 4 illustrates the differences of soil chemotaxonomic markers between the upper soil layers of the three forests. Those components occurred in each sample and, in order to prevent interference with the variance of the samples, are not included in the figure.

The principal component analysis of soil samples from three forest stands brought a clear separation of the stands (figure not shown). The soil of the spruce forest differed most from the deciduous stands with regard to its soil microbial characteristics. More specifically, the lower BAS, the lower SIR and lipid-phosphate derived microbial biomass as well as the highest RQ brought a statistically clear separation for spruce.

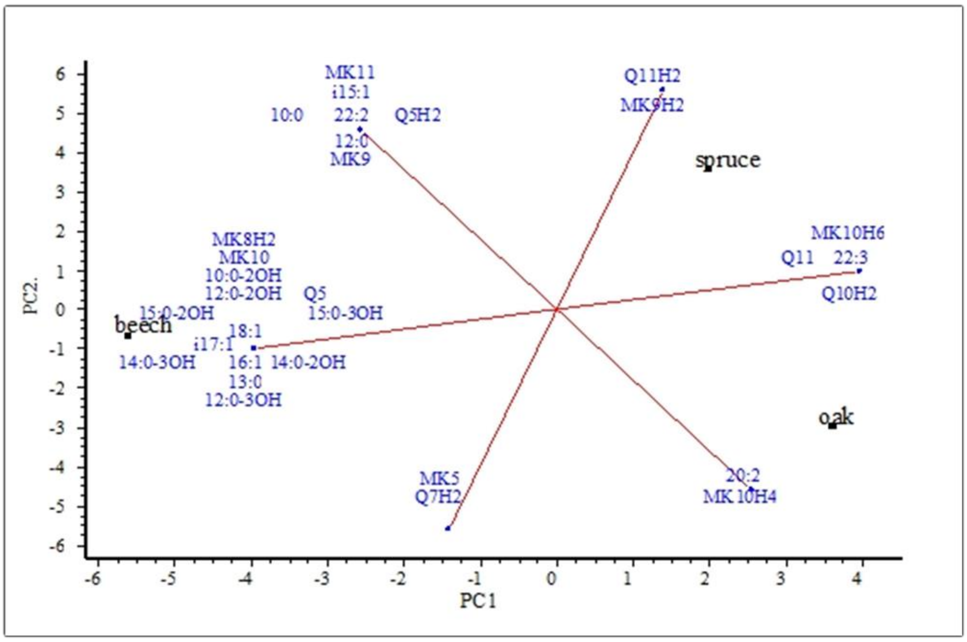

Figure 4. Main component analyses of the microbial communities described by chemotaxonomical markers (PLFA and RQ) in the spruce (*P. abies*), beech (*F. sylvatica*) and sessile oak (*Q. petrea*) forests soils

The abovementioned results indicate that acidification of the upper soil was greatest in the coniferous stand. Considering the highly acidic range and the high level of hidden-acidity, inherent small differences in pH can seriously impact the flora and fauna of the ecosystems, as observed with pH<4.2 for soil biota by Mössmer (2001), or as described in a long term study by Oulehle et al. (2007).

Forest stands usually need to restore mineral phosphorus daily because the plants can completely take up the available amount in a short time. The different order in comparison of humus contents vs. readily available phosphorus is partly justified by the slightly more intense microbial degradation measured in the beech forest, as suggested by BAS values.

Based on the concentrations of soil organic matter and, thus, the important macro-nutrients, oak and beech stands experienced more favourable conditions than the spruce forest. Lower soil pH-values and low availability of nutrients may result in reduced plant biomass production, assuming slower microbial turnover by spruce (Gisi 1990; Blume et al. 2016).

As expected, beech and oak litter proved to be more easily biodegradable than spruce needles (Gencsi – Vancsura, 1997). However, the accumulation of a thick layer of spruce needles has not yet been found, likely due to the short history of the conifer stands at the site.
Although we expected lower microbial metabolic activity in the upper mineral soil under spruce, results showed an opposite trend, with lower metabolic activity in the deciduous stands. On one hand, it must be noted that the level of metabolic activity in the mineral soil of all stands was almost two orders of magnitude smaller than measured in the litter layer, which still indicates that decay of organic matter is altogether faster in the deciduous stands overall. The more intense breakdown in the upper mineral soil of the mostly acidic soil under spruce can perhaps find its causes in the slower transformation taking place in the litter layer, which leads to a higher transport of weakly transformed, easily degradable compounds to the upper mineral soil layer. This could be also indicated by the closest C / N ratio under spruce as well.

Similar results were found in the literature. Joergensen and Scheu (1999) studied soil chemical and microbial gradients with depth under beech and spruce forests.

Microbial biomass values delivered from SIR were very high according to the data recorded in Dilly (2003). This is probably the result of the less intense soil acidification and the higher average temperatures of the Sopron sites. A comparison of data to a Hungarian study (Molnár et al. 2016) on arable land proved our values to be higher, probably as forest litter remains on soil surface as opposed to the annual removal of biomass in agriculture.

Similar to decay activity, microbial biomass was much smaller in the mineral soil compared to the litter in all three forests respectively. A slight shift of microbial decay from the litter layer to upper mineral soil is again indicated in the case of spruce with high microbial stocks at the upper 10 cm of the mineral soil. Our data matches those in Raubuch and Beese (1999), who found a clearly marked gradient down from fresh litter throughout to mineral B horizon regarding microbial biomass and the SIR-C_{mic}.

The metabolic quotient (q) was higher for spruce both for the litter and the mineral soil layer. Scheu and Parkinson (1994) studied the microbial biomass, BAS, RQ, and C_{mic}/C_{org} ratios in different soil layers of a poplar and of a pine forest in Alberta, Canada. The q-ratio decreased strongly with increasing soil depth, from which the authors concluded that the use of the carbon content of the substrate by microorganisms (i.e. assimilation!) becomes more efficient at the later stages of decomposition in both types of forests.

Similar to findings of Djajakirana et al. (1996), our PLFA results showed a higher proportion of fungi in the microbial communities under spruce than in the deciduous stands. A higher RQ experienced in the litter and in the mineral soil of spruce indicates that the fungal/bacterial ratios are increased with progressing soil acidification, while the carbon originating from available organic material sources can be assimilated less efficiently by the microbes. This results in higher proportions of CO_2 released during decay of the same amount of organic compounds. This assumption could be controlled with the use of the selective inhibition method.

Lower biomass values derived from lipid-phosphate are probably explained by the increased number of active microbes after the addition of glucose in the SIR method. However, there was a good correlation of microbial biomass values in terms of comparison of the three forest stands.

It should be also noted that the results of the PLFA analysis detected a large amount of plant-characteristic compounds, so the lipid phosphate biomass values may not only characterize the microbial biomass, but are also influenced by the remains of fine roots in the soil samples. Consequently, these results should be treated with some reservations.

The above-described biological indicators confirm that the microbial processes suffer inhibition in the mostly acidified forest soil under spruce and even the effectiveness of microbial metabolism was reduced.

Among the chemical characteristics of the soil, highest latent acidity (y_2-value), and the lowest clay+silt contents separate the soil under spruce statistically again. The deciduous beech and oak stands showed higher mean values of pH, higher nutrient contents and base saturation as well as higher proportions of fine particles, indicating more stable soil structures. These results are consistent with the phenomenon described in literature, that deciduous stands tend to build in higher amounts of the so-called “basic” or “alkaline forming” cations, repeatedly resulting in higher proportions of these cations in their litter, which then get incorporated into the humus compounds of the upper mineral soil (Blume et al. 2016).

More favourable soil chemical and physical characteristics lead to better overall nutrient and hydrological cycling. Also, metabolic activity values and microbial biomass values are higher, and the breakdown is more efficient in the deciduous stands than it is in coniferous stands.

Similar correlations were shown by Bååth and Anderson (2003) who studied 53 deciduous forests soils for soil fungal/bacterial ratios in the microbial biomass, combining the SIR method with the selective inhibition of respiration (SI) technique. Strong linear correlation was found between the total microbial biomass calculated from the SIR- and PLFA-methods. Both biomass values were positively correlated with soil pH. The fungal/bacterial ratio value specified with selective inhibition was significantly decreased with increasing soil pH.

Several compounds found in our samples can be characteristic of a wide range of microbes, some for plants and others only generally for bacterial and plant mitochondria. These had little taxonomic value for our study. Nonetheless, it is not surprising to find these compounds in large quantities in forest soils.

Similarly, compounds specific for common Gram-positive soil bacteria – e.g. *Bacillus, Agromyces, Actinomyces, Aureobacterium* genus (MK-7, branched iso-, anteiso fatty acids with 16-19 carbon atoms) – were found. These formed the dominant faction in all three soils.

Chemotaxonomic markers separate the beech forest soil clearly. On the one hand, this is due to the presence of large amounts of short-chain hydroxy-fatty acids, which are mainly characteristic for lipopolysaccharide layers in Gram-negative bacteria. The diversity of these compounds is conspicuous in the soil of the beech stand, and some are even specific for a narrower range of taxa, e.g. C12:0-2OH - Alcaligenes, Chitinomonas; C14:0 -Alcaligenes, C15:0-2OH - Burkholderia.

Gram-negative soil bacteria belong to a diverse, wide range of multiple bacterial genera, which are often heterotrophic, breaking down their carbon sources by respiration or fermentation. Among these chemoautotrophic bacteria (e.g. *Nitrosomonas*, *Nitrobacter*, *Thiobacillus*), there are those for which the source of carbon is atmospheric CO_2. Their total absence in the soil of oak and spruce is unlikely, but their presence may be "masked" by other common compounds.

The Q-5 compound appeared only in the beech soil. Although we do not consider it as a main quinone of any bacteria, it is a secondary quinone in a number of Gram-negative, facultative anaerobic organisms (e.g. *Escherichia, Klebsiella, Proteus, Aeromonas* genera). Some of these can carry out very intense mineralisation ("rot") even in the absence of O_2, without producing harmful by-products.

The *K. pneumoniae* found here is a common nitrogen fixing representative of this genus. Species of *Aeromonas* are capable of butylene glycol fermentation, while species of the *Proteus* genus mix with acidic fermentations. These organisms are largely not soil bacteria; however, it is conceivable that they could have found their way into the soil via animal faeces. Otherwise, members of the *Enterobacteriaceae* family cannot survive long in this environment.

The C18:1 fatty acid appears also only under beech. Besides plants, this may be characteristic for mycorrhizae as well. Iso branched C17:1 and C15:1 fatty acids are characteristic markers of *Cytophaga* genus and of some sulphate-reducing bacteria. The largest amount of the MK5 compound, which is specific as a main-chinone for Capnocytophaga species and as a side-chinone for Flavobacterium, was found in the soil of the beech stand. These are typical residents of root surfaces of various plants.

Other compounds were detected in the soil of the beech stand: MK-9, MK-10, MK-11 can be at first quinones of some common soil bacteria (*Agrobacterium*, *Aureobacterium*, *Rathayibacter*, etc.). On the other hand, these act as main- and secondary quinones of the *Bacteroides* genus. The presence of the *Bacteroides* genus is probable. Other fatty acids characteristically found in anaerobic bacteria were detected in addition to these quinones. The species of the genus *Bacteroides* – together with other anaerobes (e.g. *Clostridium*) – are characterized by their role in causing "soil sickness" in badly aerated soils.

Compounds specific for microfungi were found in soil samples from the oak stand, and even more typically, in the samples from the spruce stand. Besides these, we found greater quantities of polyunsaturated menaquinones ($MK10H_4$, $MK10H_6$) in both soils, which suggests the presence of Actinobacteria, a very common group of Gram-positive bacteria living in soils. In terms of their metabolism, Actinobacteria are obligate aerobic saprophytes, and comprise an average of about 1-10% of the total soil bacterial population. They are completely absent in the litter layer and usually have their largest numbers in 5-10 cm depth of the mineral soil. They grow on multicomponent substrates, attack mostly hardly-degradable materials, like lignin, chitin, and starch. Several Actinobacteria (specifically *Streptomyces* species) produce antibiotics such as streptomycin, chloramphenicol, or tetracycline, and they are partly responsible for the typical scent of the soil, which is due to the release of gaseous Terpent derivates (e.g. geosmin) due Gisi (1990).
In the same samples, the C20:2 and C22:3 compounds suggest the presence of protozoa and cyanobacteria. In the soil, these spend the active phase of their lives in the water-filled soil pores and in surface water films on soil particles and roots.

Regarding the physical and chemical indicators as well as microbial activity and biomass patterns, the results of the microbial community investigations show a different distribution of the three forest stands. While soil acidification under spruce resulted in more unfavourable conditions compared to those of the nearly similar deciduous forests soils, the microbial community compositions were closer to each other in the spruce and the oak stands, and we saw a more distinct, specific microbial soil community under beech. This separation of beech originated partly from the presence of microbes, suggesting anaerobic conditions (facultative and obligate anaerobes) compared with the aerobic conditions indicating microbes of the other two forest soils. A reason for this could be the close parallel layering of the beach litter leaves, which, in contrast to spruce needles and curvy oak leaves, seal the soil surface during precipitation.

Microorganism are critical in mediating C- and N-turnover in soils. Yet, a recent study (Zheng et al. 2019) has shown that soil-C processes were only directly affected by the soil environment, but not affected by microbial community composition. In contrast, soil-N processes were significantly related to bacterial/archaeal community composition and bacterial/archaeal/fungal richness/diversity, but not directly affected by the soil environment.

All of this demonstrates that the ecological assessment of forest soils should never be conducted solely by physical-chemical characterization. It is equally important to perform additional microbiological studies, and vice versa.

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