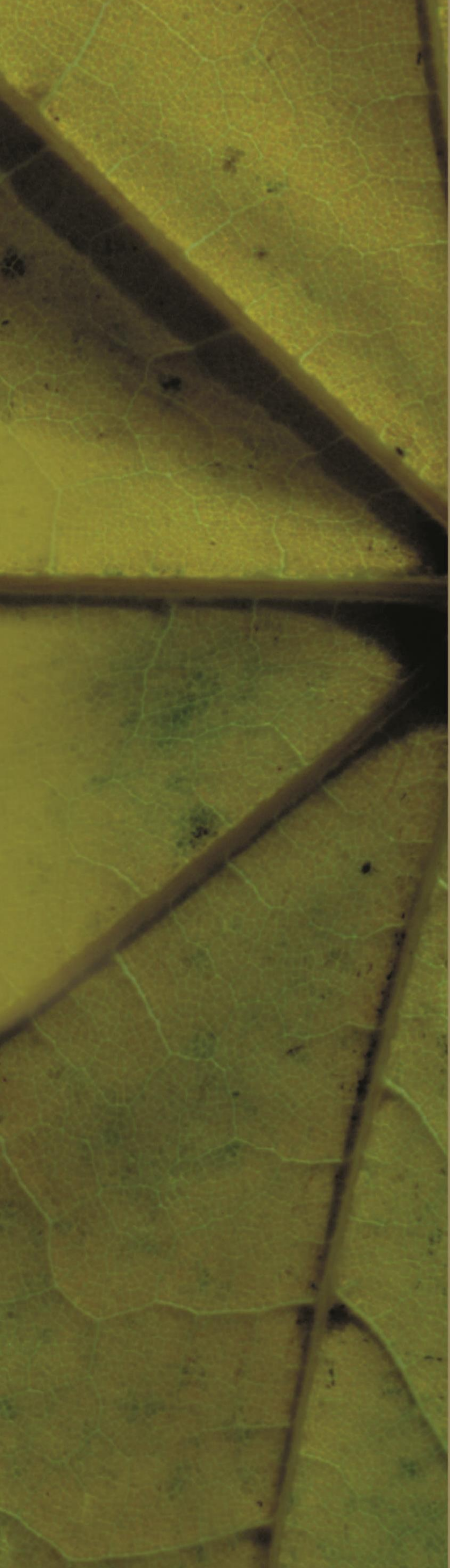

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Monitoring of the Hydrological Balance in the Area of the Kiskunság National Park Directorate

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Abstract – The aim of this paper is to show how hydrological measurements made in forests and grasslands can contribute to the conservation treatment of ecologically significant habitats. The study was carried out in three different forest stands and their surrounding grasslands in the area of the Kiskunság National Park Directorate between 2012 and 2015. Different methods were applied during the research of the water balance. The average values of canopy interception were 23% in the Scots pine stand and 19.2% in the grey poplar stand. Rainfall quantity, intensity, and dispersion as well as tree structure and health greatly influenced interception. The transpiration values were 205 mm in the coniferous stand, 405 mm in the deciduous stand, and 370 mm in the black locust stand. The water balance of the habitats show that the water uptake is much lower in the grasslands than it is in the surrounding forest stands.

precipitation / soil moisture / interception / water balance / forest stands

Kivonat – **Hidrológiai vizsgálatok a Kiskunsági Nemzeti Park Igazgatóság területén.** Jelen vizsgálat a különböző erdőállományokban és gyepterületeken végzett hidrológiai mérések alapján egészíti ki, támasztja alá az egyes ökológiai szempontból jelentős élőhelyek szakszerű természetvédelmi kezelését. A vizsgálatok a Kiskunsági Nemzeti Park Igazgatóság működési területén elhelyezkedő három erdőrészletben és közvetlen közelükben lévő gyepterületen folytak 2012–2015 között. Munkánk során különféle módszereket alkalmaztunk az élőhelyek vízháztartásának vizsgálatához. A koronaintercepció átlagos értéke az erdei fenyves állományban 23%, ezzel szemben a szürke nyáras állományban 19,2% volt. Az intercepció mértékét döntően befolyásolta a leérkező csapadék mennyisége, intenzitása, eloszlás és a faállomány szerkezeti jellemzői és egészségi állapota. A transpiráció értéke a tűlevelű állományban 205 mm, a nyáras faállományban 405 mm és az akácos állományban 370 mm volt. Az élőhelyek vízháztartásának vizsgálata során megállapítottuk, hogy a vizsgált tisztások vízfogyasztása jóval alacsonyabb, mint a mellette elhelyezkedő erdőállományoké.

csapadék / talajnedvesség / intercepció / vízháztartás / erdőállományok

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1 INTRODUCTION

Due to the implementation of several programmes, such as the Afforestation Program of the Great Hungarian Plain, the Poplar Program, and the Pine Program, forest extension has increased almost threefold in Hungary since 1920. Recovering the loss of forest area proved a challenge for foresters. Nonetheless, their committed professionalism combined with the above mentioned afforestation programmes has made the region between the Danube and the Tisza rivers the most afforested part of the Great Plain. Mainly alien species (*Pinus sylvestris*, *Pinus nigra*, *Robinia pseudoacacia*) were planted here in order to improve the sand in the region. Environmental organizations have criticized these afforested plantations in the Danube-Tisza sand ridge area whereas governmental conservation management groups have more varied perspectives about these plantations as several National Park Directorates manage forest stands in the area.

Groundwater levels have decreased significantly in the region between the Danube and the Tisza since the 1970s, and the tendency can be seen even today (Pálfai 1993, 2010). Many researchers have tackled this important issue and have attempted to discover what the cause or causes of the decreasing groundwater level might be. Nevertheless, decreasing groundwater levels are a complex problem. Several researchers cite improperly controlled residential, horticultural, and agricultural water usage as major causes for the groundwater decline in the region, while others claim the drilling and boring associated with petroleum, natural gas, and shale gas exploration are to blame. Other researchers suggest that sand ridge forests can affect groundwater considerably leading to decreased levels (Major 1974, 2002, Major – Neppel 1988, 1990, Szodfridt 1990, 1993, Pálfai 2010). Concerning all the viewpoints and interests of conservation treatment, water management, agriculture, and silviculture, it is crucial to initiate research into the water balance of the different forest stands. Examining the water balance process and dealing with its integration into conservation treatment is also essential. It could be useful if each sector determined the role of different forest stands in the water balance.

The main purpose of this paper is to provide information about the water balance features of sand ridge forest stands in the area of the Kiskunság National Park Directorate and to monitor the changes in different types of forests. While conducting the survey, the following are considered: (1) What impact do forest stands that are typical to the area have on changes in groundwater level? (2) What is the difference between the water balance of the examined ecosystems (deciduous, coniferous forests) and the neighbouring grasslands?

2 MATERIALS AND METHODS

2.1 Research area

Research was carried out in the area of the Kiskunság National Park Directorate (*Figure 1*). The two main sites comprised three forest stands in Bócsa (H: 19° 29’ 38” W: 46° 37’ 37”) and two other places in Pusztaszer (H: 20° 02’ 17” W: 46° 33’ 29”). In Bócsa, data were collected in two stands (Scots pine and grey poplar) and the surrounding grassland. The forest stands are homogeneous; the trees are the same age and were planted using the same technology. In Pusztaszer, the other main area of the research, data were collected in an old black locust forest stand that was established from second growth, and from the grassland next to it (*Figure 1*).

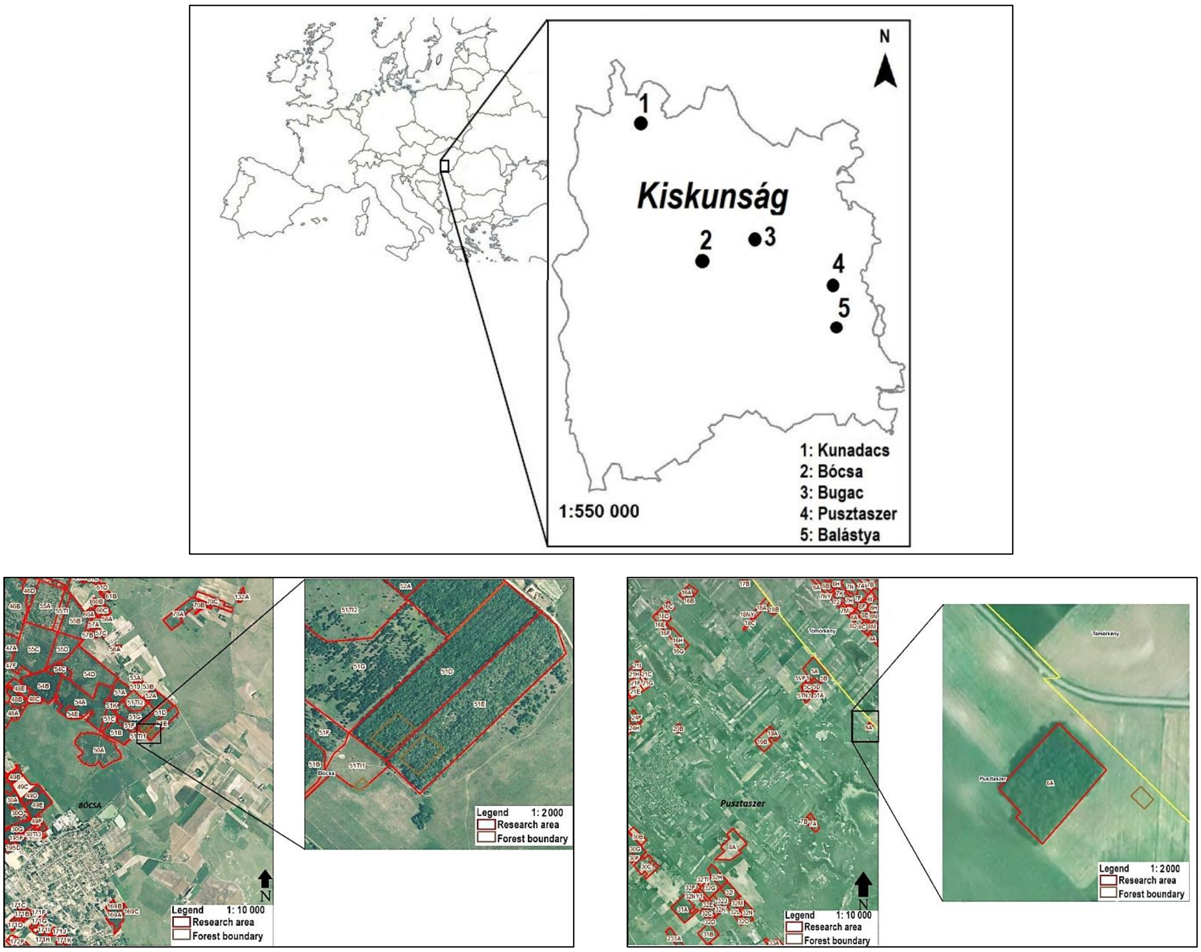

Figure 1. Research sites (Bócsa and Pusztaszer)

2.2 Applied methods

Open air precipitation was measured between March 2012 and March 2015 using Hellmann rain gauge units. Precipitation was assessed daily in Bócsa, Bugac and Pusztaszer; two observers assisted in our work in Balástya and Kunadacs (*Figure 1*).
We measured the throughfall and stemflow of a Scots pine monoculture stand (Bócsa 51 D) and a grey poplar monoculture stand (Bócsa 51 E) over the period from April 2012 to October 2014. Control measurements (groundwater level, soil moisture) were conducted in the grassland next to the above-mentioned forest stands (Bócsa 51 TI 1).

The throughfall was determined using Hellmann rain gauge units (one placed in a row of trees, another between two rows of trees, and the third placed in a thin grove). Twenty funnels (each 280 cm^2) were also applied at every meter in both forests at 1 meter height from the ground. A further ten gauge units (each 100 cm^2) were applied horizontally in a random way at the ground surface. For the calculation of stemflow, trunk collars (connected with collecting vessels) were placed on each tree. The trunk collar system was built with regard to the distribution of the tree trunk diameters (*Figure 2*).

Meteorological data (temperature, humidity, precipitation, radiation, speed, and wind direction) were collected with a BOREAS Meteo Global HI weather station employed in Bócsa (Bócsa 51 TI 1). This data collection was conducted hourly between January 2012 and March 2015. The groundwater level was observed hourly with Dataqua, LUB 222 sensors, and HYGR data loggers in Bócsa and Pusztaszer between November 2013 and February 2015.

Figure 2. Trunk collar system with Hellmann rain gauge unit

To protect against possible data logger malfunction or failure, Dataqua, a DA-OP LED water gauge was used weekly for the manual detection of the groundwater level (*Figure 3*). Soil moisture data was recorded with a manual sensor (TDR-system digital PT-1) and with automatic data loggers in the grassland (Bócsa 51 TI 1), in the Scots pine stand (Bócsa 51 D) and in the grey polar stand (Bócsa 51 E). Automatic soil moisture measuring was surveyed with a HOBO MicroStation data logger manufactured by Onsetcomp and with twelve 10 HS soil moisture sensors manufactured by Decagon.

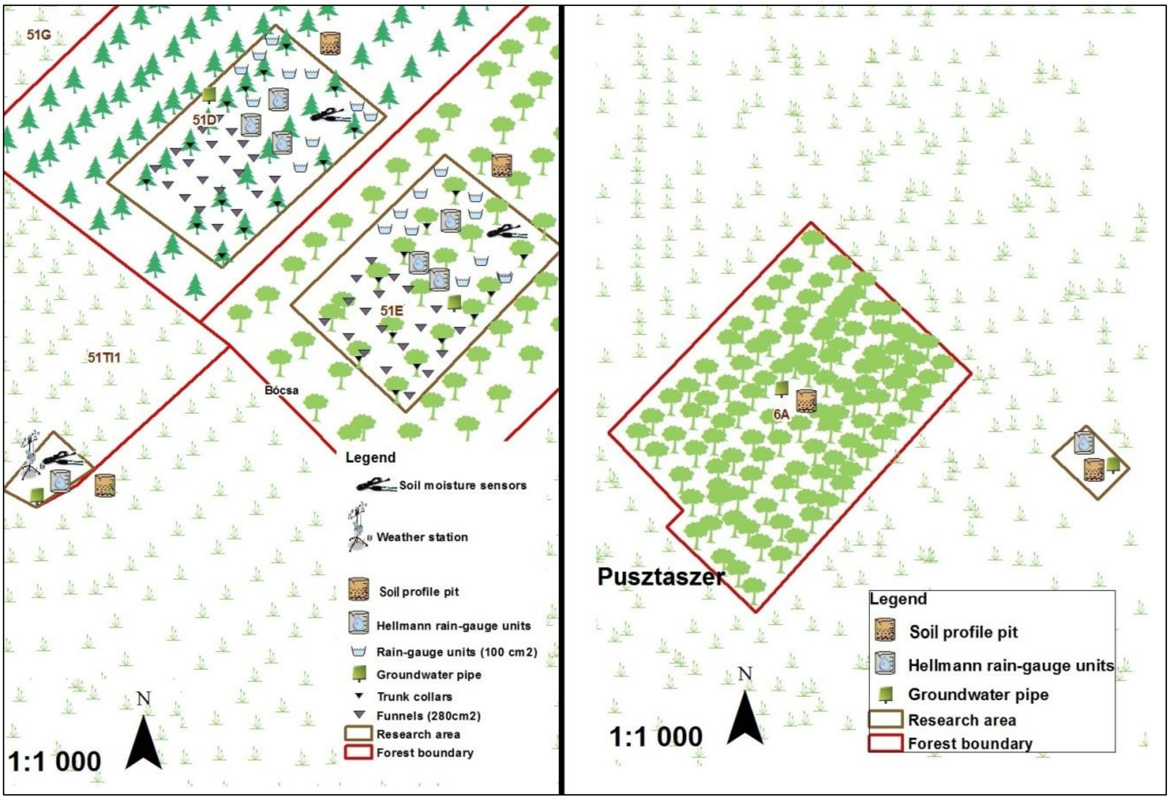

Figure 3. Distribution of the sensors in Bócsa and Pusztaszer

The data collection took place in four soil layers (0–25 cm, 25–50 cm, 50–75 cm, 75–100 cm, respectively) in each site between September 2013 and May 2014. The soil moisture was also observed manually with a TDR-system digital PT-1 soil moisture sensor manufactured by “Kapacitív Kkt” and it was measured in 80 cm bulk layers weekly. Soil moisture data were collected from December 2013 to March 2015.

2.3 Processing data

We processed the data collected during the research with the following methods:

- manual measurements (open air precipitation, throughfall, stemflow, groundwater, soil moisture) were processed with Microsoft Excel 2010 to clarify data. We also used Microsoft Excel 2010 to select and illustrate the data.
- automated soil moisture data were selected and analysed using authorised data-processing software. The false data were filtered by the mentioned software. On the other hand, the processing of meteorological and groundwater level data required the use of Microsoft Excel 2010 and extension programmes.
- the water balance equation was applied to estimate water balance (Szász – Tőkei 1997) and the approach of White (White 1932, Loheide et al. 2005) was applied to the processed data of the survey. The water uptake from the groundwater of the forest stands was estimated with the method of White (White 1932).

The White method uses the following expression:

$$ET_G = S_Y(\Delta s/t+R_n) \tag{1}$$

Where:

ET_G: the rate of evapotranspirative consumption of groundwater averaged over a 24-hour period (L/T),
S_Y: the specific yield (dimensionless),
Δs: daily change in storage (L),
R_n: the net inflow (recovery) rate (L/T),
t: the time period of one day expressed in the appropriate time units (T).

The following equation was used to calculate the water balance (the water balance equation applied for lowland forests, from the top of the canopy down to the rooting depth):

$$\Delta S = (P+Cr)-(ET+Q+R+I) \tag{2}$$

Where:

ΔS: Change of the stored water in the layer,
P: Precipitation,
Cr: Capillary rise (ET_G from the first equation),
ET: Evapotranspiration – transpiration of plants (from the soil moisture and from the groundwater) and evaporation of the ground surface (including the litter interception) –,
Q: Surface outflow,
R: Recharge to groundwater,
I: Crown interception

(we have neglected P_{micro}: Microprecipitation at the ground surface, *Si:* Surface inflow and *Ssi:* Subsurface inflow, *Rss:* Subsurface outflow were taken into account in capillary rise and recharge to groundwater).

We calculated transpiration with help of evapotranspiration and the evaporation. The previously mentioned water balance equation (Szász – Tőkei 1997) was used for rainless seasons, so the values of interception and deep seepage were neglected; after that, the value of evapotranspiration was calculated from the restoration change of soil moisture (Moltschanow 1957, Gácsi 2000). During the rainless season, the soil moisture was measured and the restoration of soil moisture was calculated with the aforementioned data in the upper 100 cm soil layer.

From the obtained value of evapotranspiration, the evaporation was left and the value of transpiration was received. The forest evaporation data were used according to Járó (1981) and the evaporation data of grassland were used according to Hagyó (2009). The groundwater recharge was determined by the interception value and evapotranspiration as a remaining member of the water balance equation (Gácsi 2000).

The analysis of water fluxes of the sample areas was conducted by the water balance equation. The value of evaporation was estimated by the results of Járó (1981), Járó and Sitkey (1995) and Hagyó (2009). Járó (1981) estimated the value of the ground surface evaporation of the forest stand, which is equal with interception of the undergrowth and litter interception. The average of this value was taken into consideration. Hagyó estimated evaporation of the grassland with a SWAP model (van Dam 2000). The potential evapotranspiration was given with the Penman-Monteith equation according to Allen et al. (1998). The grassland results of Hagyó (2009) were also taken into account for the vegetation period.

3 RESULTS

During the three years of research, more than 354,800 data records were collected, out of which 6,137 records were collected manually and 348,663 were collected with data loggers. The spatial distribution of the precipitation varied in each sample area. Out of the five sample areas, the largest quantity of daily rainfall was recorded in Kunadacs on March 31, 2013 (60 mm) (*Figure 4*).

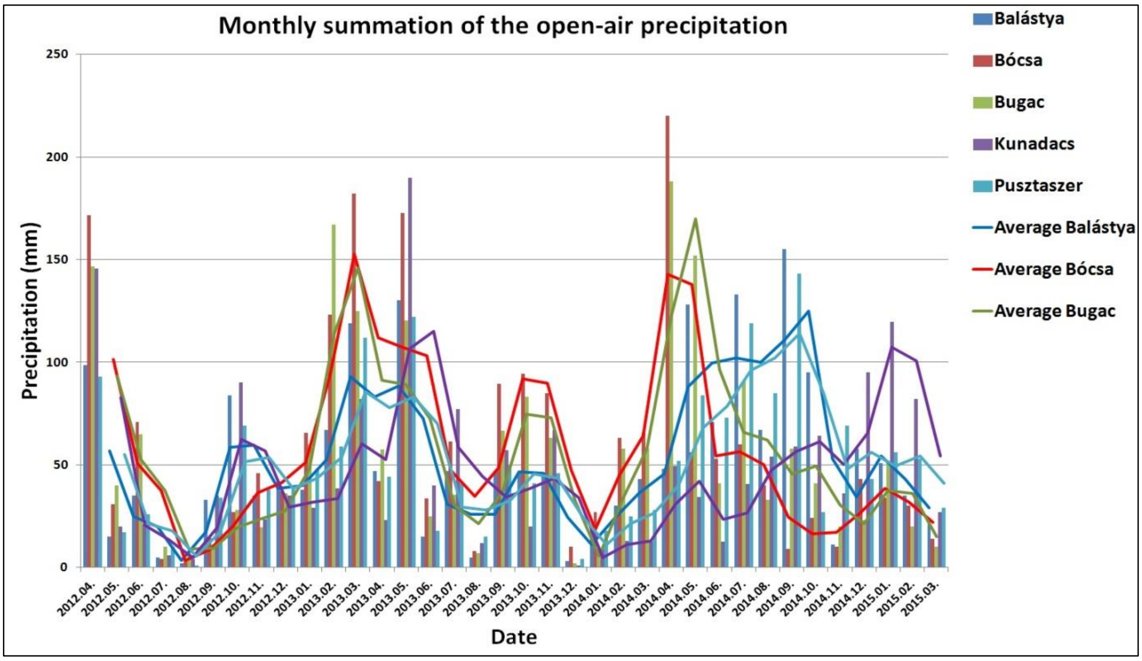

Figure 4. Time series of the precipitation in the research sites – April 2012–March 2015 (the moving average of the monthly summation of the open air precipitation)

Meteorological data were similar to the average in Bócsa between January 1, 2012 and March 31, 2015, but extremes could be detected on several occasions (in extended dry periods in April and July 2013 as well as in June 2014). The total annual rainfall in 2012 was 420.6 mm, which is below the Hungarian average data (omsz.hu); conversely, it was above the national average (omsz.hu) in 2013 (599 mm) and in 2014 (807.9 mm). Extended dry periods occurred in March, July, and August 2012, while August 2013 and March 2014 could be considered droughty (*Figure 5*). There were some dry periods typically in spring and in summer.

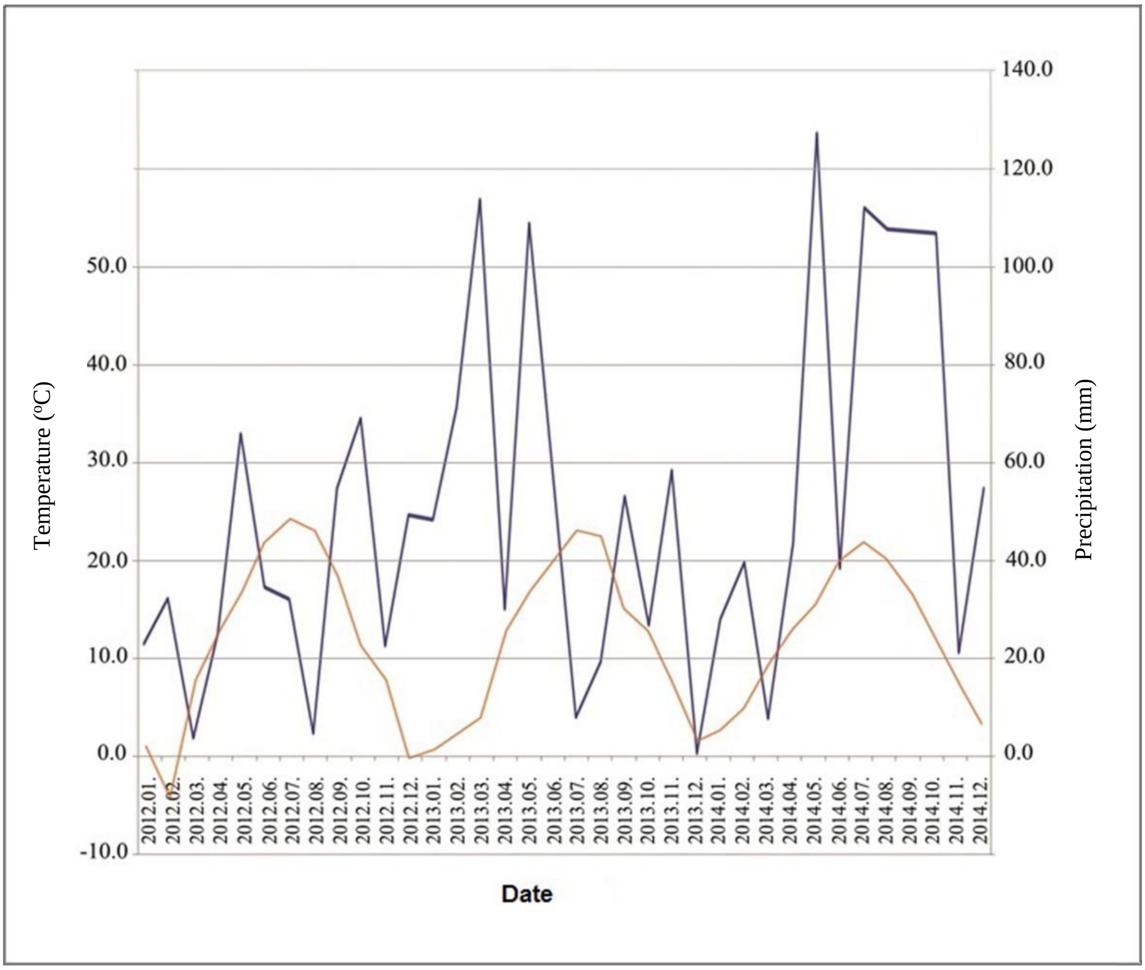

Figure 5. Climate graph of Bócsa 51 TI1

The average value of canopy interception was 23% in the Scots pine stand in Bócsa (in 2012: 22%, in 2013: 24%, in 2014: 23%), while it was 19.2% in the grey poplar stand (in 2012: 18.5%, in 2013: 20%, in 2014: 19%) between March 30, 2012 and March 31, 2015 *(Figure 6)*.

The canopy interception was lower in the case of the grey poplar stand than the average published. This lower value can be explained by the lower canopy closure, the poor quality of trunks, the loose distribution of branches, missed treatments, and the many gaps caused by dead trees.

The interception of the grasslands was based on the results of Hagyó (2009) in Bugac. The interception of the black locust forest stand was determined by the results of Járó (1980). The stemflow value was 4% in the Scots pine stand (in 2012: 1.5%, in 2013: 4%, in 2014: 2.5%), and 10% in the grey poplar stand (in 2012: 8%, in 2013: 12%, in 2014: 10%) during the period of March 30, 2012 and March 31, 2015.

Stemflow value is lower in Scots pine stands because the tree bark is thick, rough, and absorbent. On the other hand, this value is higher in grey poplar stands, as the tree bark is smooth, thereby allowing more rainfall to flow down the trees.

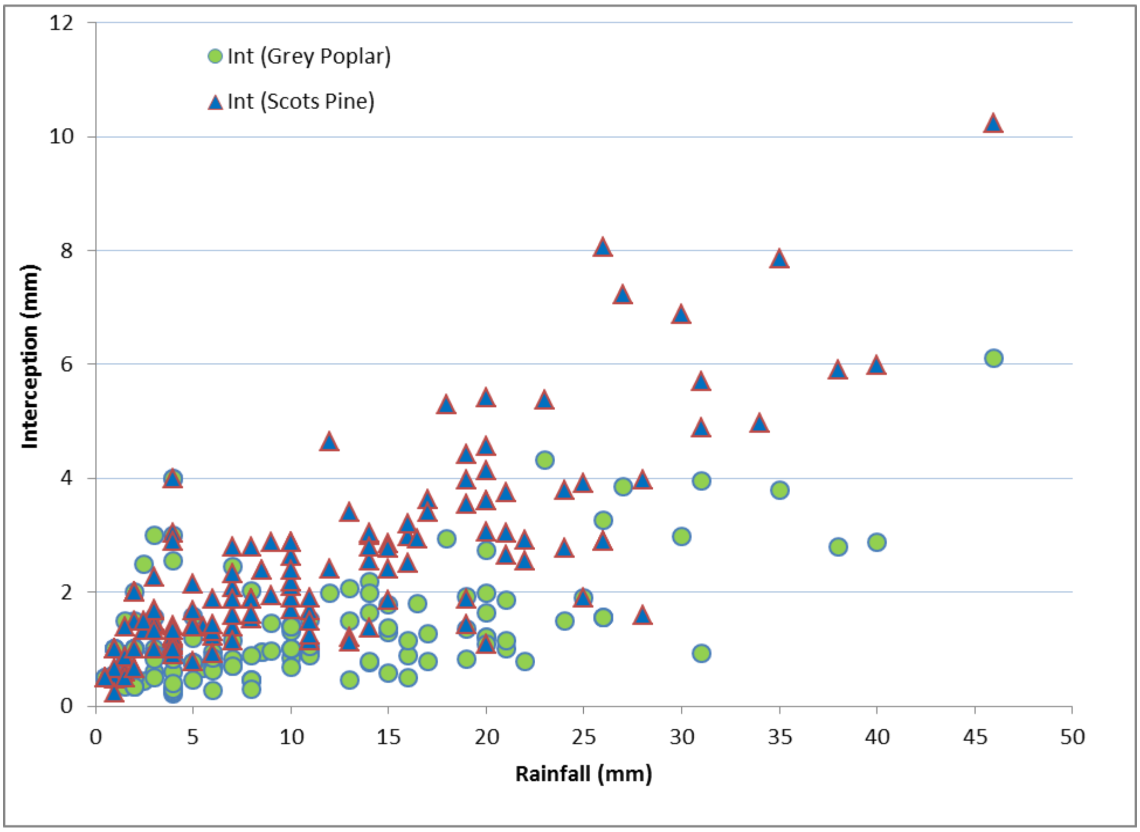

Figure 6. Interception as a function of rainfall (between March 2012 and March 2015)

The groundwater level was usually detected at 3.4 m (below the terrain) in Bócsa over the period of November 25, 2013 and February 2, 2015. This level is regarded as relatively deep for vegetation groundwater use in the Great Hungarian Plain, but in the region of the Kiskunság Sand Ridge, it is a typical value. It seems to be average according to former references (Gácsi 2000) and by the Directorate of Water Management in Szeged: 3.5 m (below the terrain) in Orgovány and 3.3 m (below the terrain) in Bócsa in 2014.

The average value of groundwater level was 2.1 m in Pusztaszer during the research period. This value of 2.1 m is above the average in Kiskunság Sand Ridge compared with the data of 2.8 m in Ópusztaszer in 2014, and 2.9 m in Balástya in 2014 compiled by the Directorate for Environmental Protection and Water Management of the Lower Tisza District in Szeged. Analysing groundwater level records, significant differences can be detected between the grassland and the forest stand. Our results also establish that lower groundwater level records are typical under forest stands; during the vegetation period, the groundwater level under forest was 38 cm lower in Bócsa, while it was 47 cm lower in Pusztaszer (*Figure 7* and *Figure 8*).

Black locust and grey poplar stands are able to reach and uptake groundwater from deeper layers with their roots (Keresztesi 1969, Kárász 1986, Csiha – Keserű 2014). The diurnal signal was observed in the black locust and grey poplar stands; therefore, the water uptake from the groundwater was estimated (Gribovszki et al. 2010). The studied coniferous stands are unable to reach and uptake the groundwater from deeper layers (the diurnal signal was not observed). Thus, coniferous stands can only affect groundwater levels by interception throughout the year.

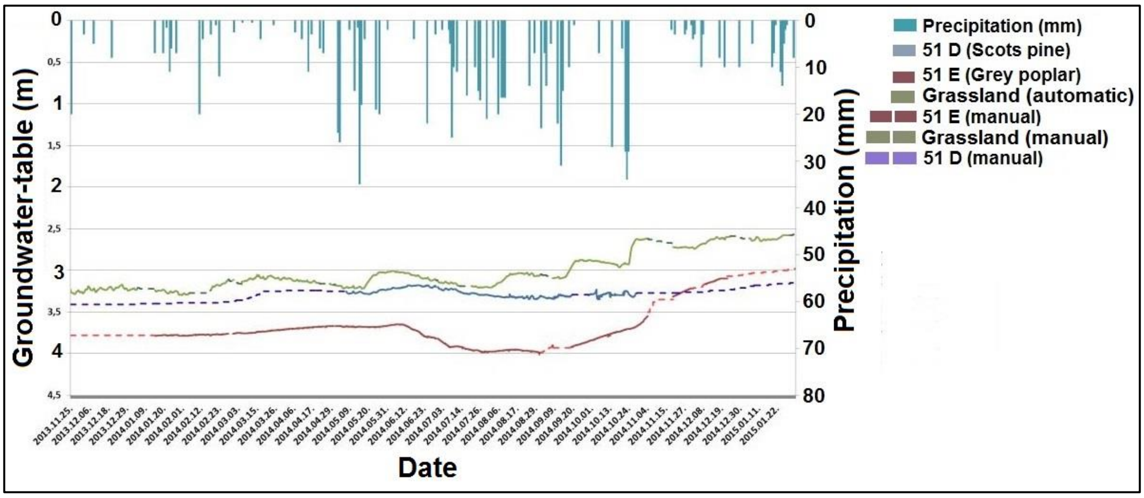

Figure 7. Changes in the water table in Bócsa

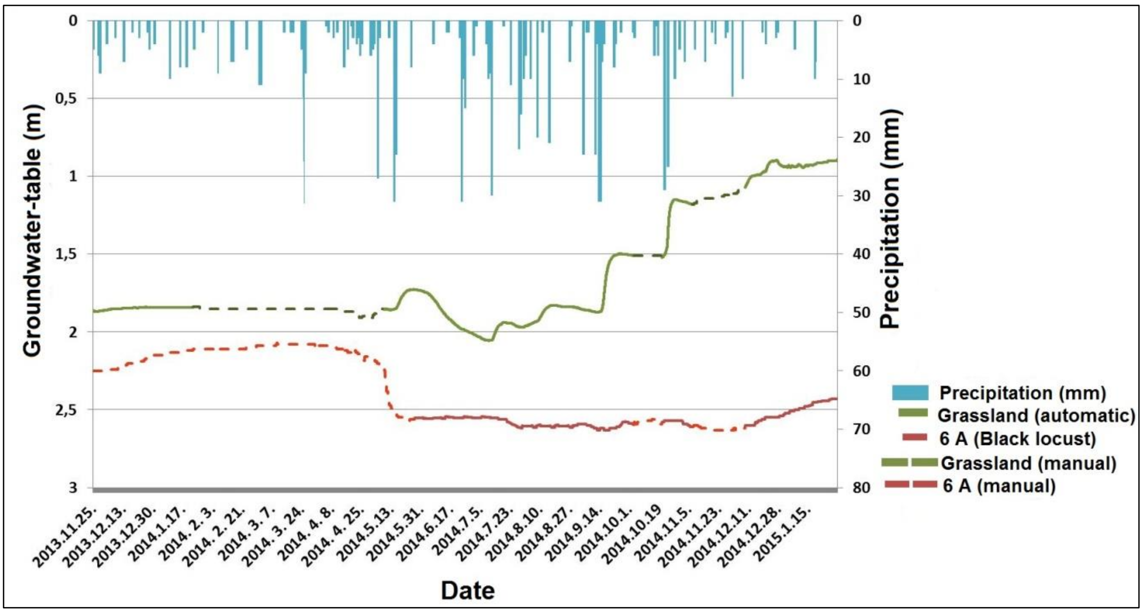

Figure 8. Changes in the water table in Pusztaszer (upper 80 cm)

In the case of soil moisture in Bócsa, the differences between grasslands and forest stands were obvious in the sample area of Pusztaszer (The value of soil moisture was 3% lower in Bócsa and 4% lower in Pusztaszer). The soil moisture data detected in the grasslands followed the distribution of daily precipitation evidently. On the contrary, in the black locust forest stands the value of soil moisture followed the daily rainfall slowly and unevenly (*Figure 9*). The reason for the low moisture contents during the summer was the increased water use in the vegetation period. With a developed root system, the sprouts of black locust forest stands can dry the upper soil level within a short time (~10 days), which has a great influence on the quantity of infiltration during the vegetation period.

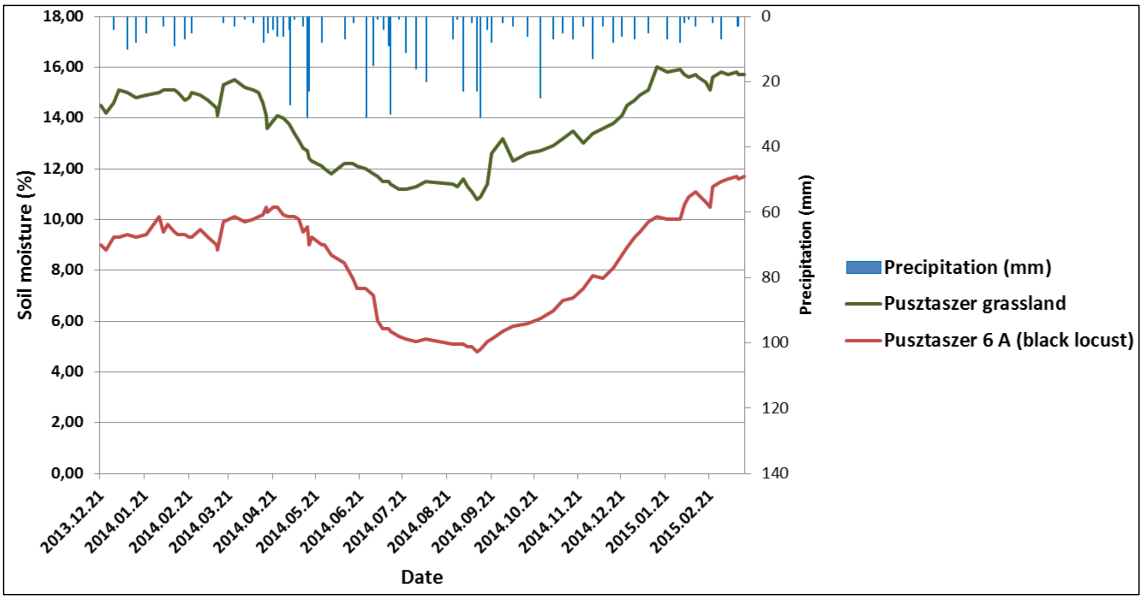

Figure 9. Fluctuation of the soil moisture in Pusztaszer PT-1 (upper 80 cm)

The soil moisture in the upper soil layer (0–25 cm) of the control grassland area was the most diverse, while the moisture content was more balanced in the deepest layer.

In Bócsa, the increase of the moisture content was observed in all of the four soil layers in the late autumn-early winter period; following that, a temporary decrease was detected.

The late winter precipitation and snow melting affected an increase in the value of the soil moisture; then, a decrease in the soil moisture of the grassland starts again at the beginning of the vegetation period (*Figure 10*).

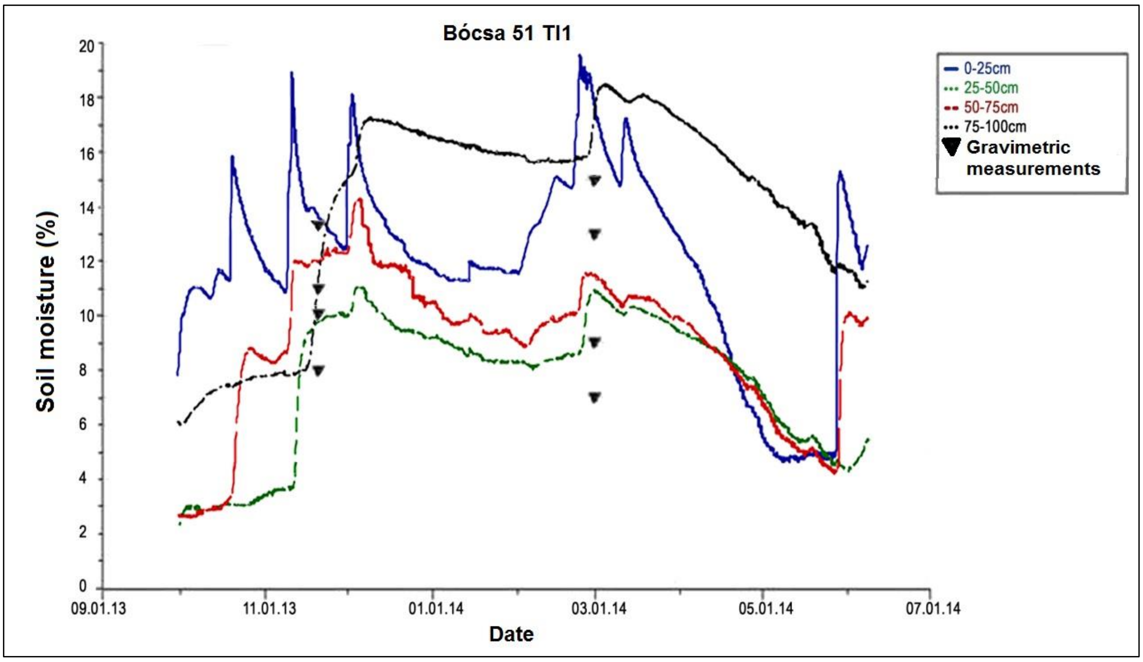

Figure 10. Fluctuation of the soil moisture in Bócsa 51TI1(10HS)

The soil moisture content of the Scots pine stand (Bócsa 51 D) was almost the same in the two upper layers (0–25 cm, 25–50 cm). The third soil layer (50–75 cm) partly follows the periodic changes of the two upper soil layers. A continuous increase tendency was observed in the lowest soil layer (75–100 cm) (*Figure 11*).

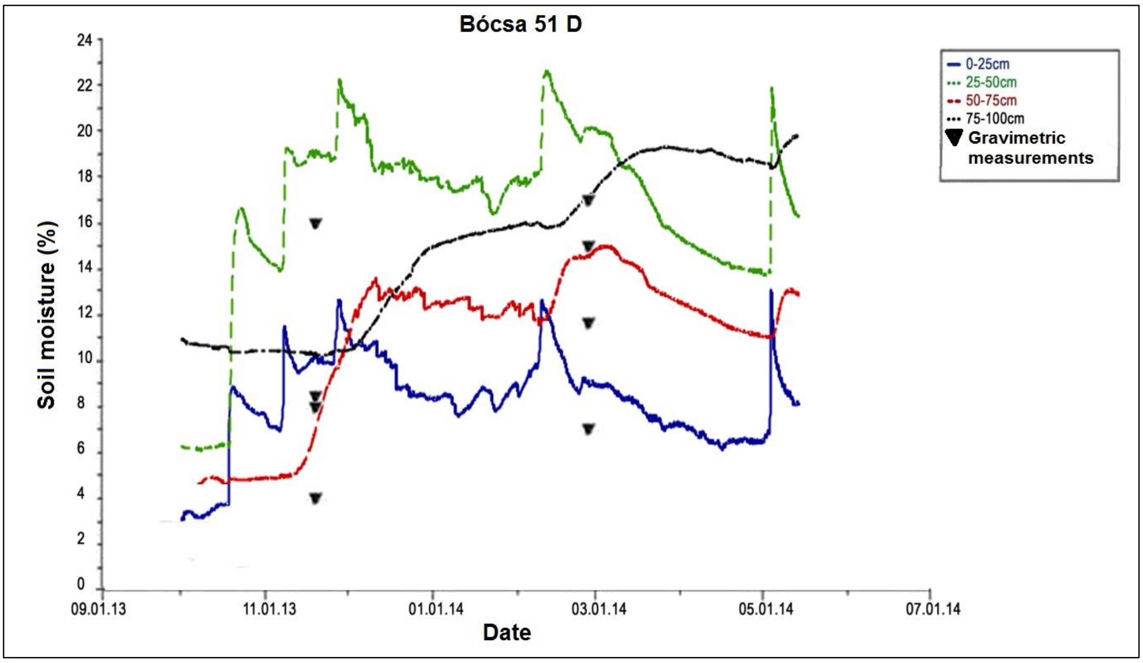

Figure 11. Fluctuation of the soil moisture in Bócsa 51D (10HS).

As for the grassland, the value of the soil moisture content of the pine stand starts to increase in late autumn. Following a short decrease period in the beginning of winter, there is a sudden increase, as Hagyó published in 2009. During the spring months, the value of the soil moisture shows a decreasing tendency. The reasons for the lower moisture content in the pine forest are the deeper root system of the trees and the loss of the interception.

Similar moisture content dynamics of the four soil layers was observed in the grey poplar stand (Bócsa 51 E). Generally, larger soil moisture content fluctuation characterizes the poplar stands. As mentioned earlier, the value of the soil moisture content of the poplar stand also starts to increase in late autumn, followed by a short decrease period in the beginning of winter, which then turns into a sudden increase. During the spring and early summer, the value of the soil moisture usually shows a decreasing tendency (*Figure 12*).

The spring decrease of the soil moisture could relate to the well-developed root system of the poplar stand.

In our research, the calculation (estimating) of water balance elements was based on field measurements as well as the basic values; published data were set with the help of field measurements. The value of evaporation is 95 mm in forest stands, and 125 mm in the case of the grasslands (based on Járó 1981, Hagyó 2009).

The differences in evaporation were significant regarding the grassland, the coniferous stand, and deciduous stands in the case of transpiration. The difference was noticeable between the grassland and the two forest stands. Transpiration in the coniferous stand was lower because the roots were unable to reach the groundwater level. The Scots pine can only uptake water from rainfall infiltrating into the soil. The value of evapotranspiration was the highest in the case of the grey poplar stand (*Table 1*). Deciduous stands have extensive roots so they more easily access groundwater in the upper layers.

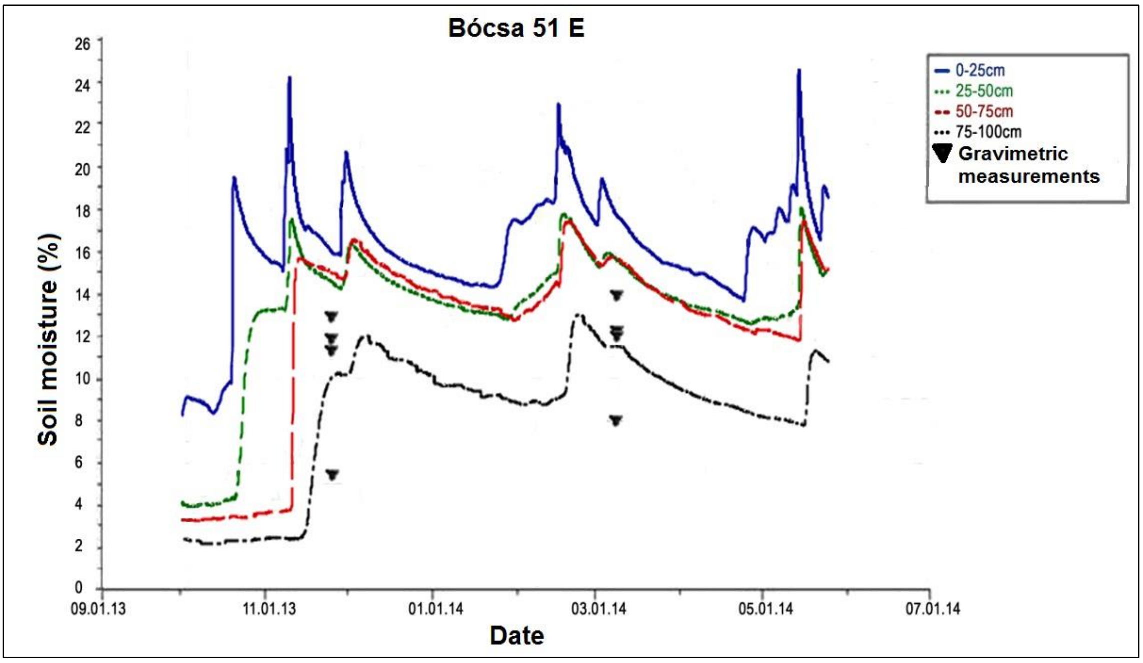

Figure 12. Fluctuation of the soil moisture in Bócsa 51E (10HS)

Table 1. Water balance elements

Date	**31 March – 01 September 2014**					
Research sites	Bócsa 51 D (Scots pine)		Bócsa 51 E (grey poplar)		Bócsa TI1 (grassland)	
Precipitation	428 mm	100%	428 mm	66%	428 mm	100%
Interception	98 mm	23%	81 mm	12%	30 mm	7%
Evaporation	95 mm	22%	95 mm	15%	125 mm	29%
Transpiration (from vadose zone and from groundwater)	205 mm	48%	405 mm	62%	85 mm	20%
Total recharge	88 mm	20%	153 mm	23%	229 mm	53%
Capillary rise	–	–	230 mm	34%	–	–
Change of the water content of the soil	–58 mm	–13%	–76 mm	–12%	–41 mm	–9%

Date	**31 March – 01 September 2014**			
Research sites	Pusztaszer TI (grassland)		Pusztaszer 6 A (black locust)	
Precipitation	407 mm	100%	407 mm	75%
Interception	28 mm	7%	102 mm	19%
Evaporation	125 mm	31%	95 mm	17%
Transpiration (from vadose zone and from groundwater)	135 mm	33%	370 mm	68%
Total recharge	168 mm	41%	43 mm	8%
Capillary rise	–	–	136 mm	25%
Change of the water content of the soil	–49 mm	–12%	–67 mm	–12%

4 DISCUSSION AND CONCLUSIONS

We measured open air precipitation by using Hellmann rain-gauge units in five sample areas (in Balástya, Bócsa, Bugac, Kunadacs and Pusztaszer). A groundwater level measuring system was applied in five sites in Bócsa and in Pusztaszer. In Bócsa, we operated a weather station in one sample area, and we used an automatic moisture measuring system in three sample areas. If this measuring system was developed further, it could be connected to other systems such as the Forest Research Institute and could be used for long-term research in the future.

Analysing the interception data, we found that the interception values are affected by rainfall, that is, by its quantity, intensity, distribution and physical features. Interception values are also affected by the structure of the forest stands, that is, by the type of tree species, by tree trunk shape and distribution, tree density, and the foliage and the health of the forest stand. The values of the interception measured in the Scots pine forest stand can be regarded as higher than the former results. In the grey poplar stand, the values of interception were lower than the average values, which can be explained by the lower foliage, the poor quality of trunks, and the weak density of the branches as well as the leaks due to the dead trees in the stand. When we compared canopy interception with the published data (Járó 1980: 16%, Gácsi 2000: 19.5%, Sitkey 2004: 25%), our results in the Scots pine stand proved to be a bit above the previously published average.

It is difficult to compare the results with former references (Járó 1980: 24%, Sitkey 2004: 23%) since they refer to stands of different age, source, and growth.

Analysing stemflow values, we found that there is less stemflow in pine forest stands, as pine has thick, absorbent bark. However, the stemflow value was higher in the grey poplar stand since grey poplar has smooth bark, which helps water flow down the trunks. It is not always feasible to compare the results with the results found in literature because of the differences in forest stands and measuring methods. In the case of stemflow, it is also difficult to compare references (Járó 1980, Gácsi 2000, Sitkey 2004) since they contain only interception data regarding stemflow as a negligible quantity.

Groundwater levels typically presented lower values under the examined forest stands throughout our research (Móricz et al. 2012, Gribovszki et al. 2014, Tóth et al. 2014). The grey poplar stand in Bócsa and the black locust stand in Pusztaszer are able to reach and uptake the groundwater from the deeper layers with the help of their root system. The examined Scots pine stand does not affect the groundwater levels as much as the deciduous forest stands do. This statement corresponds to the results by Gácsi 2000; on the other hand, it contradicts to the hypotheses by Major and Neppel (Major – Neppel 1988, Major 1994, 2002)

The difference in the fluctuation of soil moisture between the grasslands and the forest stands is obvious in Bócsa and in Pusztaszer. The data collected prove that the examined forest stands uptake more water from deeper layers with the help of their root system (layers which cannot be reached by herbaceous vegetation). This phenomenon affects deep seepage as well. The herbaceous vegetation influences soil moisture in the upper layers of the soil between 0–50 cm. On the other hand, the values of soil moisture decrease in layers between 75–100 cm as well in the case of deciduous forest stands in the growing season. In the forest stands and in the grasslands, the volumes of soil moisture were similar to the results published by Hagyó in 2009. The fluctuation of the soil moisture values in the two upper layers (0–25 cm, 25–50 cm) in the coniferous stand was similar to the results by Gácsi 2000. In the deeper layers of the ground (50–75 cm, 75–100 cm), the measured soil moisture values are more balanced and display typical trends.

By using the water balance equation, it is clear that the transpiration of both grasslands were much lower (85 mm and 135 mm) than that of the neighbouring forest stands. The value of transpiration was lower (205 mm) in the Scots pine stand, since its root system does not reach the groundwater level. Coniferous stands can only uptake the water from layers infiltrated by rainfall. The value of transpiration was the highest in the grey poplar and black locust forest stands (405 mm and 370 mm) as the trees can uptake the water from the upper and the deeper layers with the help of their expanded root system. The values of the capillary rise were 136 mm in the black locust stand and 230 mm in the grey poplar stand.

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Above-Ground Biomass of Black Locust *(Robinia pseudoacacia* L.*)* Trees and Stands

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Abstract – The increasing demand for forest products, diminishing forest land areas, and general concern about the long-term effects of deforestation have increased the need for multipurpose tree species with rapid growth rates. Consequently, information on renewable energy resources is becoming increasingly crucial, and forest biomass determination is becoming a significant part of forestry. Black locust (*Robinia pseudoacacia* L.) is a fast growing, nitrogen fixing, stress tolerant species with durable and high quality wood that can be used for many purposes including wall panelling; vine props; furniture; pulp and paper; animal feed stock; bee forage; and biomass energy. This article presents the above-ground biomass of black locust, both for individual trees and for stands. Information concerning wet and absolute dry wood for stem, merchantable ($d_{1.3} > 5$ cm) and small ($d_{1.3} < 5$ cm) wood, and for other tree parts (foliage, bark) for individual trees and for black locust stands are detailed in dendromass tables by six yield classes.

black locust / ***Robinia pseudoacacia*** L. / **forest biomass / dendromass**

Kivonat – Akác (Robinia pseudoacacia) fák és faállományok föld feletti biomasszája. Az erdészeti termékek iránti növekvő kereslet, a csökkenő erdőterületek és az erdőirtás hosszú távú hatásai miatti általános aggodalom megnövelte a gyors növekedésű, többcélú fafajok iránti igényt. Tehát a megújítható erdei energiaforrásokra vonatkozó információk egyre fontosabbak, ennélfogva az erdei biomassza meghatározása fontos részévé válik az erdőgazdálkodásnak. Az akác (*Robinia pseudoacacia* L.) egy gyorsan növő, nitrogénmegkötő, stressztűrő faj, mely számos célra alkalmas (lambéria, szőlőkaró, bútor, cellulóz és papír, állati takarmány, méhlegelő és biomassza energia), tartós és jó minőségű faanyaggal rendelkezik. Jelen tanulmány az akác faegyedek és állományok föld feletti biomasszáját mutatja be. Nedves és abszolút száraz törzsre, vastag ($d_{1,3} > 5$ cm) és vékony fára ($d_{1,3} < 5$ cm) és a fák egyéb részeire (levél, kéreg) vonatkozóan, az egyes fák, illetve állományok adatait szemlélteti dendromassza táblázatokban, hat fatermési osztályba sorolva.

fehér akác / ***Robinia pseudoacacia*** **L. / erdei biomassza / dendromassza**

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1 INTRODUCTION

Between 1610 and 1620, black locust (*Robinia pseudoacacia* L.) became the first forest tree species imported to Europe (France) from North America (Bartha 2016). Since then, the species has experienced periodic vicissitudes in terms of interest and enthusiasm for its cultivation and utilization. Over the last twenty years, interest in the species has grown in an increasing number of countries. The reasons for this are as follows: (1) the energy crisis has stimulated research into fast growing, nitrogen-fixing trees such as black locust and has introduced new growing techniques (Short Rotation Forestry) for them; (2) countries such as Hungary, Romania, France, Slovakia, Bulgaria, Korea, and China are vigorously developing the species; (3) from both practical and biological research standpoints, the species has many desirable characteristics (durable wood, easy regeneration); (4) the species is resilient to climate change and air pollution.

Forest biomass (dendromass) is fundamentally different from other forms of biomass such as agricultural biomass. In this paper, we employ the following definitions: *Dendromass:* the total organic production of the trees in forest stands including foliage and volume of stumps and roots (above-ground dendromass lacks the latter components). Forest growing stock, which is the above-ground total volume without leaves in broadleaved stands and with needles in coniferous stands, provides an overwhelming portion of biomass. We use above-ground volume and biomass in this study.

This study aims to provide data on the above-ground biomass of black locust trees and stands.

2 MATERIALS AND METHODS

To investigate the structural distribution of the above-ground biomass of black locust in Hungary, we took detailed measurements of 65 trees of different origins, ages, and diameters ranging from 7 cm to 35 cm, with the average diameter being 18.6 cm. We separated the trees into height and growing space classes. Detailed measurements were taken for data on stem volume, merchantable wood and small wood volume, and other tree parts. Using these data, different biomass components can be accurately determined. The data is summarised in a table containing the following entries:

1. tree number,
2. height class,
3. growing space class,
4. breast height diameter (cm),
5. tree height (m),
6. crown proportion (%),
7. merchantable volume (diameter > 5 cm) (volume over and under bark) (m^3),
8. stem volume (m^3),
9. small (unmerchantable) wood volume (diameter < 5 cm) (m^3),
10. above-ground total volume (7+9) (volume over and under bark) (m^3),
11. bark volume (m^3),
12. raw foliage volume (m^3),
13. green mass of merchantable wood (kg),
14. green mass of unmerchantable wood (kg),
15. green mass of above ground total volume (kg),
16. green mass of the raw foliage (kg),
17. mass of bark (kg),

18. bulk density of the merchantable volume under bark (kg/m^3),
19. bulk density of unmerchantable volume over bark (kg/m^3)
20. bulk density of raw foliage without bark (kg/m^3)

We used stem analysis in 2 m sections to determine merchantable volume. We determined small wood volume by water displacement, and green foliage and mass data with weight measurement. In addition to our data, we utilized the data and research results of Fekete (1937) and Sopp (1974) to determine bark proportion. The green bulk density (green mass divided by volume) of the black locust trees we investigated was

merchantable volume: $\rho_{wetmerch} = 971\ \mathrm{kg/m^3}$,
small wood volume: $\rho_{wetunmerch} = 913\ \mathrm{kg/m^3}$.

Absolute dry bulk density based on laboratory measurements:

merchantable volume: $\rho_{drymerch} = 727\ \mathrm{kg/m^3}$,
unmerchantable volume: $\rho_{dryunmerch} = 700\ \mathrm{kg/m^3}$.

3 RESULTS

There are several approaches to determine foliage biomass. One approach determines the entire crown biomass including branches. Another method determines the biomass of foliage and branch components separately. Using these data, we can develop relationships to estimate raw foliage mass in terms of various tree parameters (breast height diameter, tree height etc.). In this study, we treated foliage as a separate biomass component, and ascertained its mass as a function of breast height diameter. We used the mass data of foliage specified in the materials and methods section. The following linear regression was fitted to the data:

$$m_{wetfoliage} = -2.25130 + 0.68785 \times d_{1,3},$$

where:

$m_{wetfoliage}$ = green foliage biomass,
r^2 = 0.811. In addition to green foliage mass, we calculated the absolute dry mass of foliage.

Green volume, green mass and absolute dry mass of foliage are shown as a function of breast height diameter in *Table 1*. In addition to breast height diameter, foliage weight is also influenced by other factors (crown closure, height class of the tree, genetic factors, etc.). Previous studies also found breast height diameter as the most reliable estimator of foliage mass. In addition to our data, we also used those of Sopp (1974) to estimate bark volume.

We prepared a mass table for black locust *(Table 2)* providing *the mass in green and absolute dry state of single trees* by merchantable and small wood, the foliage mass and total mass in green and absolute dry state. The table is based on the following equations (equation form and independent variables are based on Forress (1969)):

Merchantable volume $v_{merch} = 0.09236 - 0.00076871 \times d_{1.3} + 0.0027454 \times h + 0.00037522 \times d_{1.3}^2 + 0.000024513 \times h \times d_{1.3}^2 - 0.020365 \times \ln(h \times d_{1.3}^2)$
Total volume $v_{total} = 0.066731 + 0.0016704 \times d_{1.3} + 0.001685897 \times h + 0.00038029 \times d_{1.3}^2 + 0.000024291 \times h \times d_{1.3}^2 - 0.016587 \times \ln(h \times d_{1.3}^2)$
Unmerchantable volume $v_{unmerch} = v_{tot} - v_{merch}$
Wet merchantable mass $m_{wetmerch} = v_{merch} \times \rho_{wetmerch}$
Wet unmerchantable mass $m_{wetunmrch} = v_{unmerch} \times \rho_{wetunmerch}$

Wet total mass $m_{wettotal} = m_{wetunmrch} + m_{wetmerch}$
Dry merchantable mass $m_{drymerch} = v_{merch} \times \rho_{drymerch}$
Dry unmerchantable mass $m_{dryunmrch} = v_{unmerch} \times \rho_{dryunmerch}$
Dry total mass $m_{drytotal} = m_{dryunmrch} + m_{drymerch}$
Wet foliage mass $m_{wetfoliage} = -2.25130 + 0.68785 \times d_{1,3}$
Dry foliage mass $m_{dryfoliage} = m_{wetfoliage} \times 0.52874$
Wet total mass $m_{wettotal} = m_{wettotal} + m_{wetfoliage}$
Dry total mass $m_{drytotal} = m_{drytotal} + m_{dryfoliage}$

Table 1. Black locust single tree foliage volume and mass as a function of breast height diameter (DBH)

DBH	Raw green volume of foliage	Mass of foliage		DBH	Raw green volume of foliage	Mass of foliage	
		Raw green	Absol. dry			Raw green	Absol. dry
(cm)	(m^3)	(t)		(cm)	(m^3)	(t)	
4	0.0006	0.0005	0.0001	**23**	0.0192	0.0136	0.0035
5	0.0016	0.0012	0.0003	**24**	0.0261	0.0142	0.0037
6	0.0026	0.0019	0.0005	**25**	0.0211	0.0149	0.0039
7	0.0036	0.0026	0.0007	**26**	0.0221	0.0156	0.0040
8	0.0045	0.0032	0.0008	**27**	0.0231	0.0163	0.0042
9	0.0055	0.0039	0.0010	**28**	0.0241	0.0170	0.0044
10	0.0065	0.0046	0.0012	**29**	0.0251	0.0177	0.0046
11	0.0075	0.0053	0.0014	**30**	0.0261	0.0184	0.0048
12	0.0085	0.0060	0.0016	**31**	0.0270	0.0191	0.0050
13	0.0095	0.0067	0.0017	**32**	0.0279	0.0197	0.0051
14	0.0105	0.0074	0.0019	**33**	0.0289	0.0204	0.0053
15	0.0114	0.0081	0.0021	**34**	0.0299	0.0211	0.0055
16	0.0123	0.0087	0.0023	**35**	0.0309	0.0218	0.0057
17	0.0133	0.0094	0.0025	**36**	0.0319	0.0225	0.0058
18	0.0143	0.0101	0.0026	**37**	0.0329	0.0232	0.0060
19	0.0153	0.0108	0.0028	**38**	0.0339	0.0239	0.0062
20	0.0163	0.0115	0.0030	**39**	0.0348	0.0246	0.0064
21	0.0173	0.0122	0.0032	**40**	0.0358	0.0252	0.0065
22	0.0183	0.0129	0.0033				

Using single tree dendromass data, we analysed the *above-ground dendromass of black locust stands* by using the mass table for the average tree for each entry in the yield table. As a basis, we used the Hungarian black locust yield table by Rédei (1984).

In *Table 3*, we present the volume of black locust by small wood volume and merchantable volume; foliage green volume; absolute dry above-ground mass of small wood volume, merchantable and total volume; mass of foliage; and total dendromass for the first three yield classes of the yield table. The ratio of small wood volume and merchantable volume was based on Burján (1976). The figures presented are for the total stand. The values in the table are good estimates of the composition and mass of the above-ground dendromass of black locust stands.

Table 2. *Above-ground mass in wet and absolute dry state of black locust single trees*

$d_{1,3}$ (cm)	h (m)	Volume (m^3)			Mass wet (kg)			Mass dry (kg)			Foliage mass (kg)		Total mass (kg)	
		unmerch.	merch.	total	unmerch.	merch.	total	unmerch.	merch.	total	wet	dry	wet	dry
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
8	6	0.010	0.015	0.025	9.352	14.493	23.845	7.171	10.851	18.021	3.3	0.8	27.097	18.853
8	7	0.010	0.016	0.026	8.904	15.634	24.537	6.826	11.705	18.532	3.3	0.8	27.789	19.364
8	8	0.009	0.018	0.027	8.384	17.182	25.566	6.428	12.865	19.292	3.3	0.8	28.818	20.124
9	7	0.013	0.020	0.033	11.997	19.255	31.253	9.199	14.417	23.615	3.9	1.0	35.192	24.629
9	8	0.013	0.022	0.034	11.474	21.209	32.683	8.797	15.879	24.676	3.9	1.0	36.622	25.690
9	9	0.012	0.024	0.036	10.897	23.473	34.370	8.354	17.575	25.929	3.9	1.0	38.309	26.943
10	8	0.016	0.028	0.044	14.485	26.836	41.321	11.106	20.092	31.198	4.6	1.2	45.948	32.394
10	9	0.015	0.030	0.046	13.903	29.553	43.456	10.660	22.127	32.786	4.6	1.2	48.083	33.982
10	10	0.015	0.033	0.048	13.279	32.515	45.795	10.181	24.345	34.526	4.6	1.2	50.422	35.722
11	8	0.019	0.035	0.054	17.432	33.970	51.402	13.365	25.434	38.799	5.3	1.4	56.717	40.177
11	9	0.018	0.038	0.057	16.847	37.187	54.033	12.916	27.842	40.759	5.3	1.4	59.348	42.137
11	10	0.018	0.042	0.060	16.218	40.649	56.867	12.434	30.435	42.869	5.3	1.4	62.182	44.247
11	11	0.017	0.046	0.063	15.555	44.310	59.865	11.926	33.176	45.102	5.3	1.4	65.180	46.480
12	9	0.022	0.048	0.069	19.738	46.306	66.044	15.133	34.670	49.803	6.0	1.6	72.047	51.363
12	10	0.021	0.052	0.073	19.105	50.316	69.421	14.648	37.672	52.320	6.0	1.6	75.424	53.880
12	11	0.020	0.056	0.076	18.437	54.525	72.962	14.136	40.823	54.959	6.0	1.6	78.965	56.519
12	12	0.019	0.061	0.080	17.741	58.897	76.638	13.602	44.097	57.699	6.0	1.6	82.641	59.259
13	10	0.024	0.063	0.087	21.949	61.463	83.412	16.828	46.018	62.847	6.7	1.7	90.103	64.589
13	11	0.023	0.068	0.092	21.276	66.267	87.543	16.313	49.615	65.927	6.7	1.7	94.234	67.669
13	12	0.023	0.073	0.096	20.575	71.234	91.809	15.775	53.334	69.109	6.7	1.7	98.500	70.851
13	13	0.022	0.079	0.100	19.849	76.340	96.189	15.218	57.157	72.375	6.7	1.7	102.880	74.117
14	11	0.026	0.082	0.108	24.079	79.496	103.575	18.462	59.519	77.981	7.4	1.9	110.953	79.905
14	12	0.026	0.088	0.113	23.372	85.106	108.478	17.919	63.720	81.640	7.4	1.9	115.857	83.564
14	13	0.025	0.094	0.118	22.641	90.854	113.495	17.359	68.024	85.383	7.4	1.9	120.874	87.307
14	14	0.024	0.100	0.124	21.890	96.720	118.610	16.783	72.415	89.198	7.4	1.9	125.988	91.122
15	12	0.029	0.103	0.132	26.139	100.480	126.619	20.041	75.231	95.271	8.1	2.1	134.685	97.377
15	13	0.028	0.110	0.138	25.402	106.919	132.320	19.476	80.051	99.527	8.1	2.1	140.387	101.633
15	14	0.027	0.117	0.144	24.644	113.474	138.119	18.895	84.960	103.855	8.1	2.1	146.185	105.961

Table 2 continued

$d_{1,3}$ (cm)	h (m)	Volume (m^3)			Mass wet (kg)			Mass dry (kg)			Foliage mass (kg)		Total mass (kg)	
		unmerch.	merch.	total	unmerch.	merch.	total	unmerch.	merch.	total	wet	dry	wet	dry
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
16	12	0.032	0.121	0.152	28.879	117.330	146.209	22.142	87.847	109.988	8.8	2.3	154.963	112.250
16	13	0.031	0.128	0.159	28.136	124.507	152.642	21.572	93.220	114.791	8.8	2.3	161.397	117.053
16	14	0.030	0.136	0.166	27.372	131.800	159.172	20.986	98.681	119.667	8.8	2.3	167.927	121.929
16	15	0.029	0.143	0.172	26.591	139.195	165.786	20.387	104.217	124.604	8.8	2.3	174.540	126.866
17	13	0.034	0.148	0.182	30.847	143.597	174.444	23.650	107.513	131.163	9.4	2.4	183.886	133.607
17	14	0.033	0.156	0.189	30.076	151.676	181.752	23.060	113.562	136.621	9.4	2.4	191.195	139.065
17	15	0.032	0.165	0.197	29.289	159.856	189.145	22.456	119.686	142.142	9.4	2.4	198.587	144.586
18	14	0.036	0.178	0.214	32.760	173.084	205.844	25.118	129.590	154.708	10.1	2.6	215.974	157.334
18	15	0.035	0.188	0.223	31.965	182.097	214.063	24.508	136.339	160.847	10.1	2.6	224.193	163.473
18	16	0.034	0.197	0.231	31.155	191.199	222.354	23.887	143.153	167.040	10.1	2.6	232.484	169.666
19	14	0.039	0.202	0.241	35.427	196.009	231.436	27.162	146.755	173.916	10.8	2.8	242.254	176.724
19	15	0.038	0.212	0.250	34.624	205.903	240.528	26.546	154.162	180.709	10.8	2.8	251.345	183.517
19	16	0.037	0.222	0.259	33.806	215.886	249.692	25.919	161.636	187.556	10.8	2.8	260.510	190.364
19	17	0.036	0.233	0.269	32.975	225.945	258.920	25.282	169.168	194.450	10.8	2.8	269.738	197.258
20	15	0.041	0.238	0.279	37.267	231.262	268.529	28.573	173.149	201.721	11.5	3.0	280.035	204.711
20	16	0.040	0.249	0.289	36.441	242.172	278.614	27.940	181.317	209.257	11.5	3.0	290.119	212.247
20	17	0.039	0.261	0.300	35.602	253.160	288.762	27.296	189.544	216.840	11.5	3.0	300.268	219.830
20	18	0.038	0.272	0.310	34.751	264.216	298.967	26.644	197.822	224.466	11.5	3.0	310.473	227.456
21	15	0.044	0.266	0.310	39.896	258.162	298.058	30.588	193.289	223.877	12.2	3.2	310.251	227.049
21	16	0.043	0.278	0.321	39.062	270.048	309.110	29.949	202.189	232.137	12.2	3.2	321.304	235.309
21	17	0.042	0.290	0.332	38.214	282.012	320.226	29.299	211.146	240.445	12.2	3.2	332.420	243.617
21	18	0.041	0.303	0.344	37.355	294.044	331.399	28.640	220.155	248.795	12.2	3.2	343.593	251.967
22	16	0.046	0.308	0.354	41.669	299.505	341.174	31.948	224.243	256.191	12.9	3.4	354.055	259.545
22	17	0.045	0.322	0.367	40.813	312.492	353.305	31.292	233.967	265.258	12.9	3.4	366.186	268.612
22	18	0.044	0.335	0.379	39.945	325.547	365.492	30.626	243.741	274.367	12.9	3.4	378.374	277.721
23	16	0.048	0.340	0.389	44.265	330.533	374.798	33.938	247.474	281.413	13.6	3.5	388.368	284.949
23	17	0.048	0.355	0.402	43.400	344.591	387.991	33.275	258.000	291.275	13.6	3.5	401.561	294.811
23	18	0.047	0.369	0.416	42.523	358.718	401.241	32.602	268.577	301.179	13.6	3.5	414.810	304.715
23	19	0.046	0.384	0.430	41.635	372.906	414.541	31.922	279.199	311.121	13.6	3.5	428.110	314.657

Table 2 continued

$d_{1,3}$ (cm)	h (m)	Volume (m^3)			Mass wet (kg)			Mass dry (kg)			Foliage mass (kg)		Total mass (kg)	
		unmerch.	merch.	total	unmerch.	merch.	total	unmerch.	merch.	total	wet	dry	wet	dry
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
24	16	0.051	0.374	0.425	46.851	363.126	409.978	35.921	271.877	307.798	14.3	3.7	424.235	311.490
24	17	0.050	0.390	0.440	45.976	378.303	424.280	35.250	283.241	318.491	14.3	3.7	438.537	322.183
24	18	0.049	0.405	0.455	45.090	393.549	438.639	34.570	294.655	329.225	14.3	3.7	452.896	332.917
24	19	0.048	0.421	0.469	44.192	408.855	453.048	33.882	306.115	339.998	14.3	3.7	467.305	343.690
25	17	0.053	0.426	0.479	48.543	413.622	462.165	37.218	309.684	346.902	14.9	3.9	477.110	350.776
25	18	0.052	0.443	0.495	47.646	430.034	477.681	36.531	321.972	358.503	14.9	3.9	492.625	362.377
25	19	0.051	0.460	0.511	46.739	446.507	493.246	35.835	334.305	370.140	14.9	3.9	508.191	374.014
25	20	0.050	0.477	0.527	45.822	463.035	508.857	35.132	346.680	381.812	14.9	3.9	523.802	385.686
26	18	0.055	0.482	0.537	50.194	468.168	518.362	38.484	350.523	389.007	15.6	4.1	533.995	393.063
26	19	0.054	0.500	0.554	49.277	485.855	535.132	37.781	363.766	401.546	15.6	4.1	550.764	405.602
26	20	0.053	0.519	0.572	48.349	503.597	551.946	37.070	377.049	414.119	15.6	4.1	567.579	418.175
26	21	0.052	0.537	0.589	47.414	521.388	568.801	36.352	390.370	426.722	15.6	4.1	584.434	430.778
27	18	0.058	0.523	0.581	52.734	507.946	560.680	40.431	380.306	420.737	16.3	4.2	577.001	424.975
27	19	0.057	0.543	0.599	51.805	526.895	578.700	39.719	394.493	434.212	16.3	4.2	595.021	438.450
27	20	0.056	0.562	0.618	50.867	545.898	596.765	39.000	408.721	447.721	16.3	4.2	613.086	451.959
27	21	0.055	0.582	0.637	49.921	564.950	614.871	38.275	422.986	461.260	16.3	4.2	631.192	465.498
28	19	0.060	0.587	0.646	54.326	569.622	623.948	41.652	426.483	468.135	17.0	4.4	640.956	472.555
28	20	0.058	0.608	0.666	53.377	589.934	643.311	40.925	441.691	482.616	17.0	4.4	660.320	487.036
28	21	0.057	0.629	0.686	52.420	610.296	662.715	40.190	456.936	497.126	17.0	4.4	679.724	501.546
28	22	0.056	0.650	0.706	51.454	630.702	682.156	39.450	472.215	511.665	17.0	4.4	699.165	516.085
29	19	0.062	0.632	0.695	56.840	614.032	670.872	43.579	459.734	503.313	17.7	4.6	688.569	507.915
29	20	0.061	0.655	0.716	55.879	635.701	691.581	42.843	475.958	518.801	17.7	4.6	709.277	523.403
29	21	0.060	0.677	0.737	54.910	657.420	712.330	42.100	492.219	534.318	17.7	4.6	730.026	538.920
29	22	0.059	0.699	0.759	53.933	679.183	733.116	41.351	508.513	549.864	17.7	4.6	750.813	554.466
30	19	0.065	0.680	0.745	59.347	660.123	719.470	45.502	494.243	539.744	18.4	4.8	737.855	544.528
30	20	0.064	0.704	0.768	58.375	683.197	741.571	44.756	511.518	556.274	18.4	4.8	759.955	561.058
30	21	0.063	0.727	0.790	57.393	706.319	763.713	44.004	528.830	572.834	18.4	4.8	782.097	577.618
30	22	0.062	0.751	0.813	56.404	729.487	785.892	43.245	546.176	589.422	18.4	4.8	804.276	594.206
31	20	0.067	0.754	0.821	60.863	732.417	793.280	46.664	548.370	595.034	19.1	5.0	812.352	600.000
31	21	0.066	0.780	0.845	59.870	756.991	816.861	45.902	566.769	612.671	19.1	5.0	835.933	617.637
31	22	0.064	0.805	0.869	58.868	781.611	840.479	45.135	585.202	630.337	19.1	5.0	859.551	635.303
31	23	0.063	0.830	0.894	57.860	806.272	864.131	44.361	603.666	648.027	19.1	5.0	883.204	652.993

Table 2 continued

$d_{1,3}$ (cm)	h (m)	Volume (m^3)			Mass wet (kg)			Mass dry (kg)			Foliage mass (kg)		Total mass (kg)	
		unmerch.	merch.	total	unmerch.	merch.	total	unmerch.	merch.	total	wet	dry	wet	dry
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
32	20	0.069	0.807	0.876	63.346	783.359	846.704	48.567	586.511	635.078	19.8	5.1	866.464	640.200
32	21	0.068	0.834	0.902	62.340	809.433	871.772	47.796	606.033	653.829	19.8	5.1	891.532	658.951
32	22	0.067	0.861	0.928	61.325	835.552	896.877	47.018	625.588	672.607	19.8	5.1	916.637	677.729
32	23	0.066	0.887	0.953	60.304	861.712	922.016	46.236	645.175	691.410	19.8	5.1	941.776	696.532
33	21	0.071	0.889	0.960	64.803	863.641	928.445	49.685	646.619	696.304	20.4	5.3	948.892	701.608
33	22	0.070	0.918	0.988	63.776	891.308	955.084	48.897	667.333	716.231	20.4	5.3	975.532	721.535
33	23	0.069	0.946	1.015	62.742	919.015	981.757	48.104	688.078	736.182	20.4	5.3	1002.204	741.486
34	21	0.074	0.947	1.021	67.262	919.614	986.876	51.570	688.527	740.097	21.1	5.5	1008.012	745.583
34	22	0.073	0.977	1.050	66.221	948.875	1015.096	50.772	710.435	761.207	21.1	5.5	1036.232	766.693
34	23	0.071	1.007	1.079	65.173	978.177	1043.351	49.968	732.374	782.342	21.1	5.5	1064.486	787.828
34	24	0.070	1.038	1.108	64.119	1007.517	1071.635	49.160	754.340	803.501	21.1	5.5	1092.771	808.987
35	21	0.076	1.007	1.083	69.715	977.350	1047.065	53.451	731.755	785.205	21.8	5.7	1068.888	790.873
35	22	0.075	1.038	1.114	68.660	1008.254	1076.914	52.642	754.892	807.534	21.8	5.7	1098.737	813.202
35	23	0.074	1.070	1.144	67.598	1039.198	1106.796	51.828	778.061	829.888	21.8	5.7	1128.620	835.556
35	24	0.073	1.102	1.175	66.530	1070.179	1136.709	51.009	801.257	852.266	21.8	5.7	1158.533	857.934
36	21	0.079	1.068	1.147	72.163	1036.847	1109.010	55.328	776.300	831.628	22.5	5.9	1131.521	837.478
36	22	0.078	1.101	1.179	71.094	1069.440	1140.534	54.508	800.703	855.211	22.5	5.9	1163.045	861.061
36	23	0.077	1.135	1.212	70.018	1102.074	1172.092	53.683	825.137	878.820	22.5	5.9	1194.603	884.670
36	24	0.076	1.169	1.244	68.935	1134.746	1203.681	52.853	849.598	902.451	22.5	5.9	1226.192	908.301
37	21	0.082	1.131	1.213	74.607	1098.102	1172.709	57.201	822.163	879.364	23.2	6.0	1195.908	885.396
37	22	0.081	1.166	1.247	73.523	1132.433	1205.956	56.370	847.867	904.237	23.2	6.0	1229.155	910.269
37	23	0.079	1.202	1.281	72.432	1166.804	1239.236	55.534	873.601	929.135	23.2	6.0	1262.436	935.167
37	24	0.078	1.237	1.315	71.335	1201.214	1272.548	54.692	899.364	954.056	23.2	6.0	1295.747	960.088
38	22	0.083	1.233	1.316	75.947	1197.230	1273.178	58.229	896.382	954.610	23.9	6.2	1297.065	960.824
38	23	0.082	1.270	1.352	74.841	1233.387	1308.228	57.381	923.453	980.834	23.9	6.2	1332.115	987.048
38	24	0.081	1.307	1.388	73.728	1269.582	1343.310	56.528	950.552	1007.080	23.9	6.2	1367.197	1013.294
39	22	0.086	1.302	1.387	78.367	1263.832	1342.198	60.084	946.247	1006.331	24.6	6.4	1366.773	1012.727
39	23	0.085	1.341	1.425	77.245	1301.821	1379.066	59.224	974.690	1033.914	24.6	6.4	1403.641	1040.310
39	24	0.083	1.380	1.463	76.117	1339.848	1415.965	58.359	1003.161	1061.521	24.6	6.4	1440.540	1067.917
40	23	0.087	1.413	1.500	79.645	1372.105	1451.749	61.064	1027.312	1088.376	25.3	6.6	1477.012	1094.928
40	24	0.086	1.454	1.540	78.501	1412.012	1490.513	60.187	1057.191	1117.378	25.3	6.6	1515.775	1123.930
40	25	0.085	1.495	1.580	77.351	1451.954	1529.304	59.305	1087.096	1146.401	25.3	6.6	1554.567	1152.953

Table 3. Above-ground volume and dendromass data for black locust stands

Site class	Age	Height	Diameter	Number of stems	Total stand														
					Total	Unmerch.	Merch.	Bark	Foliage	Unmerch.	Merch.	Total	Foliage	Total	Unmerch.	Merch.	Total	Foliage	Total biomass
	years	m	cm		m^3					absoute dry mass (t)					green mass (t)				
I	5	7.2	5.2	4045	45	19.2	25.8	7.2	6.5	28.6	46.5	75.1	3.2	78.3	37.3	62.1	99.4	12.9	112.3
	10	13	9.8	2458	134	39.3	94.7	26.5	16.0	24.6	61.8	86.4	2.9	89.3	32.1	82.6	114.7	11.3	126.0
	15	17.4	14.5	1173	178	34.5	143.5	40.2	13.4	22.6	97.6	120.2	2.5	122.7	29.5	130.3	159.8	9.5	169.3
	20	20.6	18.6	785	226	30.7	195.3	50.8	12.8	19.8	130.6	150.4	2.2	152.6	25.8	174.5	200.3	8.5	208.8
	25	22.9	22.0	606	267	30.2	236.8	61.6	12.8	18.1	147.3	165.4	2.0	167.4	23.6	196.7	220.3	7.8	228.1
	30	24.4	24.9	505	304	28.9	275.1	66.0	13.2	17.7	175.1	192.8	2.0	194.8	23.1	233.8	256.9	7.5	264.4
	35	25.5	27.4	441	333	28.3	304.7	73.1	13.6	16.7	186.8	203.5	1.9	205.4	21.8	249.6	271.4	7.2	278.6
	40	26.3	29.7	398	362	26.8	335.2	80.4	14.2	16.8	218.6	235.4	1.9	237.3	21.9	292.0	313.9	7.3	321.2
II	5	6.4	4.7	4595	39	16.7	22.3	6.2	7.4	32.8	46.1	78.9	3.7	82.6	42.8	61.3	104.1	14.7	118.8
	10	11.6	8.8	2793	113	36.2	76.8	21.5	15.4	23.1	51.0	74.1	2.8	76.9	30.1	68.1	98.2	10.9	109.1
	15	15.5	13.0	1333	149	31.3	117.7	33.0	12.7	19.6	76.6	96.2	2.3	98.5	25.6	102.3	127.9	8.9	136.8
	20	18.4	16.6	893	188	32.7	155.3	40.4	11.9	21.2	104.5	125.7	2.2	127.9	27.6	139.6	167.2	8.4	175.6
	25	20.5	19.7	688	222	27.3	194.7	50.6	11.2	18.1	134.2	152.3	2.1	154.4	23.6	179.2	202.8	7.9	210.7
	30	21.8	22.3	574	252	28.5	223.5	53.6	10.5	17.1	139.5	156.6	1.9	158.5	22.3	186.3	208.6	7.4	216.0
	35	22.8	24.5	502	278	26.4	251.6	60.4	10.6	17.6	174.0	191.6	1.9	193.6	22.9	232.5	255.4	7.5	262.9
	40	23.5	26.6	452	300	25.5	274.5	65.9	10.4	17.1	191.5	208.6	2.0	210.5	22.3	255.8	278.1	7.4	285.5
III	5	5.6	4.2	5295	32	13.7	18.3	5.1	8.5	37.8	53.1	90.9	4.2	95.1	49.3	70.6	119.9	16.9	136.8
	10	10.2	7.7	3225	94	34.3	59.7	16.7	14.5	22.1	40.1	62.2	2.6	64.8	28.9	53.5	82.4	10.3	92.7
	15	13.7	11.5	1539	122	29.0	93.0	26.0	13.1	20.5	68.1	88.6	2.5	91.1	26.7	91.0	117.7	9.2	126.9
	20	16.2	14.7	1031	153	29.7	123.3	32.1	11.8	19.8	85.7	105.5	2.2	107.7	25.9	114.5	140.4	8.4	148.8
	25	18	17.4	795	181	31.5	149.5	38.9	10.6	18.9	93.1	112.0	2.0	114.0	24.6	124.3	148.9	7.5	156.4
	30	19.2	19.7	663	204	25.1	178.9	42.9	10.8	17.5	129.3	146.8	2.0	148.8	22.8	172.7	195.5	7.6	203.1
	35	20.1	21.6	579	225	25.4	199.6	47.9	10.6	17.3	140.7	158.0	1.9	159.9	22.5	187.9	210.4	7.5	217.9
	40	20.7	23.4	522	243	25.8	217.2	52.1	10.0	16.6	145.2	161.8	1.8	163.6	21.6	193.9	215.5	7.1	222.6

Table 3 continued

Site class	Age	Height	Diameter	Number of stems	Total stand														
					Total	Unmerch.	Merch.	Bark	Foliage	Unmerch.	Merch.	Total	Foliage	Total	Unmerch.	Merch.	Total	Foliage	Total biomass
	years	m	cm		m^3					absoute dry mass (t)					green mass (t)				
IV	5	4.8	3.6	6 254	26	11.1	14.9	4.2	10.0	44.7	62.7	107.4	5.0	112.4	58.2	83.4	141.6	20.0	161.6
	10	8.8	6.7	3801	75	29.4	45.6	12.8	13.7	26.9	43.7	70.6	3.0	73.6	35.1	58.3	93.4	12.2	105.6
	15	11.8	9.9	1814	98	28.7	69.3	19.4	11.8	18.2	45.6	63.8	2.2	66.0	23.7	60.9	84.6	8.3	92.9
	20	14	12.7	1215	121	25.4	95.6	24.9	11.5	17.9	69.8	87.7	2.1	89.8	23.3	93.2	116.5	8.1	124.6
	25	15.6	15.1	937	144	27.9	116.1	30.2	10.7	18.0	77.9	95.9	2.0	97.9	23.5	104.1	127.6	7.6	135.2
	30	16.7	17	781	162	28.2	133.8	32.1	10.4	18.5	91.4	109.9	2.0	111.9	24.2	122.1	146.3	7.3	153.6
	35	17.4	18.8	683	177	24.1	152.9	36.7	10.4	17.2	113.7	130.9	1.9	132.8	22.4	151.8	174.2	7.4	181.6
	40	17.9	20.3	615	192	23.6	168.4	40.4	10.0	16.2	120.0	136.2	1.8	138.0	21.1	160.2	181.3	7.1	188.4
V	5	4.1	3	7568	21	9.0	12.0	3.4	12.1	54.0	75.9	129.9	6.1	136.0	70.5	101.0	171.5	24.2	195.7
	10	7.4	5.7	4604	59	25.0	34.0	9.5	12.0	32.9	46.2	79.1	3.7	82.8	42.9	61.4	104.3	14.7	119.0
	15	10	8.4	2198	76	29.8	46.2	12.9	9.9	15.1	27.3	42.4	1.8	44.2	19.7	36.5	56.2	7.0	63.2
	20	11.8	10.7	1472	94	23.2	70.8	18.4	11.0	16.3	51.5	67.8	2.1	69.9	21.2	68.7	89.9	7.8	97.7
	25	13.2	12.7	1135	110	23.1	86.9	22.6	10.8	16.7	65.2	81.9	1.9	83.8	21.8	87.1	108.9	7.6	116.5
	30	14.1	14.4	946	124	24.9	99.1	23.8	9.9	16.2	67.0	83.2	1.9	85.0	21.2	89.5	110.7	7.0	117.7
	35	14.7	15.9	827	136	23.9	112.1	26.9	10.2	17.3	84.2	101.5	1.8	103.4	22.6	112.4	135.0	7.2	142.2
	40	15.1	17.2	745	146	25.4	120.6	28.9	9.9	17.7	87.2	104.9	1.8	106.8	23.1	116.5	139.6	7.0	146.6
VI	5	3.3	2.5	9538	15	6.4	8.6	2.4	15.3	68.1	95.7	163.8	7.6	171.4	88.8	127.2	216.0	30.5	246.5
	10	6	4.6	5796	45	19.2	25.8	7.2	9.3	41.4	58.2	99.6	4.6	104.2	54.0	77.3	131.3	18.5	149.8
	15	8.1	6.9	2767	56	23.9	32.1	9.0	10.0	19.8	27.8	47.6	2.2	49.8	25.8	36.9	62.7	8.9	71.6
	20	9.7	8.8	1 853	69	22.1	46.9	12.2	10.2	15.3	33.8	49.1	1.9	51.0	20.0	45.2	65.2	7.2	72.4
	25	10.7	10.4	1429	80	23.4	56.6	14.7	9.3	14.3	35.9	50.2	1.9	51.9	18.7	48.0	66.7	6.6	73.3
	30	11.5	11.8	1191	90	21.4	68.6	16.5	10.1	15.8	52.7	68.5	1.9	70.4	20.7	70.4	91.1	7.1	98.2
	35	12	13	1041	99	22.7	76.3	18.3	9.9	16.0	56.0	72.0	1.8	73.8	20.8	74.8	95.6	7.0	102.6
	40	12.3	14.1	938	107	23.8	83.2	20.0	9.8	16.4	59.9	76.3	1.8	78.1	21.4	80.1	101.5	6.9	108.4

4 DISCUSSION AND CONCLUSIONS

In many countries and regions there is an increasing need to express the productivity of forests in terms of weight, particularly in plantation forests that are managed for the production of industrial timber. A similar situation arises when trees are planted or natural forests are managed to produce wood energy, since mass rather than volume is a measure to quantify the production of wood for energy.

Biomass data is also important in carbon sequestration and balance studies because biomass tables provide additional data and information that conventional timber volume tables lack.

According to our yield table (Rédei 1984), the total stand volume varies between 80 and 280 m^3/ha in function of yield classes at the age of 30 years, which is the average rotation age for black locust stands in Hungary.

Yield Class I–II black locust stands are treated with a rotation of 35–40 years, and a mean annual increment of total production of 12–14 m^3/ha/yr. can be expected. Yield Class III–IV stands have a rotation of 30 years with an MAI of 8–9 m^3/ha/yr. Finally, the poorest stands (Yield Class V–VI) have a rotation of 20–25 years and an MAI of 4–6 m^3/ha/yr. The growing stock, increment, and health of first generation coppice stands are similar to those in high forests.

A large proportion of high quality saw logs is the aim of final felling in yield class I and II stands. In yield classes III and IV stands, the production of some saw logs with a high proportion of poles and props is the goal. Yield class V–VI stands are expected mainly to yield poles, props, other industrial wood products of smaller dimensions, and fuelwood. Primarily these forests serve a protective function.

Single black locust tree raw green volume of foliage (m^3) ranging from 0.0006 m^3 to 0.0358 m^3 related to the breast height diameter (ranging from 4 to 40 cm) can be seen in *Table 1*. Mass of foliage (raw green) values range from 0.0005 t to 0.0252 t, and the absolute dry mass of foliage values range from 0.0001 t to 0.0065 t.

Weight and volume tables regarding single black locust trees and black locust stands presented in this study are unique and, therefore, fill a knowledge gap that currently exists in the international literature.

Table 4. Volume and dendromass data for black locust stands at the age of 30

Site class	Height	Diameter	Number of stems	Total stand				
					Absolute dry mass		Green mass	
	(m)	(cm)		m^3	(t)	%	(t)	%
I	24.4	24.9	505	304	194.8	100	264.4	100
II	21.8	22.3	574	252	158.5	81.37	216.0	81.69
III	19.2	19.7	663	204	148.8	76.39	203.1	76.82
IV	16.7	17	781	162	111.9	57.44	153.6	58.09
V	14.1	14.4	946	124	85.0	43.63	117.7	44.52
VI	11.5	11.8	1191	90	70.4	36.14	98.2	37.14

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Utilization of Oak (*Quercus petreae* (Matt.) Liebl.) Bark for Anaerobic Digested Biogas Production

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Abstract – Fossil fuel depletion has led to an increasing number of research studies and applications focusing on renewable energy, such as different types of biomass. Lignocellulosic biomass represents an abundant source of biomass suitable for energy production in various forms. The present research investigates the application possibility of pedunculate oak bark (*Quercus petrea* (Matt.) Liebl.) for the production of biogas via anaerobic digestion. This research has significant novelty, as only a few examples on the utilization of tree bark wastes for the production of biogas can be found in the scientific literature. One of the key factors of increasing biogas yield is the efficient hydrolysis of the basic material, which is achieved by different pretreatment methods. In this study, oak bark was pretreated by microwave energy, by extraction, and by the combination of these two methods. The semi-continuous thermophylic anaerobic digestion of untreated oak bark resulted a 76.3 ml/g volatile solid specific methane yield over a 50-day period, which was not significantly lower than methane yield gained from pretreated basic material. Results indicated that oak bark is suitable for the production of biogas even without the application of the investigated pretreatment techniques. As extraction of oak bark does not impair biogas production, the complex biorefinery utilization of oak bark in the form of extraction bark polyphenols and the subsequent anaerobic fermentation of lignocellulosic residue can be accomplished in the future.

lignocelluloses / biorefinery / forestry by-products / renewable energies

Kivonat – A kocsánytalan tölgy (*Quercus petreae* (Matt.) Liebl.) kéreg alkalmazhatósága anaerob úton előállítható biogáz termelés céljára. A fosszilis energiahordozók kimerülése miatt számos alkalmazási terület és kutatás összpontosít a megújuló energiaforrásokra. A lignocellulózok, mint biomassza alapú energiahordozók kutatása releváns téma, mivel nagy mennyiségben állnak rendelkezésre. Ezen kutatás a kocsánytalan tölgy (*Quercus petreae* (Matt.) Liebl.) kéreg alkalmazási lehetőségeit vizsgálja az anaerob úton előállítható biogáz termelés céljára. A kéreg hulladék effajta felhasználásával foglalkozó szakirodalmak száma szegényes. A lignocellulózok esetében kulcs fontosságú eljárás az alapanyag hidrolízise a biogázhozam, ezzel együtt a metánhozam növelése érdekében. A tölgy kéreg alapanyag előkezelése mikrohullámmal, extrakcióval és együttes alkalmazásukkal történt. A kezeletlen tölgy kéreg 50 napos, félfolyamatos, termofil anaerob fermentáció során 76.3 ml/g szerves szárazanyag fajlagos metánhozam érhető el, ami szignifikánsan nem alacsonyabb a kezelthez képest. Az eredmények alapján a tölgy kéreg, alkalmas metán előállításra előkezelési eljárások nélkül is. Mivel a kéreg extrakciója nem rontja a biogáz termelés hatékonyságát, ezért a kéreg melléktermék komplex kémiai hasznosítása, az extrakt anyagok kivonása valamint a visszamaradt lignocellulóz vázanyag anaerob fermentációja által a jövőben lehetséges.

lignocellulózok / biofinomítás / erdészeti melléktermékek / megújuló energia

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1 INTRODUCTION

As industrialization and motorization increased, the world began to depend on fossil fuels, especially petroleum-based fuels (Nigam – Singh 2010). Today, fossil fuels make up 80% of the primary energy consumed in the world (Escober et al. 2009). The burning of fossil fuels causes much environmental damage and adds to global warming (Nigam – Singh 2010, Monlau et al. 2014). In this respect, the development and application of alternative and renewable energy sources – especially the second-generation resources, mainly lignocellulosic biomass – has become a global focus today.

There are many forms of the energetic utilization of lignocellulosic materials including the production of biogas, bioethanol, biodiesel, etc. The present study focuses on the production of biogas by anaerobic digestion. The anaerobic digestion process comprises four steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. During this process, the lignocellulosic biomass is transformed into biogas (Monlau et al. 2014); this has several benefits when compared the biogas produced from other forms of waste materials. A lesser amount of biomass sludge and the minimal odour emission are two main advantages (Smeth et al. 1999) as well as its compliance with many waste strategies (Ward et al. 2008). The energetic balance of the biogas is the most effective among the other biomass-based energy sources as the output (the energy yield from the biomass) and the input (the assigned primary energy) ratio is 28 MJ/MJ (Deublein – Steinhauser 2008).

According to the research of Brown et al. (2012), when comparing the methane yield of the anaerobic fermentation of various lignocellulosic materials, the best results were achieved for corn stover (124 ml/g VS) and wheat straw (139.1 ml/g VS) where VS stands for volatile solid. The exceptional methane yields from wheat straw and corn stover were also confirmed by Liew et al. (2012). These two basic materials are, in fact, the most commonly and successfully used lignocellulosic biomass for anaerobic fermentation to our days.

Lignocellulosic biomass is composed of three structural polymers, namely cellulose, hemicelluloses, and lignin, which are interconnected with each other by primary and secondary chemical bonds (Fengel – Wegener 1984). In order to produce biogas from lignocelluloses, structural polymers (primarily cellulose and hemicelluloses) have to be converted into monomeric sugars (Chandra et al. 2012) to enable efficient fermentation. Accordingly, the biogas production process is divided into three phases: pretreatment of the basic material, anaerobic-hydrolysis/methane production, and post-treatment of the liquid fraction.

The pretreatment of the basic material can improve the hydrolysis of structural polymers and increase the total biogas yield in the case of the lignocelluloses (Hendriks – Zeeman 2009). Pretreatments involve physical (e.g. grinding, heat treatment, microwave treatment), chemical (e.g. weak acidic hydrolysis using dilute HCl, H_2SO_4, CH_3COOH, alkaline hydrolyis by NaOH or $Ca(OH)_2$, solvent extraction, ozonolysis, etc.), combined physical-chemical (steam explosion, fiber explosion using NH_3 or CO_2, cavitation, microwave + chemical treatment) and biological pretreatments (using fungi or enzyme preparations). Through the combined application of different methods, pretreatment efficiency can be increased significantly (Sun – Cheng 2002, Taherzadeh – Karimi 2008).

Patil et al. (2016) reported on the twofold methane yield increase as an effect of combined physical-chemical pretreatment (alkaline-hydrodynamic cavitation) of wheat straw basic material. Song et al. (2014) investigated the effect of various acidic and alkaline pretreatments of wheat straw on the methane yield. According to their results, yield was improved from 100.6 ml/g VS (from untreated basic material) to 216.7 ml/g VS (optimum pretreated basic material).

As opposed to wheat straw and corn stover, only a few examples can be found in the scientific literature on the application possibilities of woody lignocellulosic wastes and by-products for anaerobic fermentation purposes. These examples involve willow shoots (Horn et al. 2011), pine bark (Salehian – Karimi 2013), and yard trimmings (Zhao et al. 2014).

Wood bark is a large volume by-product generated during the processing of wood logs (Molnár 2004). The most important wood logging species in Hungary are oak, black locust, and poplar, all of which have an especially high bark ratio. Data on logged volumes in Hungary are presented in *Table 1.*

Table 1. Most important wood species in Hungary in terms of logged volume based on data from 2015 (KSH 2015)

Species (group)	**1000 m³**
Oak (*Quercus spp*.)	1756
Black locust (*Robinia pseudoacacia* L.)	1488
Poplar (*Populus spp.)*	1329
Sum	4573

According to *Table 1.*, the species group with the highest logged volume in Hungary is oak (*Quercus spp.*, including pedunculate-, sessile-, and Turkey oak). Bark thickness depends on species, age, and ecological parameters. On average, bark volume is about 5–24% of the total volume the trunk. In the case of oak, it is about 15–25% (Molnár 2004). According to *Table 1.*, about 229,000–1,098,000 m^3 of bark waste are generated annually on average in Hungary from the logging and processing of oak, poplar and black locust. From this amount, oak bark wastes represent 260,000–439,000 m^3 annually.

The present research focuses on the application possibilities of pedunculate oak bark (*Quercus petreae* (Matt.) Liebl., hereinafter: oak) for biogas production purposes. To the best of our knowledge, the use of oak bark material for biogas production has not been investigated yet. Pretreatment of the basic material was done using microwave energy and solvent extraction as well as by the combinaton of these two methods. The key questions of the research focus on whether there is a significant effect of the investigated pretreatment methods on methane yield, and whether oak bark without pretreatment can also be used for anaerobic biogas production. Results were compared with yields obtained from other lignocellulosic materials.

2 MATERIALS AND METHODS

2.1 Sample materials

Oak bark (5–6 kg) was collected from trunks of different trees growing in a mixed oak stand near the village of Harka (Hungary). The bark was processed immediatelly after collection in the following manner: bark was chopped into ~2 cm long pieces using a Scheppach Basato 1 type band saw (Scheppach GmbH, Ichenhausen, Germany) and ground using a Retsch SK3 type hammer mill (Retsch GmbH, Haan, Germany) equipped with a sieve (mesh size < 4 mm). The ground basic material was stored at –18 °C until pretreatment.

2.2 Pretreatment methods

Extraction pretreatment: extraction was performed in order to remove such low molecular weight extractives (mainly polyphenols) that could act as inhibitors during the fermentation process. 100 g bark portions were extracted with 800 ml distilled water for 24 h at room conditions. After extraction, the solution was discarded and the particles were dried at room temperature and stored at –18 °C until use.

Microwave pretreatment: 250 g bark portions were treated with 700 Watt microwave energy in a household microwave oven for 2 x 2 min (Jackowiak et al. 2011, Makk et al. 2013). Treated bark was collected and stored at –18 °C until use.

Combined pretreatment: bark was first microwave-treated then it was extracted with the methods described above. Treated bark was dried at room temperature and stored at –18 °C until use.

The conditions of pretreatments are summarized in *Table 2.*

Table 2. Pretreatment methods and conditions

Sample	Pretreatment	Tag
Control oak bark	–	**C**
Oak bark pretreated with microvave	microwave (700 W, 2x2 min)	**M**
Oak bark pretreated with extraction	extraction (distilled water)	**X**
Combined pretreatment	microwave and extraction	**M–X**

2.3 Biogas production

The production of biogas was carried out in a 2500 ml volume brown bottle with thread neck (Merck KGgaA, Darmstadt, Germany) in a thermophilic (55 °C) environment (Memmert WNB 14 Basic water bath, Memmert GmbH, Schwabach, Germany). Biogas slugde occupied about 1000 ml from the total volume of the bottle. Graft material for the fermentation experiments was obtained from the biogas plant of the Magyar Cukor Zrt., Kaposvár (Hungary) and was specialized to the fermentation of plant biomass. The introduction of the subtrate into the reactor as well as the measurement of the biogas yield was carried out daily. The anaerobic digestion experiments were run for 50 days. Produced gas was collected into Tedlar® bags. Measurement of the gas volumes was carried out using a 500 ml Hamilton syringe (Sigma-Aldrich Kft, Budapest, Hungary).

The composition of the biogas was monitored using an Ecoprobe 5-IR type equipment (RS-Dynamics s.r.o., Prague, Czech Republic) calibrated for CH_4, CO_2 and O_2 compounds. Calibration gas mixture comprised of 60% methane (v/v), 30% CO_2 (v/v) and 10 % O_2 (v/v) and had a purity of 99.995 % (v/v). The proportion of the compounds in biogas samples was indicated in % (v/v).

3 RESULTS AND DISCUSSION

Anaerobic fermentation of untreated oak bark material (labelled with „C" in the following tables and figures) yielded 76.3 ± 2.5 ml methane/g VS based on a 50-day average production. According to Salehian – Karimi (2013), the mesophilic anaerobic digestion of pine bark yielded 33 ml methane/g VS, which could be improved up to 107 ml methane/g VS by the pretreatment of the basic material. Zhao et al. (2014) studied the methane production of yard trimmings pretreated by various methods. The digestion of untreated basic material resulted in a methane yield of 17.6 ml/g VS and topped with 44.6 ml/g VS with the best pretreatment method. Horn et al. (2011) investigated the methane production from willow shoots and the possibilities of physicochemical pretreatments to obtain improved yields. Untreated basic material resulted in 200 ml biogas/g VS, while the digestion of the optimum pretreated material yielded 440 ml biogas/g VS with 52.4–54.3% (v/v) methane contents related to the total volume of the produced biogas. According to the presented data, the methane yield of the anaerobic fermentation of untreated oak bark can be regarded as average, yet it is promising in respect to being a woody lignocellulosic material and an abundant forestry/wood industrial by-product. In the next steps, the effect of pretreatments (physical and chemical) was invesigated to assess if these pretreatments had a positive or negative effect on the overall methane yield.

3.1 Microwave pretreatment

Figure 1. summarizes the results on the fermentation of oak bark material pretreated with microwave radiation.

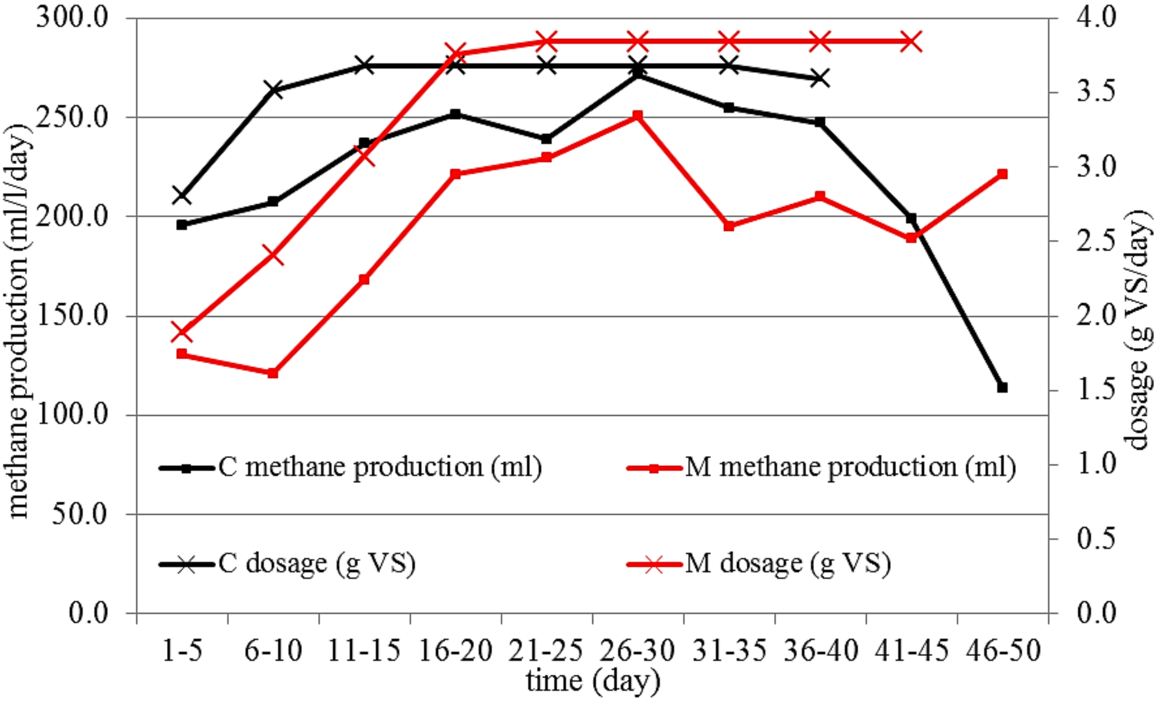

Figure 1. Methane production from oak bark and from oak bark pretreated with microwave energy. The time (day) indicates 5-day averages of methane production and dosage. Substrates: C: untreated oak bark, M: oak bark pretreated with microwave energy.

Figure 1. clearly shows that stopping the introduction of the microwave-pretreated substrate into the reactor (at days 41–45) did not result in an immediate or subsequent decrease of methane yield. Microwave pretreatment dries the basic material significantly, which can result in the accumulation of organic material in the reactor by the thickening of the sludge. Lower water contents hinder fermentation reactions significantly causing lower yields and a delayed response.

Gas yields based on a 50-day average are summarized in *Table 3*. Values for pretreated material (63.8 ± 4.1 ml/g VS) were significantly lower compared to that of the control material (76.3 ± 2.5 ml/g VS). One explanation of the lower methane production using pretreated basic material is the already mentioned thickening effect of the sludge caused by lowering water content in the reactor. The other explanation of the effect is that such cleavage and decomposition products are formed during microwave pretreatment of the basic material, which could have an inhibitory effect on methane production. Yet, investigations to prove this assumption have not been carried out in the present research.

Table 3. Methane production using untreated (C) and microwave pretreated (M) oak bark substrate (50-day averages, n=50)

		C	**M**
Methane production	(ml/l/50 days)	11083.9	9683.1
Σ added dry volatile solid	(g VS)	145.3	151.7
Average methane yield	(ml/g VS)	**76.3 ±2.5**	**63.8 ±4.1**

Results are indicated as average ± 95% confidence interval.

3.2 Extraction pretretment

The aim of the extraction of oak bark basic material was to remove compounds that could have possible inhibitory effects on fermentation and methane production. Extraction was done using distilled water as described in section 2.2. The time course of substrate dosage and of the methane production during the 50-day fermentation process is depicted in *Figure 2*.

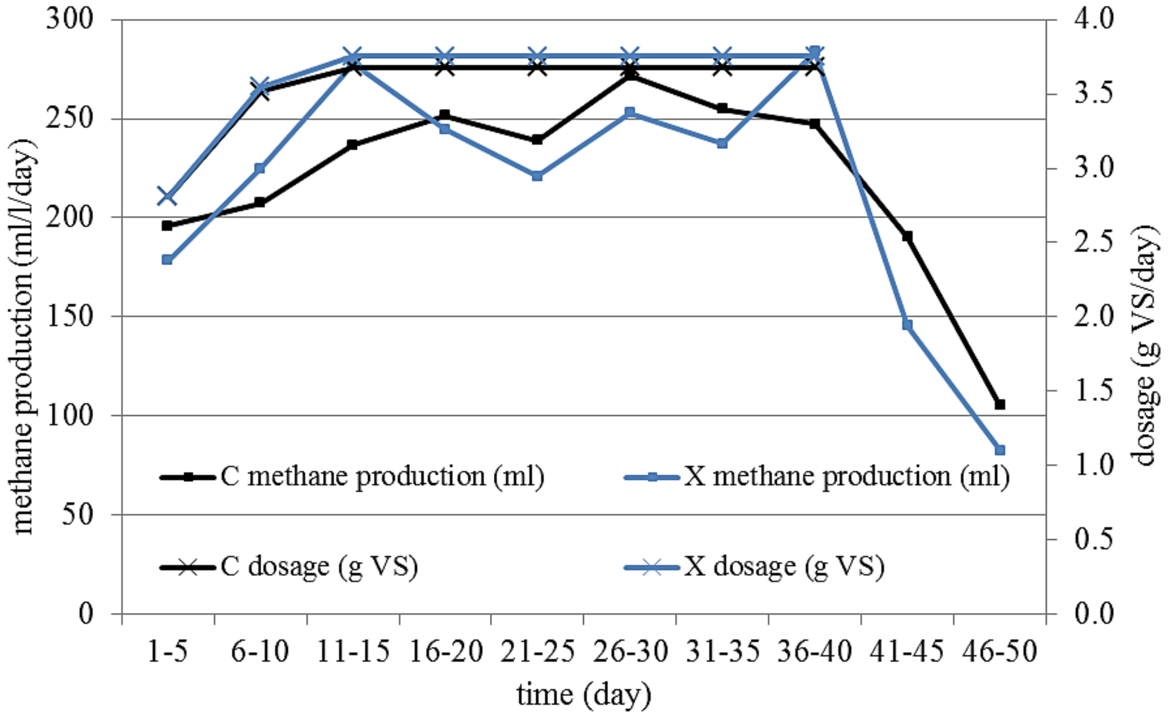

Figure 2. Methane production from oak bark and from oak bark pretreated with extraction The time (day) indicates 5-day averages of methane production and dosage. Substrates: C: untreated oak bark, X: oak bark pretreated with extraction.

According to *Figure 2.*, there is an increase in methane yield by the increase of the substrate. From these results, it was concluded that introduced organic matter was decomposed and accumulation of fermentable subtstrate was not significant, as opposed to microwave-pretreated bark (*Figure 1.*). According to *Table 4.*, the aqueous pretreatment did not result in any significant positive effect on 50-day average methane yield (72.9 ± 5.4 ml/g VS), compared to the yield produced from control substrate (76.3 ± 2.5 ml/g VS). As methane yield did not increase after extraction, it was concluded that there are no compounds present in oak bark basic material, which have an inhibitory effect on the fementation process. As extraction had no significant negative effect on methane yield (the same volume of methane is produced with and without extracting the oak bark basic material), the complex biorefinery utilization and valorization of oak bark as an abundant by-product can be accomplished by extraction (and utilization of extractives) and subsequent anaerobic fermentation of the residual bark to biogas.

Table 4. Methane production using untreated (C) and extraction pretreated (X) oak bark substrate (50-day averages, n=50)

		C	X
Methane production	(ml/l/50 days)	11083.9	10802.9
Σ added dry volatile solid	(g VS)	145.3	148.2
Average methane yield	(ml/g VS)	**76.3 ±2.5**	**72.9 ±5.4**

Results are indicated as average ± 95% confidence interval.

3.3 Combined microwave and extraction pretreatment

According to Taherzadeh – Karimi (2008), the combined pretreatment of lignocellulosic materials with microwave energy and the subsequent extraction results in a significantly improved biogas yield during anaerobic fermentation. The combined pretreatment was done on oak bark basic material and the results of methane production are depicted in *Figure 3.*

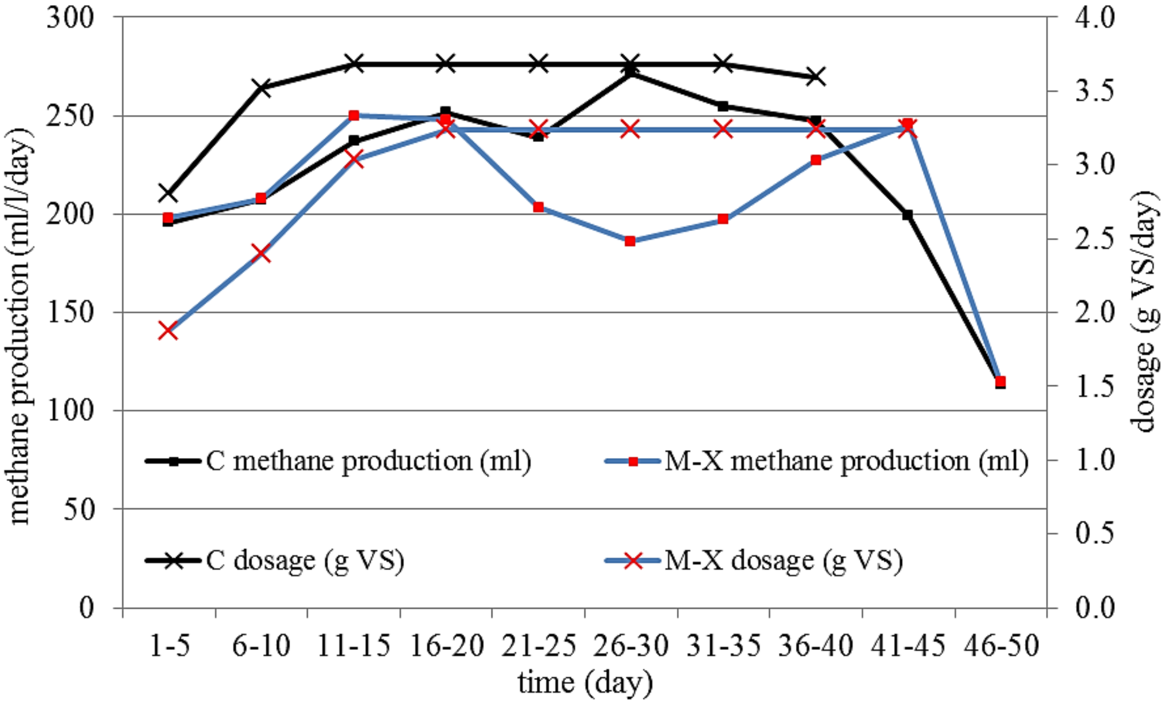

Figure 3. Methane production from oak bark and from oak bark pretreated with microwave energy and subsequent aqueous extraction. The time (day) indicates 5-day-averages of methane production and dosage. Substrates: C: untreated oak bark, M-X: oak bark pretreated with microwave energy and extraction.

According to *Figure 3.*, stopping the feeding of both control and microwave-pretreated substrate into the reactor (at days 36–40 and days 41–45 respectively) resulted in an almost immediate decrease in the methane yield, similarly to extracted basic material (see Section

3.2). Average methane yield did not differ significantly when using treated (77.7 ± 6.9 ml/g VS) and untreated (76.3 ± 2.5 ml/g VS) substrate for the fermentation (*Table 5.*).

Table 5. Methane production using untreated (C) and microwave energy/extraction pretreated (M–X) oak bark substrate (50-day averages, n=50)

		C	**M–X**
Methane production	(ml/l/50 days)	11083.9	10393.0
Σ added dry volatile solid	(g VS)	145.3	133.76
Average methane yield	(ml/g VS)	**76.3 ± 2.5**	**77.7 ± 6.9**

Results are indicated as average ± 95% confidence interval.

According to *Table 5.*, the combined pretreatement of basic material with microwave energy and extraction did not have a significant positive or negative impact on average methane production compared to the control substrate.

The use of microwave energy can not only carry out the pretreatment of basic material, but under certain circumstances (by the simultaneous application of the microwave energy and of the solvent) an efficient and exhaustive extraction can also be carried out (microwave assisted extraction – MAE). In our earlier publications, we have reported on the possibility of MAE of valuable and utilizable polyphenolic compounds from the bark tissues of oak species (Makk et al. 2013).

According to the present results, after the extraction of polyphenolic compounds from oak bark, the remaining bark residue can be utilized for anaerobic digestion to produce methane, without the extraction hampering methane yield. Through this process, the valorization of oak bark by-product by a complex biorefinery utilization in the form of the extraction of polyphenols and subsequent biogas production using the bark residues can be accomplished in the future.

4 CONCLUSIONS

The present article reported on the application possibility of oak bark, as a wood industry by-product, for the production of methane via an anaerobic fermentation process. Selected pretreatment (extraction, microwave irradiation, and the combination of both methods) were applied to the basic material in order to enhance the methane yield in the fermentation process. Only microwave pretreatment was found to effect methane yield negatively, probably due to sludge thickening or inhibitory effects. Extraction as well as combined microwave/extraction pretreatments did not influence methane yield significantly. According to the present results, oak bark can be used for anaerobic biogas production without the use of the investigated pretreatment methods. However, as shown by our earlier findings on the utilization possibilities of oak bark polyphenols extracted by microwave assisted extraction, the complex biorefinery utilization of oak bark can be accomplished in the future by microwave assisted extraction of polyphenols and subsequent biogas production using the remaining extracted bark residues. The presented processes and method could also be adapted to other forest tree species, which have not only an industrial significance as wood, but also contain bark with valuable extractives.

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Hygroscopicity of Longitudinally Compressed Wood

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Abstract – Knowledge of hygroscopicity is extremely important both in the use of native wood and modified wood. In this study, the modification method was steaming at 100 °C, then longitudinal compression at a rate of 20%. The moisture content (*MC*) of treated and untreated green beech wood (*Fagus sylvatica* L.) was reduced in a climate chamber with gradual reduction of air humidity at 20 °C. The difference of calculated fibre saturation points between control samples and samples compressed for a long time was 6% (*MC*%). In the course of desorption, this difference decreased, and finally disappeared at 10% moisture content (40% relative humidity). In the second step of the research work, the speed of vapour adsorption was checked. The absolute dry samples were placed in air with 95% relative humidity. The highest deviation in the moisture content was 1% (*MC*%) between the control and the compressed samples. The compressed wood dries faster than the control samples under the same conditions. Furthermore, during adsorption, the moisture content of the compressed samples at room conditions is lower.

equilibrium moisture content / fibre saturation point / sorption / wood bending / steaming / longitudinal compression

Kivonat – **A rostirányú tömörítés hatása a faanyag higroszkóposságára.** A higroszkóposság ismerete rendkívül fontos a kezeletlen és a modifikált faanyagok alkalmazása esetén egyaránt. A modifikációs eljárás gőzölés volt 100 °C-on, majd hosszirányú tömörítés 20% arányban. Élőnedves kezelt- és kezeletlen bükk faanyagok (*Fagus sylvatica L.*) nedvességtartalmát (*MC*) redukáltuk klímaszekrényben a páratartalom fokozatos csökkentésével 20 °C-on. Az eltérés a kontroll, valamint a hosszú ideig tömörített minták számított rosttelítettségi pontjai között 6% (*MC*%) volt. A deszorpció során ez az eltérés csökkent, majd 10% nedvességtartalomnál eltűnt (40% relatív páratartalom). Második lépésben a párafelvétel sebességét vizsgáltuk, az abszolút száraz mintákat 95% relatív páratartalmú légtérbe helyezve. A nedvességfelvétel során a kontroll és a tömörített minták nedvességtartalma között maximum 1% (*MC*%) eltérés mutatkozott. Az előzőek alapján megállapítható, hogy a tömörített faanyag gyorsabban szárad azonos körülmények között, továbbá a tömörített mintáknak a felhasználási körülmények közötti egyensúlyi nedvességtartalma alacsonyabb, mint a kontroll mintáké.

egyensúlyi nedvességtartalom / rosttelítettségi pont / szorpció / fahajlítás / gőzölés / hosszirányú tömörítés

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1 INTRODUCTION

1.1 Longitudinal compression

The combined thermo-hydro-mechanical compression along the wood grain (also known as longitudinal compression or accordionisation) (Báder – Németh 2017) results in bendable wood. With longitudinal compression, the required bending force and the modulus of elasticity decrease dramatically and provide great flexibility to the wood.

The procedure (like the Thonet-method) requires high quality hardwood material. Before compression, the wood has to be plasticized by steaming. The softening temperature of beech wood is 80 °C (Lenth-Kamke 2001), so the 100 °C saturated steaming of the samples is an appropriate pre-treatment. After compression, the sample can be held compressed for a while, allowing the wood to undergo viscoelastic relaxation. This means the sample is compressed to 20% of its original length, and this compression ratio is kept for a predetermined time. Following the method, the specimen is wet at the beginning, and as long as the moisture content is high, it can be bent more easily. Different sources give different minimal moisture contents as a limit of bendability, ranging from 15% (Vorreiter 1949, Ivánovics 2005) to 25% (Buchter et al. 1993, Szabó 2002, Kamke 2014).

Relaxation further enhances the bending properties of wood. After 1 minute of relaxation, these changes slow but do not cease. Relaxation times can be up to a daylong and this produces very different properties. This means an increment of more than 200% deflection compared to the compressed samples, and this is still without breaking (Báder – Németh 2018). After longitudinal compression and relaxation, the shortening of the samples increases (*Figure 1*).

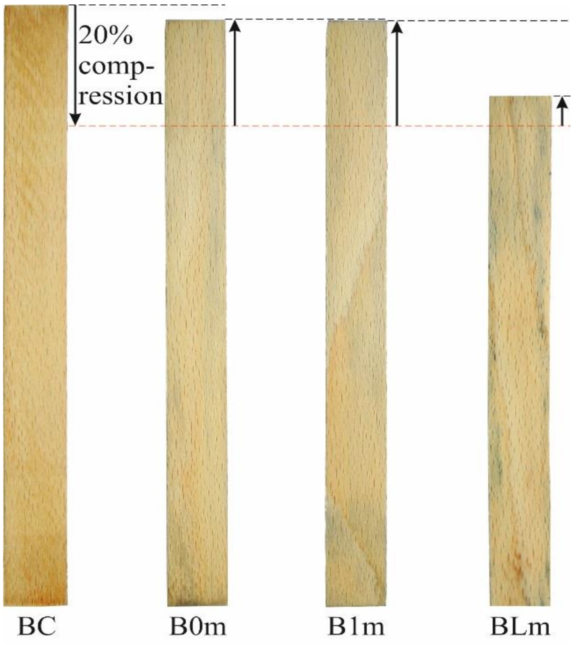

Figure 1. Shortening of samples from different treatments
(Abbreviations: BC: control sample; B0m: longitudinally compressed sample;
B1m: longitudinally compressed sample with 1 minute relaxation;
BLm: longitudinally compressed sample relaxed for a long time)

Wood has a memory-effect. After compression, shortening by a few percentages appears (*Figure* 1), and with the increasing relaxation time, shortening also increases (Báder – Németh 2018). Accordionisation indicates changes in the cell walls and in the cell structure (Báder – Németh 2017), i.e. there is a possibility that hygroscopicity also changes.

1.2 Moisture content

Wood is a hygroscopic material since it can both release water into the air and take it up depending on the circumstances (mostly air temperature and humidity) (Frandsen et al. 2007). The decrease of bonded moisture content is called desorption because water molecules disconnect from the wood tissue; water uptake is referred to as resorption or adsorption. When the moisture content (*MC*) of wood has reached a constant value at a given ambient relative humidity (*RH*) of the air, it called hygroscopic equilibrium condition or equilibrium moisture content (*EMC*). Each wood species has only one moisture content at every temperature and relative humidity combination, but they differ in their de- or adsorption. The curves, depicting the relationship between *EMC* and *RH* at a given temperature, are the sorption isotherms (*Figure 2*).

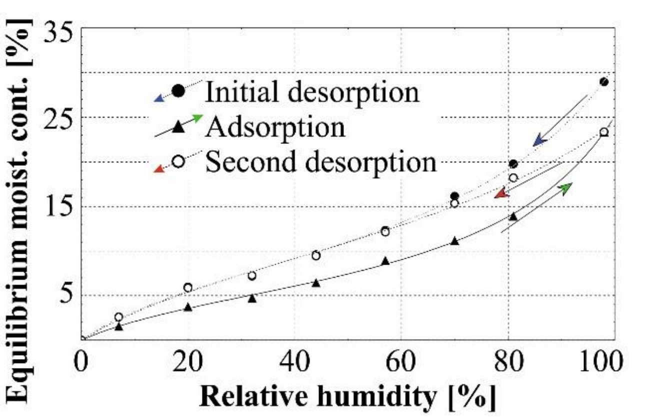

Figure 2. Sorption isotherms of robinia wood (based on Németh 2002)

The *EMC* is generally highest during the initial desorption of green wood (Skaar 1988). Higher initial moisture content results in a higher desorption curve (Németh 2002). The hygroscopicity at humidity above 50% decreases irreversibly after the initial drying of green wood (Skaar 1988). When green wood is dried, moisturized, and dried again, the initial desorption, first adsorption, and second desorption curves do not match. The difference of *MC* between desorption and adsorption curves is called sorption hysteresis (Németh 2002). Many reasons for sorption hysteresis can be found in the literature. For example:

- in the dry state, cavities are absent from the wood cell wall. New and strong bonds form in the intermicellar and interfibrillar voids and pores, between the free OH groups of facing walls. When water enters this system, it forces apart the microfibrils and causes the material to swell but cannot tear all new bonds. Thereby, wood uptakes less water from the air.
- piths are gaps in the cell walls and form canals between the cells. During drying, many piths are closed, thereby slowing and narrowing later moisture uptake.
- the state change of hemicelluloses, where expansion and contraction after volumetric relaxation processes occur are governed by the moisture content-dependent mobility of the hemicelluloses in the wood cell wall (Engelund et al. 2012).
- Sorption isotherms have a typical inverse S-shaped form (Niemz 1993, Khazaei 2008, Niemz-Sonderegger 2017, Shi-Avramidis 2017) as can be seen in *Figure 2*. This means, the curves have a higher slope, and water movement in wood is faster both at low and high RH conditions.

Softening is a weakening of the bonds of hemicelluloses and lignin, so the binding force between cells and between microfibrils decreases. Increasing moisture content decreases the softening temperature of amorphous polymers like lignin and hemicelluloses (Lenth – Kamke 2001). For example, the softening of hemicelluloses occurs at room temperature around 70-75% *RH* (Olsson and Salmén 2003, Engelund et al. 2012). The activity of chemical bonds in lignin has an extremely wide range, which leads to the degradation of lignin in a wide temperature range up to 900 °C. The decomposition range of hemicelluloses also has an upper temperature limit of 900 °C, but the process is carried out more easily (Yang et al. 2007). Wood drying to 0% *MC* is carried out above 100 °C. Treatments in a temperature range above 100 °C result in chemical transformation of the wood components (Horváth 2008, Bak 2012, Fehér et al. 2014). Wood decomposition starts at about 70 °C in wet conditions (Yang et al. 2007, Poletto et al. 2010). Hemicelluloses are the most hygroscopic of the principal cell wall components (Stamm 1964, Lenth – Kamke 2001); hence, their degradation highly affects the sorption properties of wood.

The water content of wood can be divided into two main, physically different parts. Free water is found in the cell lumens, while bound water is in the cell walls. Stamm (1950) refers to free water in wood as capillary water. Berthold et al. (1996) and Thygesen (2010) further divided bound water into non-freezing bound water and freezing bound water. Non-freezing bound water is specifically bound to hydroxyl groups of the three main wood polymers, mainly hemicelluloses. Freezing bound water is indirectly bound to the hydrophilic sites of the wood polymers, so it is more loosely bound in larger water clusters. Based on Niemz (1993) and Niem – Sonderegger (2017), there are three distinct stages of sorption. This is a more detailed description. The first stage of sorption is chemisorption, between 0% and 6% *MC*. Water molecules are linked by H - bridge bonds to adjacent cellulose chains, leading to the formation of a mono-molecular layer. The second stage is adsorption, which occurs between 6% and 15% *MC*. Water molecules are connected by Van der Waals bonds or by electrostatic forces, forming a poly-molecular water layer that is not consistent throughout the whole surface. The fibre-saturation point (*FSP*) is the last sorption period when all intermicellar and interfibrillar cavities (the cell walls) expand and are fully saturated with water, but the cell lumens contain no free water. The range from 15% *MC* to the *FSP* is called capillary condensation. Water vapour is found in the capillaries with a radius of $>5\cdot10^{-10}\ldots10^{-6}$ m, condenses on the surface of the cell wall, and is bound in intermicellar and interfibrillar cavities. As a result of increased moisture adsorption, the fibrils move as far apart as is possible given their relatively strong bonds.

FSP can be reached at 99.5% relative humidity (Engelund et al. 2012), taking into account the anatomy of wood, supposing that the pit holes (capillaries) are a maximum of 0.2 μm (Stamm 1971). For all wood species, *FSP* is accepted as 30% on average (Siau 1984, Niemz 1993), but for individual wood species, we have to consider large variations, e.g. robinia, 19.5%; oak, 24.5%; beech, 35.6% (Molnár et al. 2000). In coloured heartwood species, the heartwood usually has lower *FSP* than the sapwood (Skaar 1988).

Knowledge of wood moisture content and the change of *MC* are important because these provide answers to many questions about the behaviour of wood during later use. With the change of *MC*, there is considerable variation in strength and elasticity characteristics, density, shrinkage and swelling as well as anisotropic properties, surface adsorption, optical properties, resistance to insects and fungi, etc., between the absolute dry state and the fibre-saturation point. Dimensional stability is the most important factor. The properties vary for different tree species and with different treatments. Therefore, it is necessary to observe the moisture properties of the wood species and the differently modified wood. Moreover, we should know the moisture content uptake of longitudinally compressed wood in various humidity conditions. We did not find any scientific literature on this subject. The aim of this study is to introduce the changes in the water uptake of the wood, due to longitudinal compression and relaxation.

2 MATERIAL AND METHODS

2.1 Sample preparation

In the experiments we used 2 beech wood samples per modification type (*Fagus sylvatica* L.), from the forests of the Sopron region in Hungary. As a high-density deciduous wood specie, it is possible to compress it in the longitudinal direction (Báder – Németh 2017). Beech is a diffuse porous wood that can react faster to humidity changes than ring-porous oak wood clogged with tyloses (Niemz – Sonderegger 2017). Each sample came from the same trunk, the heartwood section, and was made to 20×20×200 mm^3 dimensions (radial × tangential × longitudinal directions).

The first step was plasticization by steaming, except of the control samples (*BC*). Steamed, non-compressed controls (*BSC*) were also made to detect the modifying effect of the steaming process. The other samples were exposed to a longitudinally compression treatment after steaming, inducing a 20% shortening from their original length. In the first method, the samples were released immediately after compression (*B0m*). In the other method, a compression force (variable in time) for 20% permanent shortening was maintained to enable relaxation for 18 hours (*BLm*). For the *BLm* treatment, the samples cooled down in a semi-closed chamber, so they did not lose their moisture content.

After the compression-relaxation process, every sample was cut into small sections (ca. 20×20×10 mm^3 R×T×L). In this manner, 30 samples were measured per modification method, and these samples could easily respond to changes of *RH* (*Figure 3*).

Figure 3. Samples of the hygroscopic measurements

2.2 Measurements

The weight measurement method makes it possible to determine the adsorption moisture limit, which is very important from a practical point of view. The moisture content (*MC*, [%]) relative to net dry weight can be calculated using the following, standardized equation (ISO 13061-1 2014):

$$MC = \frac{m_n - m_0}{m_0} \cdot 100$$

where m_n [g] is the mass of the wet wood and m_0 [g] is the mass of the absolute dry wood.

The samples were not measured individually, but rather together per modification type. Thus, we obtained the average values for mass changes and no statistical analysis could be made. However, when measured for weight, the samples were outside the climate chamber for the shortest possible time, so room humidity could only minimally change the instantaneous moisture content of the samples; this improved the accuracy of the measurements. The other advantage of this method is that a more accurate result can be obtained by measuring, with the same precision the total weight of many small samples.

From the first desorption curve, it is possible to estimate the real *FSP*, which is the upper limit of the change of mechanical properties by *MC*. Isotherms are generally taken in a relative humidity range of 0–99%. The increase in the mass of the samples gives the moisture adsorption. The equilibrium moisture value assumed by the extrapolation of the equation to 100% does not give the real *FSP* because the saturation of larger cell wall capillaries occurs at relative humidity close to 100%. Thus, a steep rise of the curve was observed, which is generally underestimated by extrapolation (Németh 2002).

MSZ EN ISO 12571:2013 standard was used as the basis for determining the course of the experiments. To adjust the moisture content by changing the humidity, we used a Binder KBF-115 climate chamber (Binder GmbH., Germany). The temperature was set to a constant 20 °C during the examinations. At this temperature, the range of *RH* is 95% – 16% in this climate chamber. In the first measurement series, the wet samples were climatised in 95% humidity until the first equilibrium moisture content was reached. We measured weight with a Precisa XT 1220M-FR scale (Precisa Instruments AG., Switzerland), which measures grams to 3 decimal places. The humidity levels were 80%, 65%, 25%, and 16%. We always waited for the balance of humidity and *EMC*. It was not necessary to examine humidity levels and *EMC* between 65% and 25% because the rate of *RH* and *MC* is approximately constant, as can be seen in *Figure 2*. Finally, the samples were dried in a Memmert type 100–800 oven (Memmert GmbH., Germany) at 103 °C. In this manner, we obtained the absolute dry mass of the samples.

In the second measurement series the absolute dry samples were again put into the climate chamber and the humidity was set to 95% to measure the speed of the moisture gain. Sample weight was measured every 30 minutes in the first 3 hours. In the subsequent 3 hours, the weight was measured hourly. After that, weight measurements were less frequent as the moisture adsorption slowed down.

3 RESULTS AND DISCUSSION

3.1 Desorption

After the compression-relaxation process at the beginning of the hygroscopicity measurements, the samples had their original green moisture content (*MC*) far above the fibre-saturation point (*FSP*). Steaming decreased the *MC* of the samples (*Figure 4*), which explains the big differences between the non-steamed control (*BC*) and all other samples (*BSC*, *B0m*, *BLm*) at the beginning.

The samples reached their first equilibrium moisture content (*EMC*) at about 40%, at 20 °C and 95% relative humidity (*RH*). Treated samples always reached *EMC* a bit earlier than the control samples.

Fibre-saturation points at 100% *RH* are calculated data with 5th order polynomials, from the previous stages of the curves in *Figure 5*. Steaming decreased the equilibrium moisture content, but there is no difference between *BSC* and *B0m* samples, so compression does not change the *FSP* and *EMC* of the beech samples. However, relaxation for a long time (*BLm* samples) further decreased *EMC*.

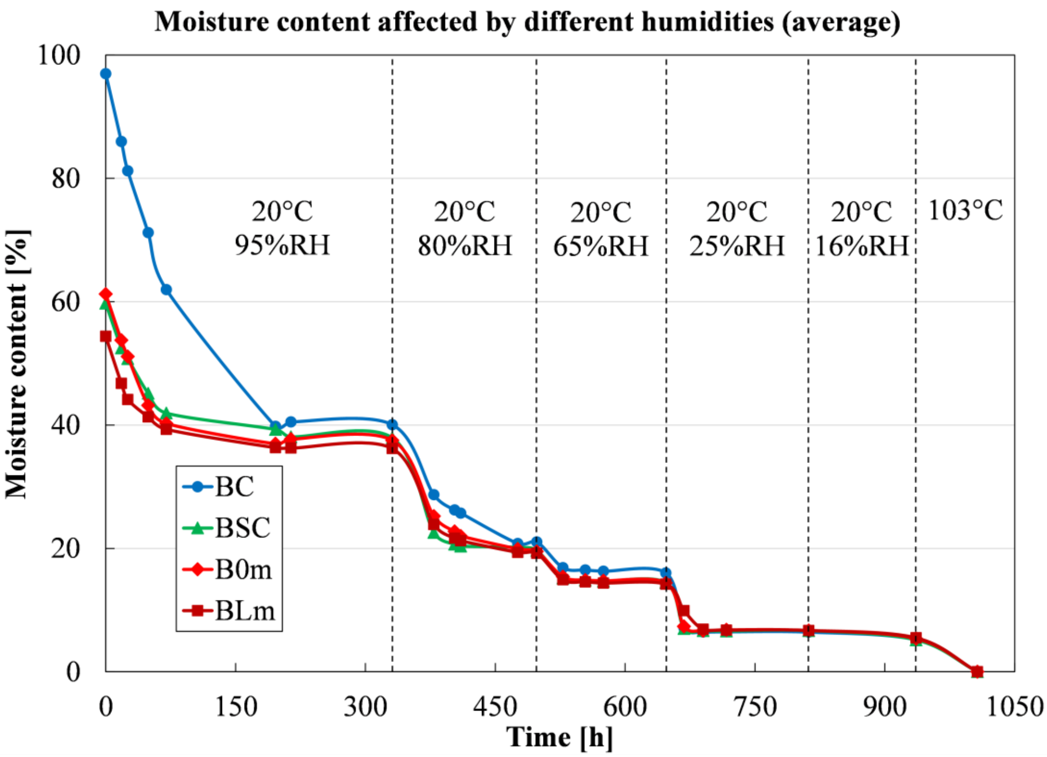

Figure 4. Moisture content of beech wood in different humidities during first desorption (Abbreviations: RH: relative humidity; BC: control sample; BSC: steamed control sample; B0m: longitudinally compressed sample; BLm: longitudinally compressed sample relaxed for a long time)

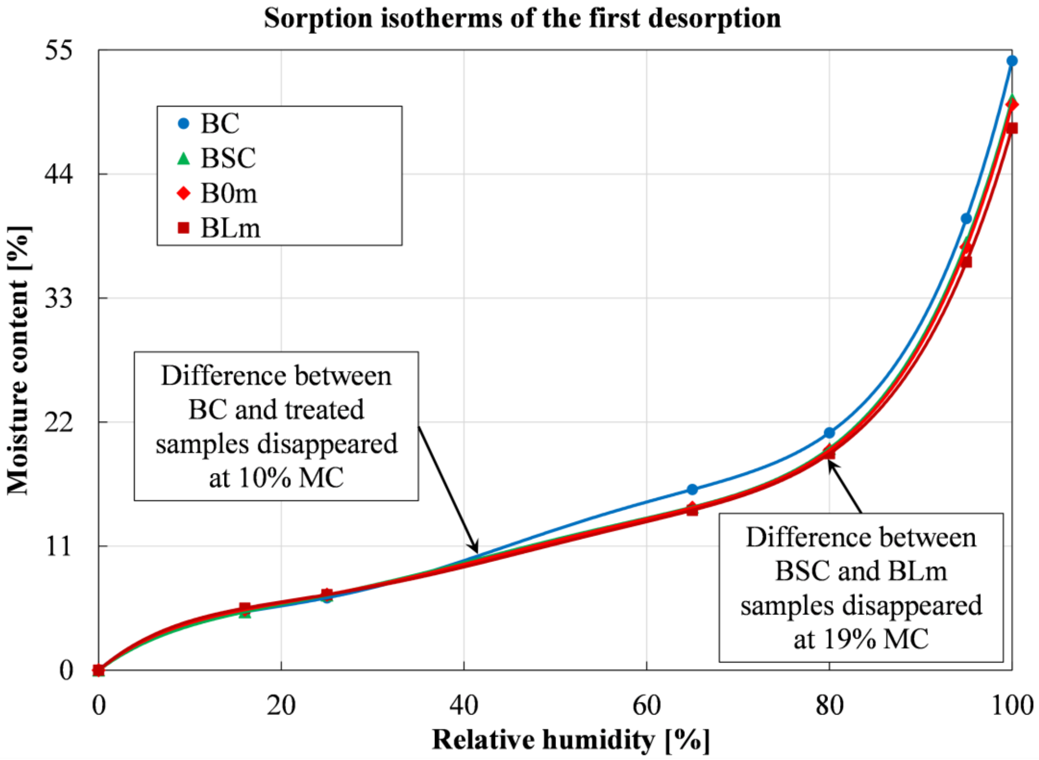

Figure 5. Sorption isotherms of beech wood at the first desorption (Abbreviations: BC: control sample; BSC: steamed control sample; B0m: longitudinally compressed sample; BLm: longitudinally compressed and long-time relaxed sample)

There was a reduction of 3.7% (*MC*%) of *FSP* between *BC* and *BSC*, and a 2.3% (*MC*%) reduction between *BSC* and *BLm* samples, so altogether there was a 6.0% (*MC*%) difference of *FSP* between *BC* and *BLm* samples. The initial large differences gradually decreased, and the difference between *BSC* and *BLm* disappeared at 19% *EMC*, while the difference between *BC* and *BSC* disappeared at 10% *EMC*. From 10% *EMC* until the absolute dry state, all equilibrium moisture contents and the decreasing speed of *MC* were the same.

3.2 Adsorption

In the second phase of the examinations with the same samples, we examined moisture uptake speed. The adsorption was continuous, which proved similar to the above-cited literature, and there were no anomalies. There was no difference of moisture adsorption between the *MC* of compressed (*B0m* and *BLm*) samples. The *MC* of control and steamed control samples started to diverge at about 7% *MC*. The maximum difference was 0.7% (*MC*%) at 12% moisture content. This means steaming increased humidity uptake speed (*Figure 6a*). Using the square root of time in the relationship of time and *MC*, the linear relationship indicates diffusion as the water uptake. In the first 7 hours, the graph of *BC* samples is almost linear, while the treated samples differ more from the straight form.

From the beginning to the end of moisture uptake, compressed samples had a lower *MC* than the control samples. The maximum difference between *BSC* and compressed samples of 1% (*MC*%) was at 12% *MC*. Above 12% *MC* all differences started to decrease, and finally disappeared at about 19% *MC* (*Figure 6b*).

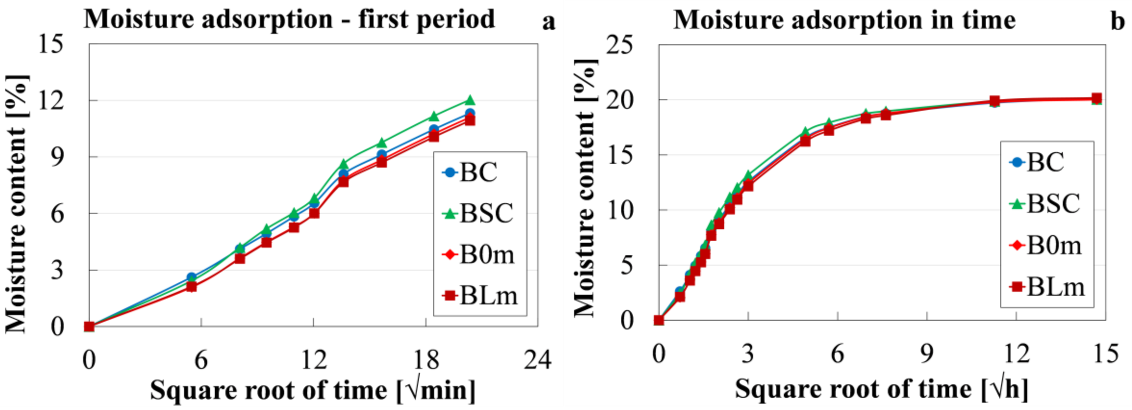

Figure 6. Moisture adsorption of beech wood at 20 °C and 95% RH, the first hours (a) and the whole process (b)

(Abbreviations: BC: control sample; BSC: steamed control sample; B0m: longitudinally compressed sample; BLm: longitudinally compressed sample relaxed for a long time)

At 95% *RH*, the maximum *EMC* was 20% for all samples after about 200 hours, so *FSP* can be estimated to be about 30% because the moisture uptake of wood increases considerably above 95% *RH* (Németh 2002). This corresponds with the *FSP* of beech wood in the literature, considering that the samples were once oven dried at 103 °C because the latter operation decreases the *EMC* of wood. The temperatures used in steaming and drying showed permanent decreases in hygroscopicity associated mostly with the thermal decomposition of the highly hydrophobic hemicelluloses.

4 CONCLUSIONS

Examinations showed the effect of longitudinal wood compression on hygroscopicity. The compression-relaxation process influenced moisture-related behaviour, but there were only small differences.

Due to compression and relaxation, the fibre-saturation point is about 6% (*MC*%) lower at desorption compared to the native wood. However, after adsorption the fibre-saturation point is the same for treated and control beech wood.

Steaming reduced the equilibrium moisture content at the beginning of the desorption by 3.7% (*MC*%). The difference later decreased, while at equilibrium moisture content below 10%, all moisture contents were the same. Compression causes up to 1% (*MC*%) deviation of adsorption between control and compressed samples. Compressing lowers, while steaming increases the speed of the humidity uptake. Under the same circumstance, the moisture content of the longitudinally compressed wood is never higher than the moisture content of the longitudinally compressed wood. This could be due to the partial degradation of hemicelluloses.

Compressed material adapts to new climatic conditions faster at first desorption, so the drying process of treated wood can be performed in less time. The moisture adsorption of compressed wood is slower. This can be considered a positive property because wood in use shrinks and swells less in varied air conditions, making it more stable and more resilient to cracking. This assumption will be the subject of a later study.

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Guide for Authors

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Contents and Abstracts of the Bulletin of Forest Science

Bulletin of Forest Science (Erdészettudományi Közlemények) is a journal supported by the Hungarian Forest Research Institute and by the Faculty of Forestry of the University of West Hungary. The papers are in Hungarian, with English summaries. The recent issue (Vol. 7, 2017) contains the following papers (with page numbers). The full papers can be found and downloaded in *pdf* format from the journal's webpage (www.erdtudkoz.hu).

Vol. 7, Nr. 1, 2017

Tamás MERTL and Endre SCHIBERNA:

Property structure of private forests in Hungary…7–23

Abstract – This paper is based on a database of land lots that are not state owned and are classified as forest in the land registry in Hungary. A description of major parameters of ownership structure can be found in this article such as the area and frequency distribution of land lots over the size of forest area within the land lots and the number of owners of the land lots, as well as the area and frequency distribution of the ownership titles over the size of area of the ownership title and the title deed types. Based on the analysis of the dataset it has been proven that the most important forms of land transactions are purchasing and inheriting, of which the numerical description is also presented. The paper contains an analysis regarding decision making within the land lots, and regarding the inequality of ownership distribution.

Péter CSÉPÁNYI, Erik MAGASSY, Csilla KONTOR, Csilla SZABÓ, Sándor SZENTPÉTERI, Rita NÉMETH, Zoltán NÉMEDY, Szabolcs MÜLLER, Miklós SZABÓ, András KOVÁCS, Gábor SZENTHE, Gábor LIMP, Zoltán OCSOVAI, Ádám BRANDHUBER, Viktor FARKAS and János PETRIK:

Reasons and consequences of ice damage of the forest stands at the Pilis Park Forestry Company…25–41

Abstract – This paper discusses the reasons and consequences of freezing rain of 1st - 3rd December 2014 on the territory of Szentendre, Visegrád, Pilismarót, Pilisszentkereszt Forestry Units of the Pilis Park Forestry Company. During the assessment the answer was looked for which stands are damaged most and which factors contributed principally to the size of the damage. For the analysis, the assessed data of the damaged forest subcompartments and the data of self-measured tree individuals were used. As a result it became clear that uneven-aged structure, containing the thick older trees contributed more to the resistance of the stands against ice, rime and snow damage than mixture ratio of tree species. In even-aged stands tree dimensions are in connection with the size of the damage.

Tivadar BALTAZÁR, Ildikó VARGA and Miloš PEJCHAL:

The possibilities of visual evaluation process of infected trees by european mistletoe (*Viscum album* L.)…43–58

Abstract – The article discusses the process of mistletoe infection rating from visual evaluation to statistical analysis of the collected data. Besides, it also deals with the most common rating systems and possibilities of their usage. Outstanding it describes also those statistical models which are the most suitable not only characterizing of the current state of mistletoe infection intensity. Furthermore, it also allows modeling the future distribution of infection. The research methodology is extremely time-consuming and labor-intensive which may increase by the size of study area. However, its implementation requires only small financial investment. Nevertheless, the exact mistletoe infection evaluation in case of all host individuals is only possible (and recommendable) in parks or other urban green areas, because these potential host species are most endangered due to the urban air contamination and by other damaging factors than trees in forest belt.

Bálint HORVÁTH and András AMBRUS:

Mark-recapture study on the featheres thorn (*Colotis pennaria*), mottled umber (*Erannis defoliaria*) and scarce umber (*Erannis aurantiaria*)…59–67

Abstract – Mark-recapture (MR) study was performed on three forest defoliating Geometrid moth species in the Kőfejtő Forest between Sopron and Kópháza. In total, we marked 1235 specimens; the recapture rate differed between the study species. The highest superpopulation size was estimated for *E. defoliaria*, followed by *E. aurantiaria* and *C. pennaria*. The daily population sizes were also estimated; it shows different swarming dynamic for each species. The movements of recaptured specimens even were investigated. In spite of the weak flying capability, we detected relative long movements for *E. defoliaria* and *E. aurantiaria*. We conclude that MR study show a more precise population size than generally used light trapping. However, we have only a few information about MR study on moth species; it requires further investigations and clarification.

László BALI, Csaba SZINETÁR, Dániel ANDRÉSI, Katalin TUBA and Kristóf KÁLMÁN:

Pitfall trapping arachnological survey in the Educational Forest of Ásotthalom …69–84

Abstract – During our research we surveyed the ground-dwelling spider fauna of the Educational Forest of Ásotthalom by pitfall trapping. The research was conducted from March to October in 2014. We collected data from three different habitats with 2 sampling sites for each: oak forest, pine forest and clearing. Our goals were to assess the ground-dwelling spider assemblages of the habitats, compare their spider fauna, determine their naturalness and examine their basic community-ecological indices. According to our data, species- and specimen number and diversity can separate the three habitats. The originality of the survey area is good, especially the clearings'. The forest and forest-edge inhabiting species were more abundant in the woodlands, while the open and dry conditions preferring species were more frequent in the clearings.

Borbála GÁLOS and Zoltán SOMOGYI:

New climate scenarios – smaller drought risk for European beech?…85–98

Impact assessments and development of adaptation measures in forestry require robust information on long-term climate tendencies. To analyse how climate change scenarios and

the uncertainty of climate models might affect conclusions of forestry impact studies, results of regional climate model ensembles run on representative concentration pathways (RCP4.5 and RCP8.5) and emission scenario (A1B) of the IPCC were used by the end of the 21st century from which temperature-precipitation indices (FAI, EQmod, TIb) were calculated that have been used to define suitable macroclimate and mortality thresholds for extreme droughts for beech for Zala County (SW Hungary).

Our results demonstrate that, in contrast to the robust warming and drying tendency of summers for the A1B scenario, the sign of the changes of precipitation projected by the RCP scenarios is rather unclear, and the simulated precipitation changes have a rather wide range and uncertainty. Despite these, all climate models agree in a significant increase of temperature that leads to more and more arid climate conditions by the end of the century. As a consequence, the macroclimatically suitable areas for beech are expected to disappear from the investigated region even assuming the lowest radiative forcing. Independently from the applied scenario, climate model and drought index, it is likely that more frequent drought periods will occur that are hotter than the most extreme event observed in the last century, so that the drought risks in forestry can be larger than what has ever been observed so far. Our results confirm that despite their uncertainty, climate change projections can already be robust enough to detect potential impacts and to support the development of adaptation measures in forestry.

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Miklós MANNINGER:

Investigation of the variation of precipitation…99–113

Abstract – The issue of the spatial variation of precipitation can be important in case of using non-locally measured data, while the knowledge about the variation in time is necessary for the interpretation of the predicted changes. At least 100-year-long data series were selected and analysed according to different time window (from monthly over the different water cycle periods to hydrological year). The 30 year reference periods used by climatologists were also taken into account.. From the statistical evaluation the results connected with the variation coefficient (CV) are shown primarily. The author stated that the mean of the shorter periods (1-3 months) is not a good parameter (CV>>30%), while the mean for longer period is more reliable. Generally, the CV of the water cycle periods of the 30-year-reference periods decreases as time goes on. It means that the amount of precipitation hasn't become more extreme. Even the variation of water cycle periods is so large that ±20% deviation from mean is still in the interquartile range, thus this kind of change in precipitation cannot be named as extreme.

Zsolt KESERŰ, Imre CSIHA, Csaba KOVÁCS, János RÁSÓ and Károly RÉDEI:

Natural regeneration of red oak (*Quercus rubra*) stands: case studies…115–125

Abstract – In Hungary the red oak (*Quercus rubra*), the most widespread non-native oak has been grown in forests for more than 100 years. Due to its fast growth, high yield and valuable timber material it is the most important exotic tree species besides the hybrid poplars and black locust. The variations of the natural regeneration technologies applicable in red oak stands should be developed according to the main felling methods and the associated natural regeneration possibilities. In the case of red oak stands the application of clear cutting-like regeneration cutting and shelterwood cutting can be recommended for the practice.

Mariann CSEPELÉNYI, Anikó HIRKA, Ágnes SZÉNÁSI, Ágnes MIKÓ, Levente SZŐCS and György CSÓKA:

Rapis area expansion and mass occurrences of the invasive oka lace bug (*Corythuca arcuata* Say 1932) in Hungary…127–134

Abstract – The North American oak lace bug (*Corythucha arcuata*) was first discovered in Europe in Northern Italy (2000). In 2013, it was found in Hungary. In the last five years, particularly in 2016 and 2017, the species showed rapid area expansion. Until autumn 2017, it has been found in all Hungarian counties except five (Borsod-Abaúj-Zemplén, Nógrád; Győr-Moson-Sopron, Vas and Veszprém). Outbreaks were recorded in many pedunculate oak stands in Békés, Csongrád, Jász-Nagykun-Szolnok and Baranya counties, covering ca. 5,000 hectares of forest area in total. Further spread and outbreaks can be expected in the next years. The severe infestation causes mass yel-lowing of the foliage by early and mid-July. Long term consequences of this effect are not yet known. Efficient and environmentally friendly control methods are not known either.

Dénes DOBROSI:

Importance of deadwood and other forest habitat variables for the bats…135–154

Abstract – In 2013, 2014 and 2015 we managed to identify 23 bat species from 82870 audio files recorded at 685 sites in the Alföld and Börzsöny by the ultrasound recording and analysing method we developed ourselves. We prepared a basic habitat evaluation of forests at each site and estimated the amount of deadwood. We were aiming to find a connection between the naturality indicator of the above mentioned forests and the activity of the bats. Through a homogeneity examination we found that the overnight activity of the environmentally significant group of bat species was in positive correlation with the ecological quality of their habitat and the amount of deadwood.