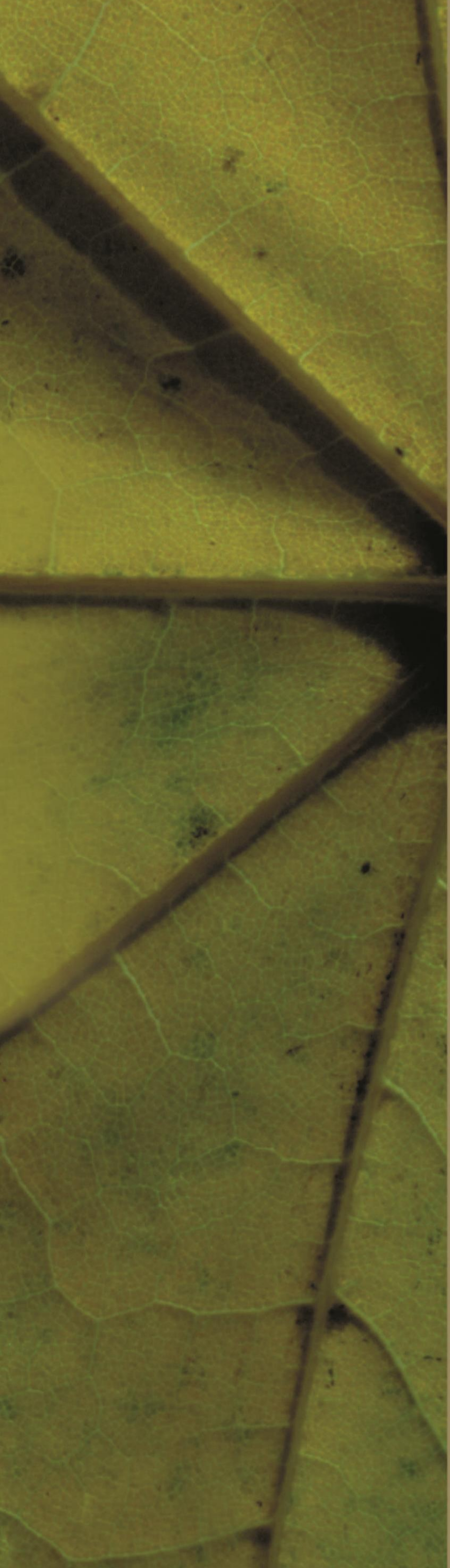

ACTA SILVATICA & LIGNARIA HUNGARICA

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UNIVERSITY OF WEST HUNGARY
PRESS

ACTA SILVATICA ET LIGNARIA HUNGARICA
AN INTERNATIONAL JOURNAL IN FOREST, WOOD AND ENVIRONMENTAL SCIENCES
issued by the Forestry Commission of the Hungarian Academy of Sciences

The journal is financially supported by the
Hungarian Academy of Sciences (HAS),
Faculty of Forestry, University of West Hungary (FF-UWH),
Faculty of Wood Sciences, University of West Hungary (FWS-UWH),
Hungarian Forest Research Institute (HFRI),
Instiute of Wildlife Management, University of West Hungary (IWM-UWH),
Sopron Scientists' Society of the Hungarian Academy of Sciences (SSS).

HU ISSN 1786-691X (Print)
HU ISSN 1787-064X (Online)

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Fax: +36 99 329 911
E-mail: aslh@nyme.hu
Information and electronic edition: http://aslh.nyme.hu

The journal is indexed in the CAB ABSTRACTS database of CAB International; by SCOPUS, Elsevier's Bibliographic Database and by EBSCOhost database

Published by UNIVERSITY OF WEST HUNGARY PRESS,
BAJCSY-ZS. U. 4., H-9400 SOPRON, HUNGARY
Cover design by ANDREA KLAUSZ
Printed by LŐVÉR-PRINT KFT., SOPRON

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10.37045/aslh-2011-0001 *Acta Silv. Lign. Hung., Vol. 7 (2011) 9–22*

Comparison of Simulated Trends of Regional Climate Change in the Carpathian Basin for the 21st Century Using Three Different Emission Scenarios

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Abstract – The present paper discusses the regional climate modeling experiments for the 21st century for the Carpathian Basin using the model PRECIS. The model PRECIS is a hydrostatic regional climate model with 25 km horizontal resolution developed at the UK Met Office, Hadley Centre. Simulated future changes – in mean climatic values, distributions and empirical probabilities – are analyzed for the period 2071–2100 (compared to 1961–1990, as a reference period). Significant warming is projected at 0.05 level for all of the A2, A1B, and B2 scenarios, the largest warming is estimated in summer. Not only the mean value is likely to change, but also the distribution of daily mean temperature. By the end of the century the annual precipitation in the Carpathian Basin is likely to decrease, and the annual distribution of monthly mean precipitation is expected to change. Significant drying is projected in the region in summer, while in winter the precipitation is estimated to increase.

Regional climate modeling / PRECIS / Temperature / Precipitation / Carpathian Basin

Kivonat – Az éghajlat várható alakulása a Kárpát-medencében a XXI. század során három különböző emisszió-szcenárió esetén. E cikk bemutatja a PRECIS regionális klímamodellel a XXI. századra végzett szimulációs futtatásaink eredményét a Kárpát-medence térségére. A PRECIS modell 25 km-es térbeli felbontást alkalmazó, hidrosztatikus regionális éghajlati modell, melyet a Brit Meteorológiai Szolgálat Hadley Központjában fejlesztettek ki. A szimulációk felhasználásával megvizsgáltuk a 2071–2100 időszakra várható éghajlatváltozást (az 1961–1990 referencia-időszakhoz viszonyítva), melyhez a meteorológiai paraméterek átlagértékeit, eloszlását és empirikus valószínűségeket is figyelembe vettünk. A modell 95%-os szinten szignifikáns melegedést prognosztizál Magyarország és a Kárpát-medence egész területére az A2, az A1B és a B2 forgatókönyvek esetén egyaránt. A legnagyobb változás mindhárom esetben nyáron várható. Eredményeink alapján egyértelmű, hogy nemcsak az átlaghőmérséklet növekedésére kell számítanunk, de a hőmérséklet eloszlása is jelentősen módosul a jövőben. Az évszázad végére a Kárpát-medencében éves átlagban a csapadék csökkenése, valamint az év során lehulló csapadékösszeg eloszlásának időbeli átrendeződése valószínűsíthető. A PRECIS szimulációk az ország egész területén szignifikáns szárazodást prognosztizálnak a nyári évszakban mind a három vizsgált szcenárió esetén. Télen viszont a csapadék növekedésére számíthatunk.

Regionális éghajlatmodellezés / PRECIS / hőmérséklet / csapadék / Kárpát-medence

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INTRODUCTION

On the basis of about 20 years' international research in the frame of the Intergovernmental Panel on Climate Change (IPCC), there is no doubt that due to anthropogenic activity the Earth is facing a global warming (IPCC 2007). Global climate models (GCMs) are widely used to estimate the future climate change, however, for regional scale analysis their coarse resolution (typically 150–200 km) limits their applicability in assessment of the regional consequences of global warming. Regional climate models nested in GCMs (Giorgi 1990) may lead to better estimations of future climate conditions in the European subregions as well as in other parts of the world since the horizontal resolution of these RCMs is much finer (around 10–25 km) than the GCMs' (IPCC 2007).

The Carpathian Basin is located in the target regions of several recent EU-projects (e.g., PRUDENCE (http://prudence.dmi.dk, Christensen – Christensen 2007), ENSEMBLES (www.ensembles-eu.org, van der Linden – Mitchell 2009), CECILIA (www.cecilia-eu.org, Halenka 2007), CLAVIER (www.clavier-eu.org, Jacob et al. 2008)) that focused on regional climate change in the 21st century using high-resolution climate model simulations, as well, as on the environmental impacts of projected climate change. In the frame of international cooperative projects, four regional climate models have been successfully adapted and tested for the region, two of them at the Eötvös Loránd University, Budapest: PRECIS (**P**roviding **Re**gional **C**limates for **I**mpact **S**tudies), and RegCM (**Reg**ional **C**limate **M**odel) (Bartholy et al. 2009a). By now after completing several RCM experiments for the Carpathian Basin and its vicinity, it is possible to estimate the future changes in the climatic means and extremes in this region for the 21st century (Torma et al. 2008, Bartholy et al. 2009a,b,c, Pieczka et al. 2010, Krüzselyi et al. 2011). These projections are especially important for planning at the low-elevation retreating limits of the closed forest zone, such as in Hungary (Mátyás 2010).

In the next section of this paper the model PRECIS is introduced, then outputs of the different experiments are used to analyze the simulated temperature and precipitation change by 2071–2100 for Hungary (compared to 1961–1990, as a reference period). Besides the evaluation of mean climate changes, extreme conditions are also discussed. Finally, the main conclusions are summarized in the last section.

1 REGIONAL CLIMATE MODEL PRECIS

PRECIS is a high resolution limited area model with both atmospheric and land surface modules. The model was developed at the Hadley Centre of the UK Met Office (Wilson et al. 2009), and it can be used over any part of the globe (e.g., Hudson – Jones 2002, Rupa Kumar et al. 2006, Taylor et al. 2007, Akhtar et al. 2008). The PRECIS regional climate model is based on the atmospheric component of HadCM3 (Gordon et al. 2000) with substantial modifications to the model physics (Jones et al. 2004). The horizontal resolution of the model can be set up to 25 or 50 km. In our studies, we used the finest possible horizontal resolution. The target region contains 123×96 grid points, with special emphasis on the Carpathian Basin and its Mediterranean vicinity containing 105×49 grid points *(Figure 1)*. In the vertical direction the model contains 19 levels using hybrid coordinates (Simmons – Burridge 1981).

In case of the control period (1961–1990), the initial conditions and the lateral boundary conditions (IC&LBC) for the regional model can be provided by ERA-40 reanalysis (Uppala et al. 2005) or by the HadCM3 ocean-atmosphere coupled GCM. For the validation of the PRECIS simulations CRU TS 1.2 data sets (Mitchell – Jones 2005) and E-OBS data (Haylock et al. 2008) were used. Significance of the bias fields were checked using Welch's t-test (Welch 1938). According to the results, PRECIS is able to sufficiently reconstruct the climate of the reference period (Bartholy et al. 2009b,c). The annual cycle of temperature is well represented, the bias (i.e., difference between simulated and observed annual and seasonal mean temperature) is found to be mostly within the interval (–1 °C; +1 °C). The largest bias values are found in summer, when the average overestimation of PRECIS over Hungary is 2 °C in case of the ERA40-driven, and 2.3–3 °C in case of the GCM-driven simulations. For precipitation a slight overestimation is dominant (only one of the completed experiments showed a small underestimation in summer), the spatial average of the bias is less then 10 mm/month (except spring). The largest precipitation bias can be found in spring which is significant in each gridpoint within the borders of Hungary. The overestimation is around 20 mm/month, which corresponds to a 40–50% relative difference between observation and simulation.

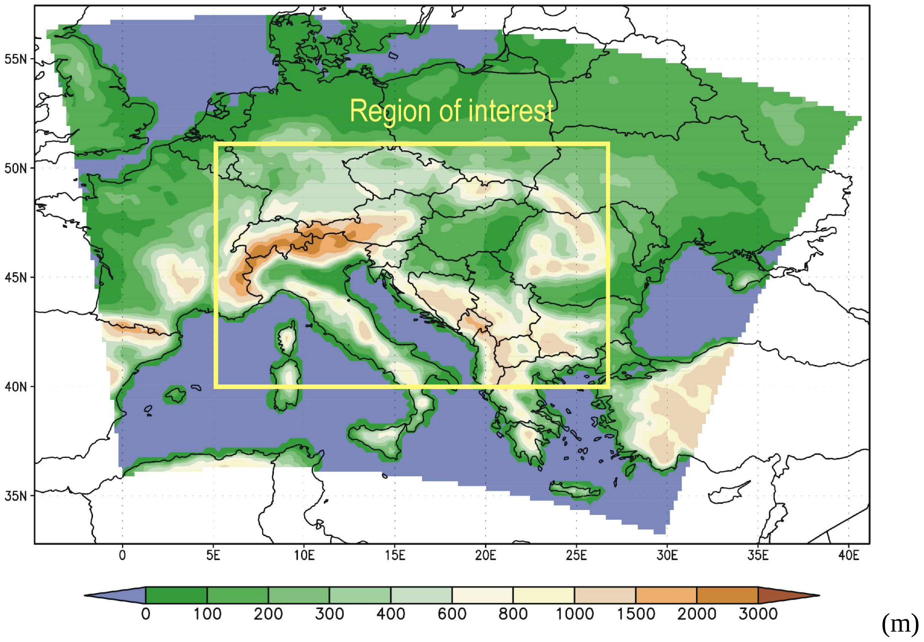

Figure 1. Geographical location and topography of the selected integration domain of model PRECIS

For the future (2071–2100) three experiments were completed, namely, for the A2, A1B, and B2 global emission scenarios (Nakicenovic – Swart 2000). The estimated global mean CO_2 concentration level for the end of the century is 856 ppm, 717 ppm, and 621 ppm, respectively. Thus, A2 can be considered the most pessimistic, and B2 the most optimistic among these scenarios. Our findings for the projected change of temperature and precipitation (compared to 1961–1990) are discussed in the next two sections.

2 SIMULATED TEMPERATURE CHANGE BY 2071–2100

For 2071–2100 A2, A1B, and B2 scenario runs have been completed using the model PRECIS. A2 scenario implies the highest temperature values in the Carpathian Basin (due to the highest estimated CO_2 concentration level). The projected annual mean temperature change for Hungary is between 4.0 °C and 5.4 °C. The projected seasonal mean changes are summarized in *Table 1*. It can be clearly seen that the largest warming is likely to occur in summer (the spatial average of the simulated change is 6.0–8.0 °C). The least warming is projected for spring and winter. The simulated change is significant at 0.05 level for each season and grid point (Pieczka et al. 2010).

Table 1. Projected seasonal mean temperature change (°C) for Hungary by 2071–2100 (reference period: 1961–1990)

	Winter	Spring	Summer	Autumn
B2 scenario	3.2	3.1	6.0	3.9
A1B scenario	4.1	3.7	6.7	5.0
A2 scenario	4.2	4.2	8.0	5.2

The year-to-year variation of seasonal mean temperature for Hungary is presented in *Figure 2*. All the time series highlight the significant warming for each season and for all scenarios. The largest seasonal warming is projected for summer. The mean temperature in autumn is likely to increase more than in spring, thus autumn may become warmer than spring due to the robust warming in late summer/early autumn (Bartholy et al. 2009c). The year-to-year variation in the transition seasons is also likely to increase to up to 1.5–2 times of their current value in case of the A2 and B2 scenarios, however, such a change is not projected for A1B. Standard deviation of winter mean temperature is projected to slightly decrease in case of all scenarios. According to the simulations, the presently quite large standard deviation in summer is likely to slightly decrease for B2, and slightly increase for A1B and A2 scenarios, but no robust change is projected. On the continuous 140-years simulation of A1B the warming trend is obvious for each season, with the highest rate in summer – to visualize this tendency, the fitted linear trends using the least squares method are shown for the entire 1961–2100 period.

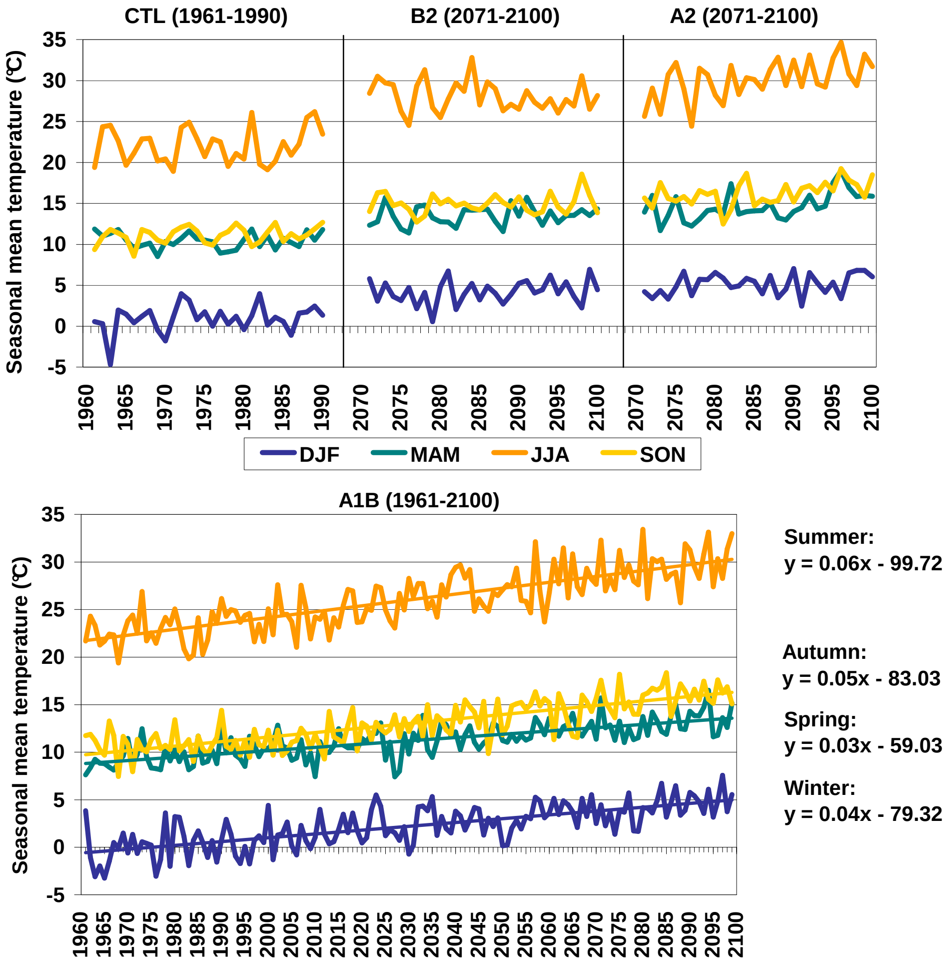

Figure 2. Year-to-year variation of seasonal mean temperature (°C) for Hungary. In case of A1B simulation the fitted linear trends are also shown for 1961–2100

In *Figure 3* Box-Whisker plot diagrams calculated from the simulated values of monthly temperature anomalies for 2071–2100 (relative to the 1961–1990 monthly mean values) in all the gridpoints located within Hungary, are shown for all scenarios. The small rectangles represent the lower and the upper quartiles, and the vertical lines indicate the minimum and the maximum of the sample (the size of the entire sample is 6,870). The lower quartile values are always positive (and in most of the summer and autumn months the minimum values are also above 0 °C), which highlights the projected warming trend. The middle 50% of the sample is represented by the boxes: the larger the size, the larger the variance of the sample. In case of the different scenarios, the total ranges of the middle-half of the monthly anomalies are similar (around 2–5 °C), the largest ranges are projected in the summer months. Negative anomalies compared to the mean of 1961–1990 are likely to occur by 2071–2100 only in a few cases and locations, mainly in the winter months (especially, in December and February).

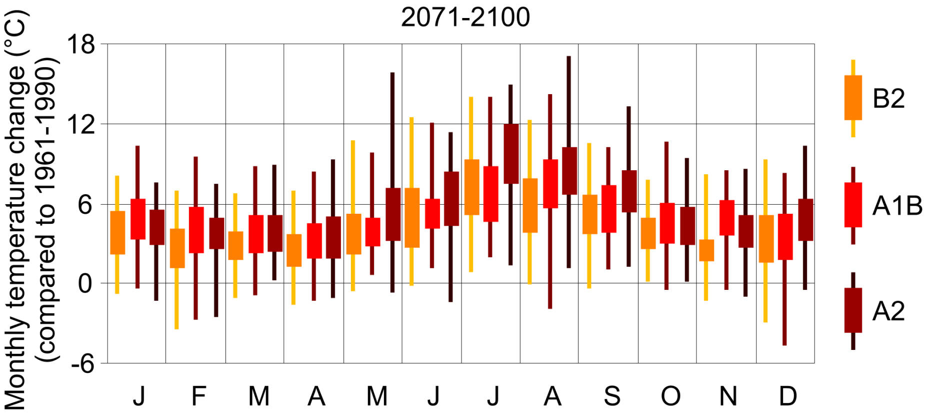

Figure 3. Distribution of projected monthly temperature change (°C) in the gridpoints located within Hungary for 2071–2100 (reference period: 1961–1990)

The distribution change of simulated daily mean temperature is also analyzed. The results for January and July (being the coldest and the warmest months, respectively) can be seen in *Figure 4*.

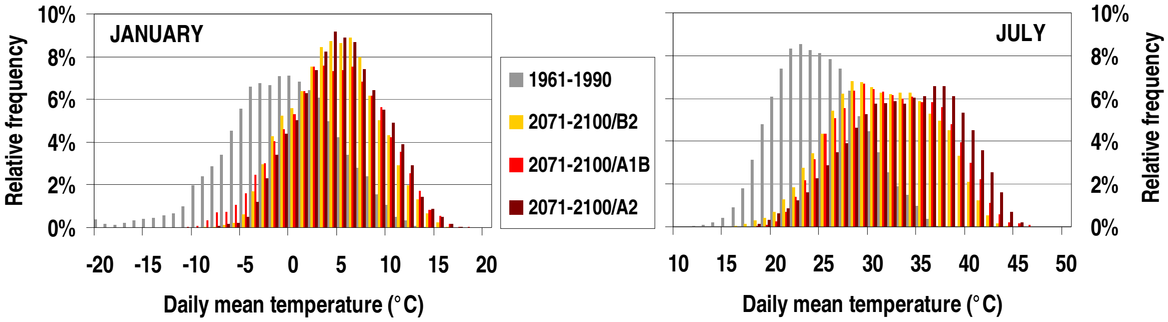

Figure 4. Distribution change of simulated daily mean temperature in January (left panel) and July (right panel)

In January the distribution is projected to shift towards the larger temperature values (the projected monthly mean change is about +5.2 °C, +5.0 °C, and +5.7 °C in case of B2, A1B, and A2 scenario, respectively), which implies less cold and more warm and record warm periods in winter. In July (shown in the right panel) not only a shift, but also a shape-change of the empirical distribution is visible. The relative frequency values of different temperature intervals are likely to change remarkably (the projected monthly mean temperature increase is about +6.3 °C, +7.1 °C, and +8.4 °C in case of B2, A1B, and A2 scenario, respectively). The projected distribution changes for these three scenarios are very similar in the winter months (January is shown in this paper as an example), but differ more in case of the summer months (especially in July and August, from which July is shown in *Figure 4*). Thus, for the summer the simulations imply less cold and more hot periods, and larger record hot conditions than in the reference period. This frequency shift is larger in case of A2 scenario than A1B or B2 scenario.

In order to evaluate the projected distribution change from a spatial aspect, a special method has been developed. The main aim of this method is to quantify the empirical probability of temperature or precipitation anomalies exceeding given thresholds based on the model simulations, and then to compare to the occurrence determined from observational datasets (such as the E-OBS gridded data (Haylock et al. 2008)). The comparison enables the provision of a clear message to the impact modelers on the distribution shift for instance.

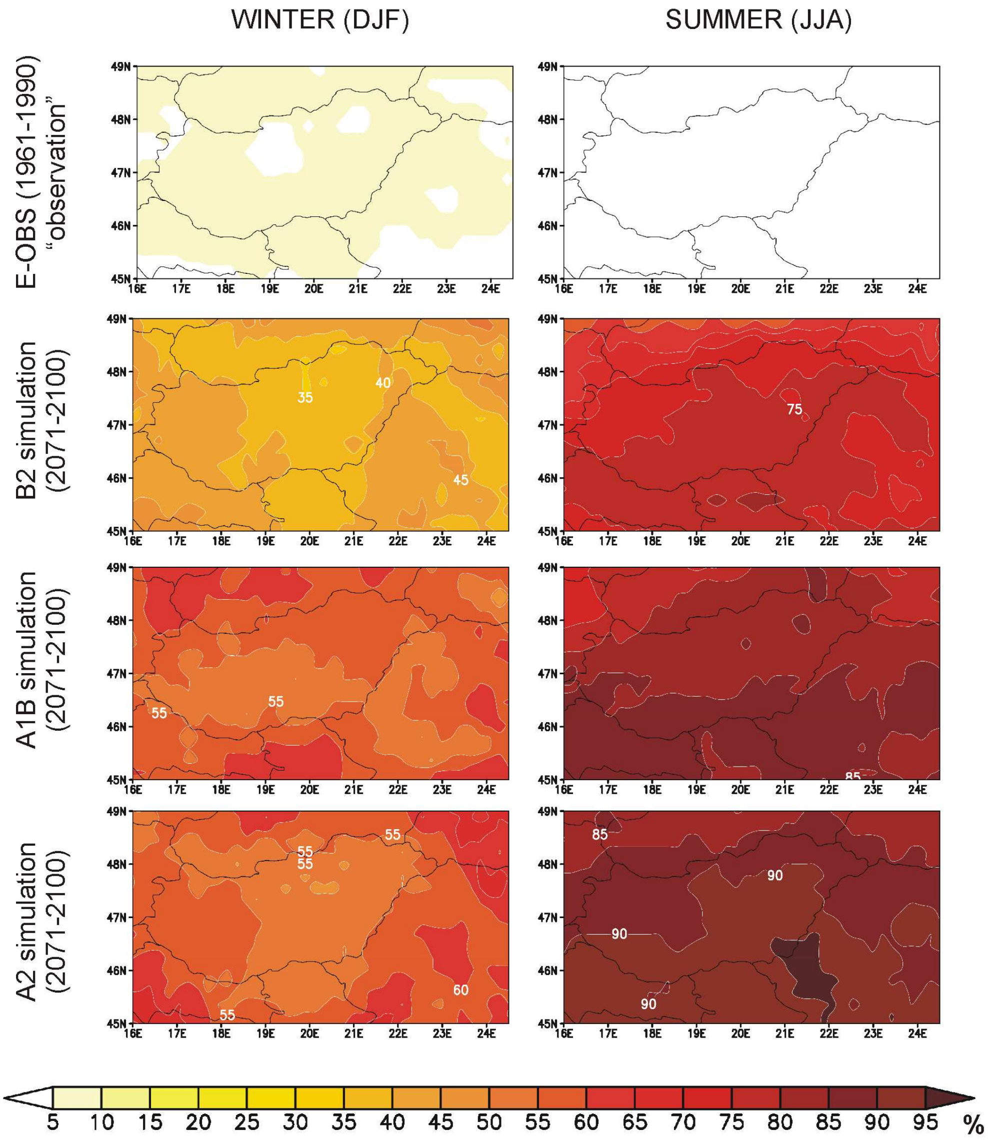

Figure 5. Seasonal empirical probability of monthly temperature anomaly exceeding 4 °C (relative to the 1961–1990 monthly mean values)

Among the various threshold values used during the analysis *Figure 5* shows the empirical probability of temperature anomaly exceeding 4 °C in winter and summer for the reference period (1961–1990) and the target period (2071–2100) for the three scenarios. (PRECIS experiments project at least 4 °C annual warming for Hungary.) For the end-users these maps may provide useful spatial information about the probability of threshold exceedance. In past climatic conditions, monthly temperature anomaly exceeding 4 °C occurred in about 5–10% of all the winter months, and it hardly ever happened in the other seasons (only summer and winter are shown). According to the PRECIS simulations, this is very likely to change in the future: by the end of the 21st century the monthly temperature anomaly (e.g., the difference from the mean of 1961–1990) exceeding 4 °C will become quite frequent (B2: 35–45% in winter, 70–80% in summer; A1B: 50–60% in winter, 80–85% in summer, A2: 50–60% in winter, 85–95% in summer). The largest probability values can be seen in summer. The spatial structure of the empirical probability fields is similar, but the values differ, namely, probability values for A2 are larger than for A1B and B2. In summer a zonal structure can be recognized, with the largest probability values in the eastern/southern part of Hungary.

3 SIMULATED PRECIPITATION CHANGE BY 2071–2100

The model predicts about 20% annual precipitation decrease on average for Hungary by the end of the 21st century in case of A2 and B2 scenarios, but gives practically no change in annual precipitation in case of A1B. However, if seasonal or monthly simulated changes are evaluated, the largest change is projected for summer, namely, significant drying is likely according to the simulations for the whole country (the simulated precipitation decrease is 34%, 43%, and 58% using spatial averages in case of A1B, B2, and A2, respectively). Also, for spring and autumn the projected trend is negative (except for A1B in spring, when it is slightly positive), but it is much smaller than in summer and not significant at 0.05 level. The direction of simulated precipitation change in the transition seasons involves large uncertainties. In winter a slight increase is projected (in spatial average about 14%), which is significant in case of A2 in the Transdanubium, where the simulated winter precipitation change may exceed 30–40% (Pieczka et al. 2010). The A1B experiment projects a larger, significant precipitation increase (34% in spatial average) for the entire country.

Precipitation is highly variable both in space and time. According to the PRECIS simulations the year-to-year variation in Hungary will remarkably change in the future (*Figure 6 and Figure 7*). The results suggest a major annual redistribution of precipitation, a significant decrease in summer precipitation, as well, as in interannual variation of summer precipitation, and increase of the interannual variation in spring and winter. In summer both the seasonal sum and the temporal standard deviation is likely to decrease dramatically, by about 50% in case of A2 and B2 scenarios. The largest decrease of the standard deviation is expected in June, July, and September, in the rest of the year the simulated changes are less pronounced. However, the simulated year-to-year variation increase of monthly precipitation in spring is quite large, especially, in May in case of A2 scenario. The results from the A1B experiment suggest that by the middle of the century the sum and variation of precipitation in summer and winter will be almost equal, and by the end of the century most of the precipitation will fall during winter – but in some years the opposite may happen (*see Figure 6*). Trends in spring and autumn precipitation change are small and not significant.

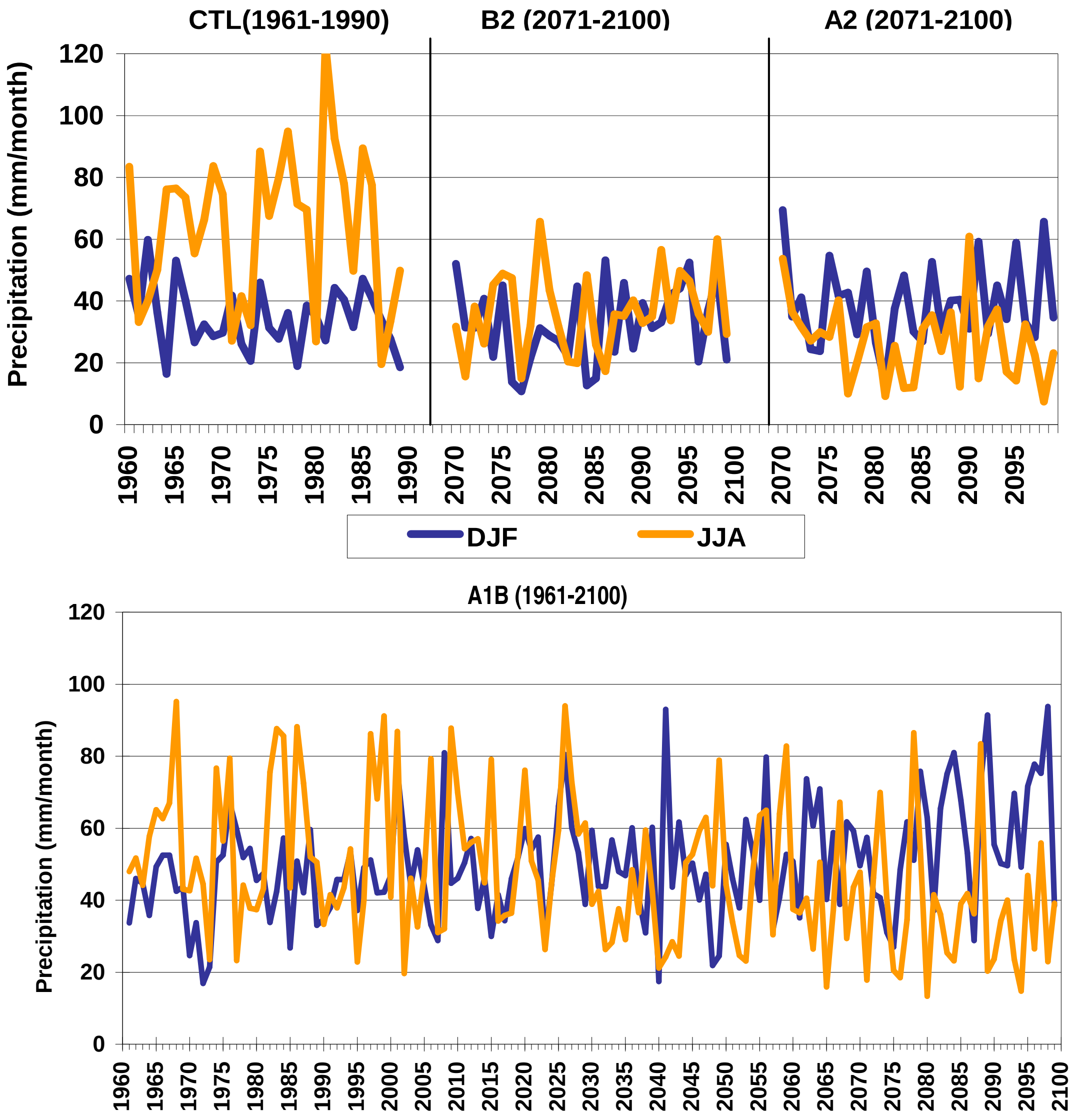

Figure 6. Year-to-year variation of seasonal mean precipitation (mm/month) for Hungary in winter and summer

The projected change in the annual distribution of simulated monthly mean precipitation is shown in *Figure 8*. In the present climate (1961–1990), the wettest months in Hungary are in late spring, early summer (May, June), when the monthly mean precipitation sum exceeds 60 mm. The driest months are January and February with about 30–35 mm total precipitation on average. The PRECIS simulations suggest that in case of all three scenarios, the annual distribution of monthly precipitation is very likely to be restructured in the future. The driest months are projected no longer to occur during winter, but in July and August instead (in case of A2 with less than 20 mm, in case of A1B around 20–25 mm, and in case of B2 with about 25–30 mm on average by 2071–2100). The wettest month of the A2 scenario run is projected to be April with about 65–70 mm precipitation on average, while in case of the B2 and A1B simulations the wettest months are April, May and June with about 60 mm (B2) / over 60 mm (A1B) total precipitation on average.

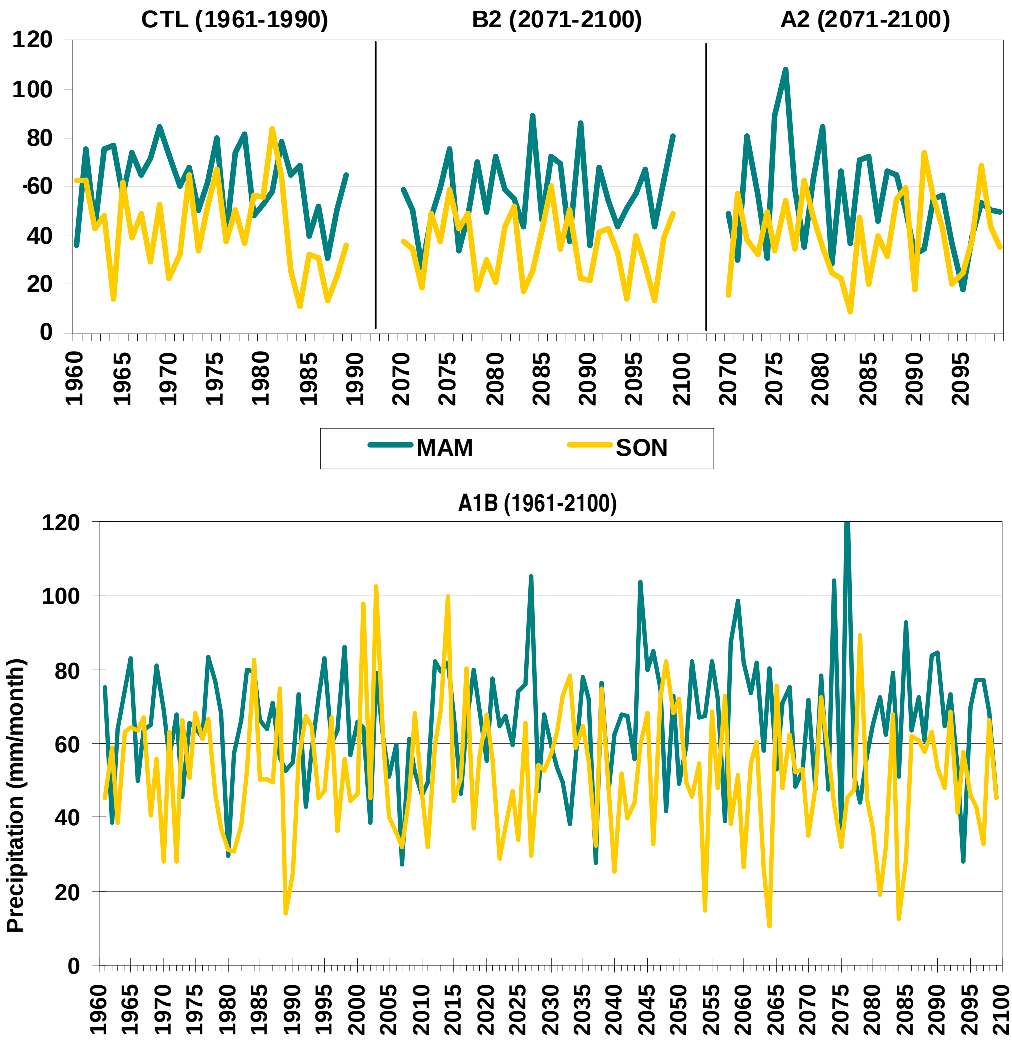

Figure 7. Year-to-year variation of seasonal mean precipitation (mm/month) for Hungary in spring and autumn

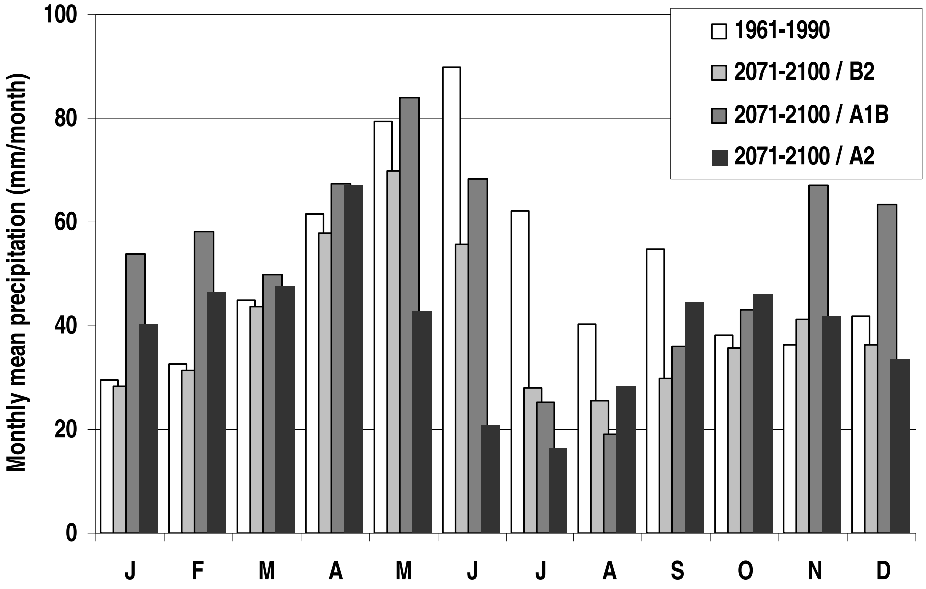

Figure 8. Annual distribution of simulated monthly mean precipitation (mm/month) in the reference period (1961–1990) and in the target period (2071–2100)

Overall, the model PRECIS predicts a drier climate in the Carpathian Basin. The more pronounced changes will probably happen during winter and summer months. In case of the empirical probability analysis threshold values –20% and +20% were selected since two of the presented experiments suggest 20% annual precipitation decrease for Hungary. The empirical probability of negative precipitation anomaly exceeding –20% in past (1961–1990) climatic conditions occurred in about 40–55% of all the autumn months, and 30–40% of all the months in the other three seasons (*Figure 9*). According to the PRECIS simulations, a drying tendency is projected by the end of the 21st century, especially, in the summer months (the occurrence of the monthly precipitation anomaly exceeding –20% increases significantly to 70–80% in case of B2 and A1B, and 80–90% in case of A2 scenarios). In winter a less pronounced frequency increase is expected (B2: to 40–60%, A2: to 30–50%), and in case of A1B even a slight decrease can be seen (to 20–30%).

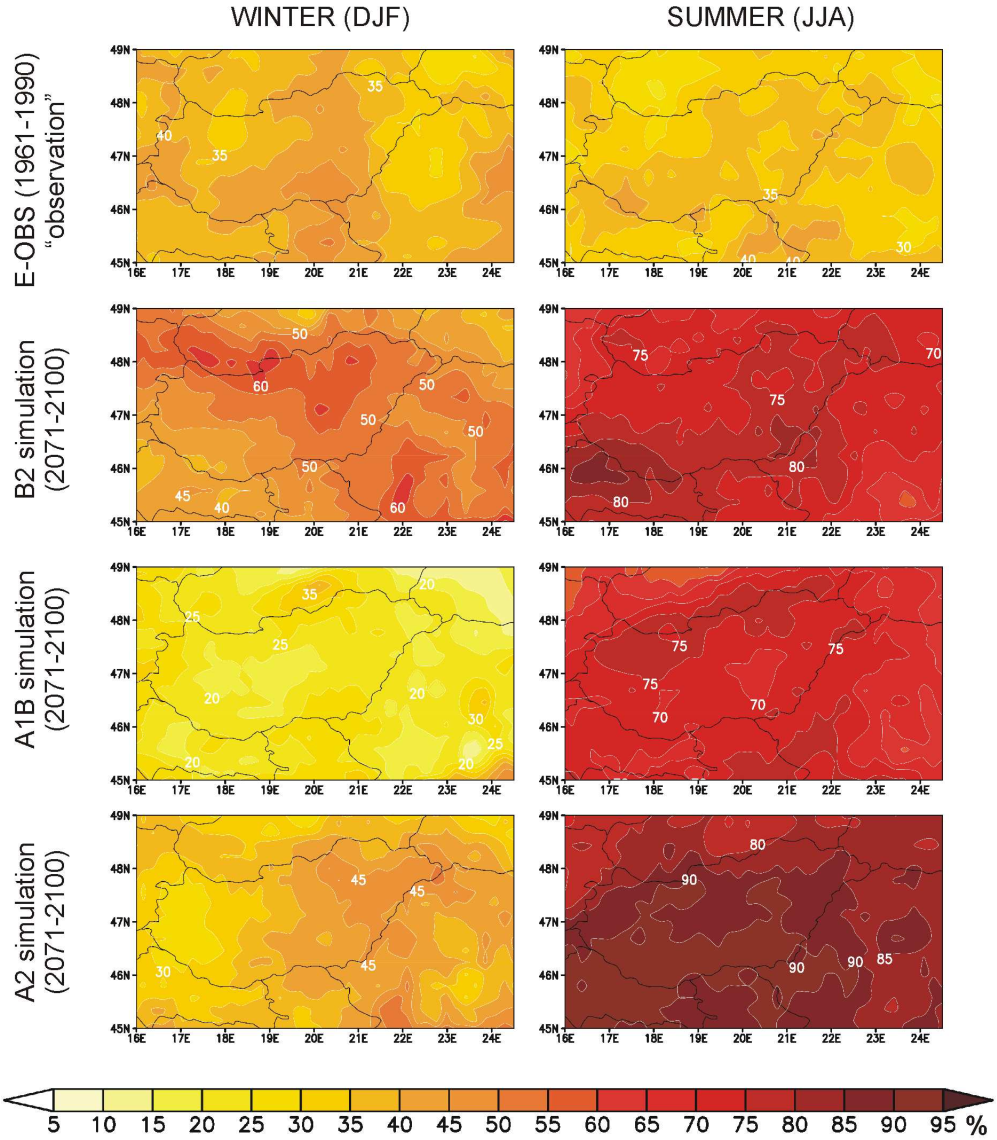

Figure 9. Seasonal empirical probability of monthly precipitation anomaly exceeding –20% (relative to the 1961–1990 monthly mean values)

The empirical probability of positive precipitation anomaly exceeding 20% in the past climatic conditions occurred about 25–35% of all the months throughout the year. A major decrease is projected for the summer months: the probability of wet conditions decreases to 0-20% in case of B2, to 5–15% in case of A1B, and to 0–10% in case of A2 *(Figure 10)*. Based on these maps (*Figures 9* and *10*) it can be clearly seen that in case of the A2 scenario the amplitude of the summer changes are likely to be larger than in case of B2 or A1B. For winter the changes are less pronounced for B2, but for A2 a major increase is projected in the Transdanubium (from 25–35% to 45–55%) and for A1B scenario for the entire country (to 45–60%), as we mentioned earlier. In winter, in case of A2 the wetter periods are likely to become more frequent in the whole country, while the dry periods will become less frequent mainly in the area of Transdanubium. This finding is even more pronounced in case of A1B scenario, however, valid not only for parts of the country but for the entire area.

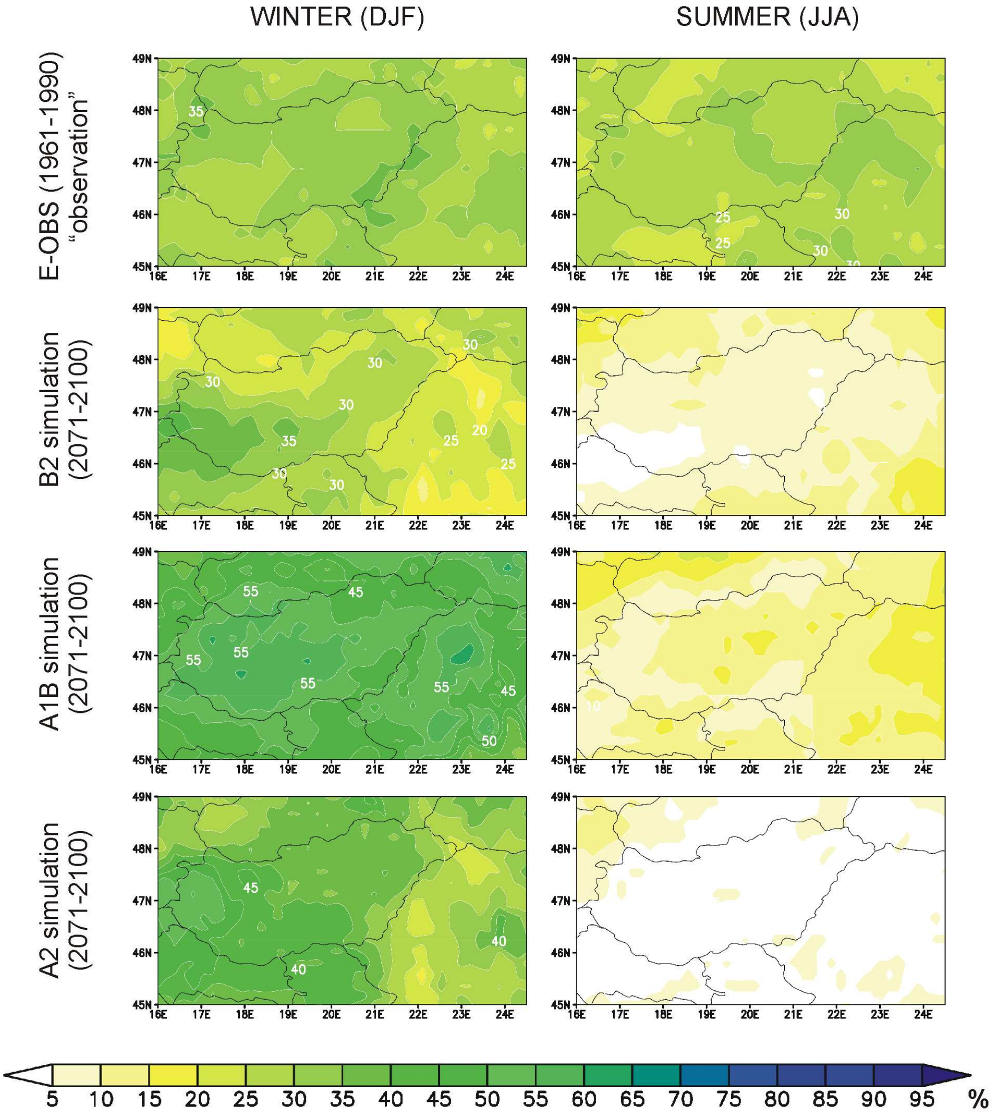

Figure 10. Seasonal empirical probability of monthly precipitation anomaly exceeding +20% (relative to the 1961–1990 monthly mean values)

4 SUMMARY

The climate conditions of the 1961–1990 (reference) and 2071–2100 periods have been simulated using the PRECIS regional climate model. In the present paper the projected temperature and precipitation changes for the Carpathian Basin for the end of the 21st century (compared to the mean of 1961–1990) have been analyzed. The main conclusions can be drawn as follows.

(i) The sign of the simulated temperature change is the same for all the three scenarios, the projected annual temperature increase is in the range of 4.0–5.4 °C. The amplitude of the projected warming is the largest in case of A2, according to which the highest CO_2 concentration level is estimated.

(ii) In all the four seasons significant warming is projected at 0.05 level in all simulations, the largest warming is likely to occur in summer (for Hungary the spatial average warming by the end of the 21st century is likely to reach 6–8 °C).

(iii) Not only the mean climatic conditions will change, but also the distribution of the daily (and monthly) mean temperature, implying more frequent warm and hot periods and greater record hot conditions than in the 1961–1990 reference period.

(iv) By the end of the century the annual precipitation in the Carpathian Basin is likely to decrease by about 20% for both A2 and B2 scenarios. The A1B scenario does not project such annual changes.

(v) Significant drying is projected in the region, especially, in summer (the seasonal precipitation amounts as well, as the probability of occurrence of wetter periods are likely to decrease in Hungary) while in winter the precipitation is projected to increase. The direction of precipitation change in the transition seasons is uncertain, the simulations do not estimate significant changes.

(vi) According to the PRECIS simulations the annual distribution of monthly mean precipitation is also expected to change. In the 1961–1990 reference period the wettest months in Hungary occurred in May and June, and the driest months were January and February. In the 2071–2100 future period, the driest months are projected to be July and August, while the wettest April, May and June.

PRECIS is only one of the four RCMs adapted and used for assessing the regional climate change in Hungary. Obviously, these experiments differ in many aspects, e.g., in model formulation, physical parameterization, spatial resolution, driving boundary conditions and forcings. Due to these differences besides the robust future changes suggested by the different RCM results the uncertainties associated to the estimated changes for the Carpathian Basin can be also assessed (Krüzselyi et al. 2011). Moreover, previous RCM results based on PRUDENCE outputs (Batholy et al. 2008) and ENSEMBLES outputs (Bartholy et al. 2011) also enable us to evaluate the PRECIS simulations. Compared to these other RCM experiments, PRECIS results for Hungary project somewhat warmer conditions than the mean temperature change of all the available simulation results. The largest seasonal warming projected for summer by PRECIS simulations are consistent with other results (Bartholy et al. 2008, 2011). In case of precipitation projections, the uncertainty is much larger than in case of temperature. The RCM results often disagree in the sign of the projected seasonal and annual changes, which are often non-significant. However, the summer drying is estimated by most of the RCM experiments, as well, as PRECIS runs presented in this paper. Slightly wetter winter conditions are also likely to occur in the future compared to the reference period 1961–1990. From this sense PRECIS simulations are consistent with the available RCM results.

Acknowledgments: Research leading to this paper has been supported by the following sources: the Hungarian Ministry of Environment and Water, the Hungarian Academy of Sciences under the program 2006/TKI/246 titled Adaptation to climate change, the Hungarian National Science Research Foundation under grants T-049824, K-67626, K-69164 and K-78125, the Hungarian National Research Development Program under grants NKFP-3A/082/2004 and NKFP-6/079/2005, and the CECILIA project of the European Union Nr. 6 program (contract no. GOCE-037005). The European Union and the European Social Fund have provided financial support to the project under the grant agreement no. TÁMOP 4.2.1/B-09/1/KMR-2010–0003.

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10.37045/aslh-2011-0002 *Acta Silv. Lign. Hung., Vol. 7 (2011) 23–38*

Comparison of 19th Century and Present Concentrations and Depositions of Ozone in Central Europe

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Abstract – Ozone, one of the most important trace gases in atmosphere was discovered by Christian Friedrich Schönbein (1799–1886), a chemistry professor at the University of Basel. The method developed by him was used from the middle of nineteenth century until the 1920's in much of the world. The measurement method is based essentially on the color-change of an indicator test paper. We obtained records for ozone measured in the Habsburg Empire using Schönbein's method for analyze the long term environmental processes. According to records kept in the Habsburg Empire, ozone was measured at more than twenty sites between 1853–1856. On the territory of the Kingdom of Hungary, ozone was measured at Szeged, Buda and Selmecbánya (Schemnitz, Banska Štiavnica) among others. Long term datasets are available from Buda (1871–1898) and Ó-Gyalla (Altdala, Hurbanovo, 1898–1905). Ozone was measured during both day- and nighttime. Additionally meteorological variables (like air temperature, relative humidity, air pressure, wind speed, cloud cover, precipitation) were also observed several times a day. The data reported in the yearbooks were collected and evaluated in this study to reconstruct the ozone dataset. Depending on concentrations and deposition velocity over different vegetated surfaces the ozone deposition can be estimated. The reliability of estimations and reconstructed ozone deposition values are also discussed. Finally ozone datasets from the 19th and 21st century and the differences in ozone concentration and deposition between rural and urban areas are compared. Ozone concentrations and deposition are found to be approximately three times higher now than in the 19th century.

ozone concentration and deposition / Schönbein's method / historical datasets

Kivonat – A jelenlegi és a XIX. századi ózonmérések összehasonlítása. Az ózon fontos légköri nyomgáz, amelyet Christian Friedrich Schönbein (1799–1886), a bázeli egyetem kémia professzora fedezett fel. Az általa kifejlesztett mérési eljárást a XIX. század közepétől az 1920-as évekig használták világszerte. Egy indikátor papír színváltozását regisztrálták tíz, illetve tizennégy fokozatú skálán. A Habsburg Birodalomban végzett feljegyzések szerint az ózon koncentrációt több mint 20 helyen mérték 1853 és 1856 között. A Magyar Királyság területén ózonmérések folytak többek között Szegeden, Budán és Selmecbányán. Hosszúidejű megfigyelési sorok vannak Budáról (1871–1898) és Ó-Gyalláról (1898–1905). Az ózont nappali és éjszakai periódusban mérték. A meteorológiai elemeket – mint a hőmérséklet, relatív nedvesség, légnyomás, szél, felhőzet, csapadék – szintén naponta többször feljegyezték. Az évkönyvekben közölt adatokat dolgoztuk fel, létrehozva egy hosszúidejű ózon-adatbázist. A koncentráció és a különböző ökoszisztémákra jellemző ülepedési sebesség ismeretében az ózon terhelést is

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meghatároztuk. Összehasonlítottuk a XIX. századi és a XXI. századi ózonméréseket. Elemeztük a városi és vidéki mérőhelyeken mért ózon koncentráció és ülepedési értékek különbségeit. Az ózon szint és az ülepedés mértéke jelenleg hozzávetőlegesen 3-szorosa a XIX. századi értékeknek.

ózon koncentráció / Schönbein módszer/ történelmi adatsorok

1 DISCOVERY OF OZONE AND ITS ENVIRONMENTAL EFFECTS

The first technique for measuring ozone was developed by Schönbein. The method was based on an indicator paper coated with starched potassium iodide. A color-change of an indicator test paper was recorded on a scale ranging from 0 to 10 or 0 to 14. The strip of paper turns brown depending on the extent of the reaction of iodine with ozone and also because of humidity. Because of the effect of humidity on the measurement, the relation between color change and the concentration of ozone is not linear (e.g., Fox 1873; Linvill et al. 1980; Kley et al. 1988; Walshaw 1990; Möller 1999; Mordecai 2001).

Ozone is beneficial in the stratosphere by absorbing UV radiation, in the same time it is a pollutant near the surface. Ozone near the surface harms vegetation and animals, it is toxic to humans; decreased agricultural crop yields and damage to man-made materials are examples among its negative effects. Ozone is a secondary pollutant meaning that it is not directly emitted into the atmosphere. Instead, ozone is produced in the atmosphere by photochemical reactions involving precursor species (such as NO, NO_2, CO, VOC) released from man-made sources (such as traffic and industry) and from natural sources (such as vegetation and lightning). Stratospheric-tropospheric exchange is another important source of tropospheric ozone (Sándor et al. 1994). The concentration of near surface ozone has characteristic seasonal and daily variations. Its seasonal variation is characterized by winter minima and summer maxima in areas that are strongly influenced by pollution sources. Secondary maxima occur in early spring due to intrusions of stratospheric air. The highest ozone concentrations are typically found in the afternoon and in the early evening as the result of photochemical activity. In remote areas, i.e., areas not strongly influenced by recent pollution, ozone has a maximum in spring and a minimum in fall. The diurnal variation of ozone is much weaker in remote areas than in polluted areas and maxima can occur at any time of the day or night (Nolle et al. 2002; Wilson et al. 2011).

Ozone is a potent greenhouse gas and is ranked third in importance after CO_2 and CH_4 (IPCC 2007). For calculating the contribution of ozone to radiative, and hence climate forcing due to anthropogenic activities, it is necessary to know the history of ozone extending from the pre-industrial era to the present. In addition, long term trends in ozone concentrations are needed to assess the long-term effects of exposure of vegetation to ozone. Currently, measurements of ozone are obtained routinely around the world by surface based measurement networks and by satellites. However, these methods have only been in use for a few decades and other techniques must be relied on to obtain semi-quantitative data for ozone.

2 CALCULATION OF OZONE CONCENTRATION AND FLUX FROM HISTORICAL MEASUREMENTS

Since shortly after the development of the Schönbein test paper method, studies have attempted to relate the color changes to ozone concentrations. Fox (1873) noted that the color change is related to humidity. This happens because a damper surface can absorb more ozone. He also found that higher temperatures lead to higher ozone. Albert-Levy (1877) realized that gases such as SO_2 lead to reduction of ozone and developed the first quantitative method for measuring ozone, based on the oxidation of arsenite. Several more recent studies have examined the question of how to relate Schönbein numbers from the color changes to ozone concentrations (e.g., Linvill et al. 1980; Bojkov 1986; Volz–Kley 1988; Marenco et al. 1994; Pavelin et al. 1999). Wind speed and sampling time (usually 8–14 hours) can also affect the measurements. It should be mentioned that higher values of Schönbein numbers were find in case of higher wind speeds at similar relative humidity in the historical ozone dataset of Buda (not presented here). Based on data from Linvill et al. (1980) and Anfossi et al. (1991), Pavelin et al. (1999) developed a procedure to account for the dependence on relative humidity (*Figure 1.*). It is the most accepted methodology for the conversion. The estimated error is ~ 20–25%.

The ozone flux (*F*) can be determined over a given type of vegetation using data for ozone concentration and deposition velocity (Wesely–Hicks 2000; Lagzi et al. 2004; Mészáros et al. 2009):

$$F = v_d \left(C_{ref} - C_0\right),$$
$$C_0 = 0$$

where v_d is deposition velocity, C_{ref} is concentration at reference level, C_0 is concentration at the absorbent surface.

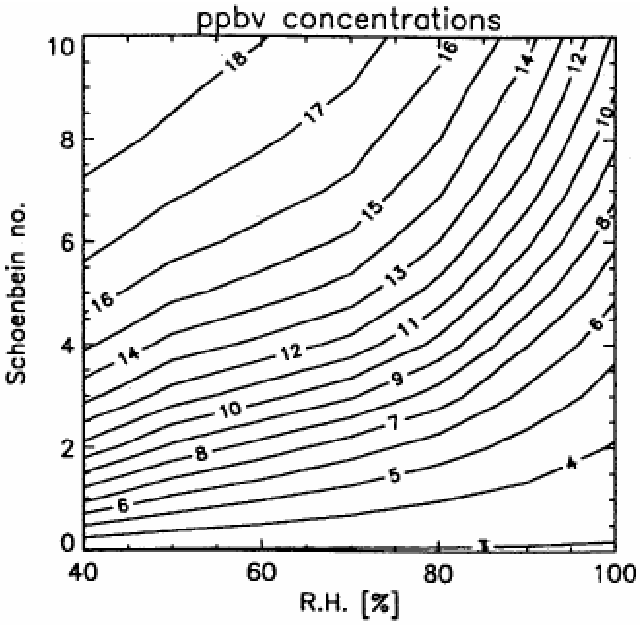

Figure 1. Humidity correction suggested by Pavelin et al. (1999) to convert Schönbein numbers to ozone concentrations in units of ppbv

Over the past few decades, numerous measurements were carried out to determine seasonal and daily variations in deposition velocity over different vegetation types (e.g. grass, deciduous, coniferous and mixed forest types). The results of these measurements could be used for parameterizing processes, or testing ozone deposition calculations using resistance models in addition to assessing ozone fluxes to vegetation (Zhang et al. 1996; Emberson et al. 2001; Lamaud et al. 2002; Lagzi et al. 2004; Büker et al. 2007).

Measurements of deposition velocity were made in the early 1990s in Hortobágy (over a grassy surface) and Nyírjes (in the Mátra Mountains over a coniferous forest) are shown in *Table 1*. Values from Nyírjes will be used for estimating ozone deposition during the vegetation growing season (from April to October) over coniferous forests. These values of deposition velocity are in good agreement (same range but little bit higher values) with other measurements found in the current literature (Padro 1996; Finkelstein et al. 2000; Zhu et al. 2008). Data shown in *Table 2* indicate that daytime deposition velocities are typically higher than nighttime values for all the ecosystems studied. Lowest 24-hour average values were found over the grassy surface, while highest values were found over forests.

Table 1. Deposition velocity of ozone [cm/s] over a coniferous forest in the Mátra Mountains on the basis of field measurement campaigns from 1991 to 1993 (Horváth et al. 1996)

	Spring	Summer	Autumn	Winter
Daytime	0.50	1.20	0.63	0.17
Nighttime	0.04	0.34	0.03	0.04
Entire day	**0.34**	**0.86**	**0.39**	**0.12**

Table 2. Deposition velocity of ozone [cm/s] over different surface types on the basis of standard values in summer (Meyers et al. 1998; Zhang et al. 2002; Lagzi et al. 2004)

	Daytime	Nighttime	**Entire day**
Grass			**0.25** (0.2–0.35)
Agricultural	0.2 – 0.7		**0.35**
Vineyard, orchard	0.3 – 0.5	0.05 – 0.2	**0.3**
Deciduous forests	0.2 – 0.95	0.2 – 0.3	**0.5** (0.3–0.7)
Mixed forests			**0.5** (0.2–0.85)
Coniferous forests	0.7 – 0.9	0.15 – 0.35	**0.6**

3 OZONE MEASUREMENTS IN THE 19TH CENTURY

Reconstructed ozone measurements, measurement sites and measurement periods from the 19th century currently available in the literature (Pavelin et al. 1999) are shown in a contemporary geographical map (*Figure 2*). We report here reconstructed ozone measurements obtained in the Habsburg Empire from the latter half of the 19th century until the 1910s.

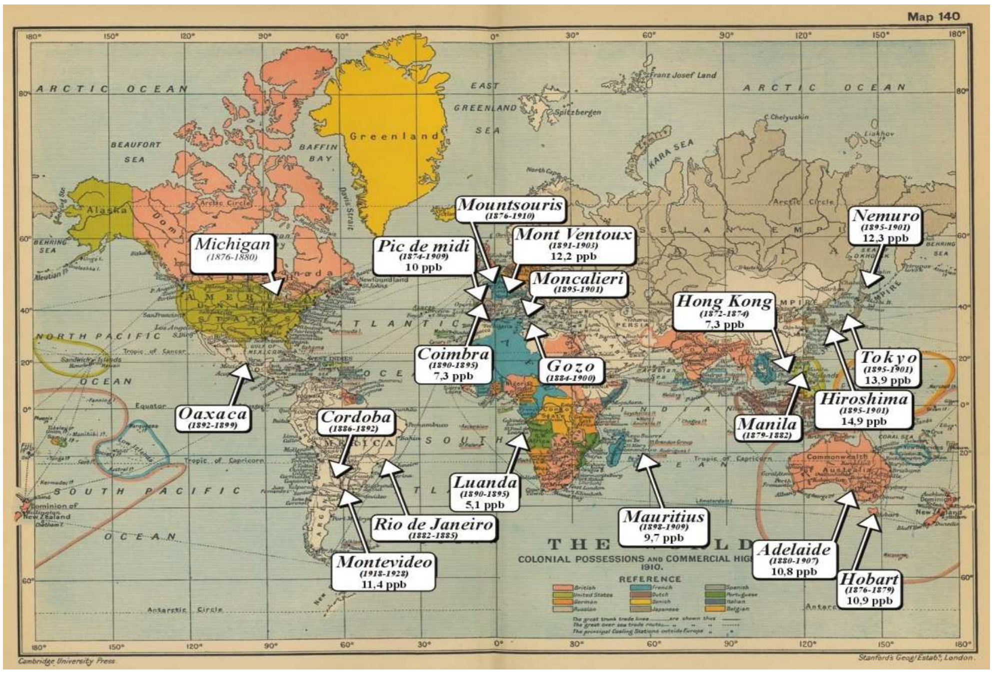

Figure 2. Ozone measurements at the end of the 19th and the beginning of the 20th century

According to the map, earliest data obtained outside the Habsburg Empire were in Hong Kong, Michigan, in France at the Pic de Midi Observatory. The measurements at each site were carried out using the Schönbein method, with different scales used, e.g., 0–10, 0–11, 0–14, 0–21. The values on the map are presented in ppbv, which has been introduced more recently. Available values were between 5 and 15 ppbv.

3.1 Ozone measurements in the Habsburg Empire between 1853–1856

It should be emphasized that the earliest datasets in the world we have are from the stations in the Habsburg Empire shown in *Figure 3*. Yearbooks between 1853–1856 of the Central Meteorological Institute of the Habsburg Empire in Vienna (Wien) contain data on ozone concentration from more than 20 stations. However, ozone data were not obtained and recorded for subsequent years, except for data obtained in Vienna.

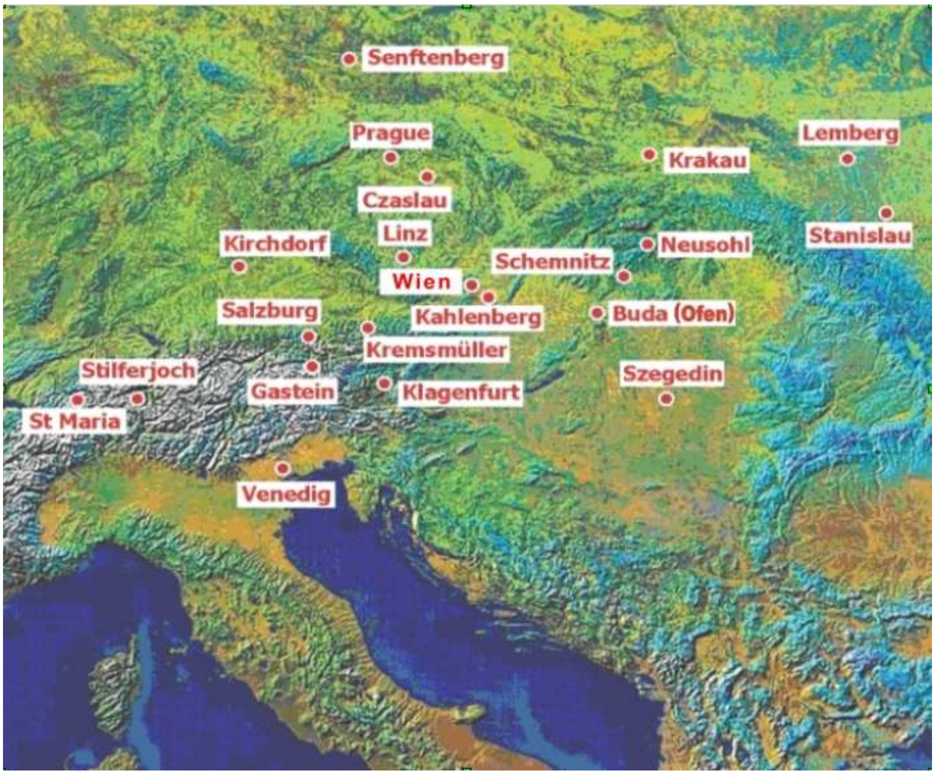

Figure 3. Ozone measurement sites in Central Europe between 1853–1856

Numerous meteorological stations in the Kingdom of Hungary also made ozone measurements using the Schönbein method (scale of 0–10) during the day and night: Buda (Ofen), Szeged (Szegedin), Selmecbánya (Schemnitz) and Besztercebánya (Neusohl). In this study, we will convert Schönbein numbers to ozone concentrations in ppbv using the approach outlined in Pavelin et al. (1999).

There are some interesting aspects of the measurement worth mentioning: (i) Vienna has quite a long ozone measurement period from 1853 to the end of 19th century; (ii) Ozone observation started in 1856 in Buda, however there was continuous published dataset in yearbooks only from 1871; (iii) in Krakau (Krakow), four Schönbein papers were simultaneously posted towards the four points of the compass to study the differences caused the wind speed outside the building (shielded vs. exposed); (iv) in Lemberg (Lviv) two daytime measurements were carried out; one in the morning and one in the afternoon. The concentrations measured were similar (Weidinger et al. 2009).

To calculate ozone level daytime and nighttime relative humidity data are needed. For humidity data missing in the yearbook, data from the nearest meteorological station were used. Of course it is a compromise but the selected stations were in the same climate region (Hungarian Plain). For Szeged we used humidity data from Temerin (near Belgrad) in one year, while in other years data was taken from Debrecen. In two other years measurements of humidity were found locally in Szeged. Meteorological measurements were usually carried out three times a day. There were two stations with more than three observations of humidity per day: in Seftenberg 5 times per day and in Kremsmünster 10 times per day. Daily (1 data/day) and monthly averages (for each daily measuring time) of relative humidity were published in the yearbooks.

3.2 Evaluation of ozone measurements in Szeged

Reconstruction of ozone data is illustrated on the dataset in Szeged (1853–1856). Schönbein's number showing annual variation with winter maxima and summer minima is shown in *Figure 4*.

Available dataset of relative humidity were i) daily averages (one value per day) and ii) monthly averages for three daily observations (0600, 1400 and 2000 hours in Central European Time). Monthly averages of relative humidity were determined by weighted averages of monthly values of three observations. Percentage differences between these values were used for reconstruction of daily variation of the relative humidity from each daily average. Using estimated relative humidity three times a day the daytime (between 0600–2000 hours) and nighttime (2000–0600 hours) relative humidity could be determined assuming linear changes between values.

Seasonal variability in daily average relative humidity is characterized by a winter maximum and a summer minimum (*Figure 4)*. In 1854 and 1856 extremely low daily average relative humidities were found in datasets from several stations suggesting these low values were not likely the result of measurement artifacts.

3.3 Spatial distribution of ozone over the Habsburg Empire in 1855

The good coverage of measuring sites of ozone allows to analyze the spatial distribution of ozone concentration. Density of measurements was quite high compared to today. The frequency of measurements allows us to determine daytime and nighttime ozone concentrations. The spatial distribution of ozone concentration in 1855 – produced from numerous measurements was characterized by maximum values around Vienna and low values (less than 10 ppbv) in Szeged and in Krakow (*Figure 5*).

3.4 Ozone deposition during the vegetation period over coniferous forests in Central Europe in 1855

A simple model using deposition velocities shown in *Table 1* was adapted to calculate ozone deposition over coniferous forests. The results for the vegetation growth season (from April to October) are presented in *Figure 6*.

Assuming the concentrations were very similar in daytime and nighttime, the differences between ozone deposition rates are caused by the different deposition velocities in daytime and nighttime (*Table 1*). Over coniferous forests during vegetation growth seasons ozone deposition was between 1,7 g/m^2 and 3 g/m^2. On the basis of land-use data from the 19th century (Timár et al. 2006, 2007) more precise calculations can be made.

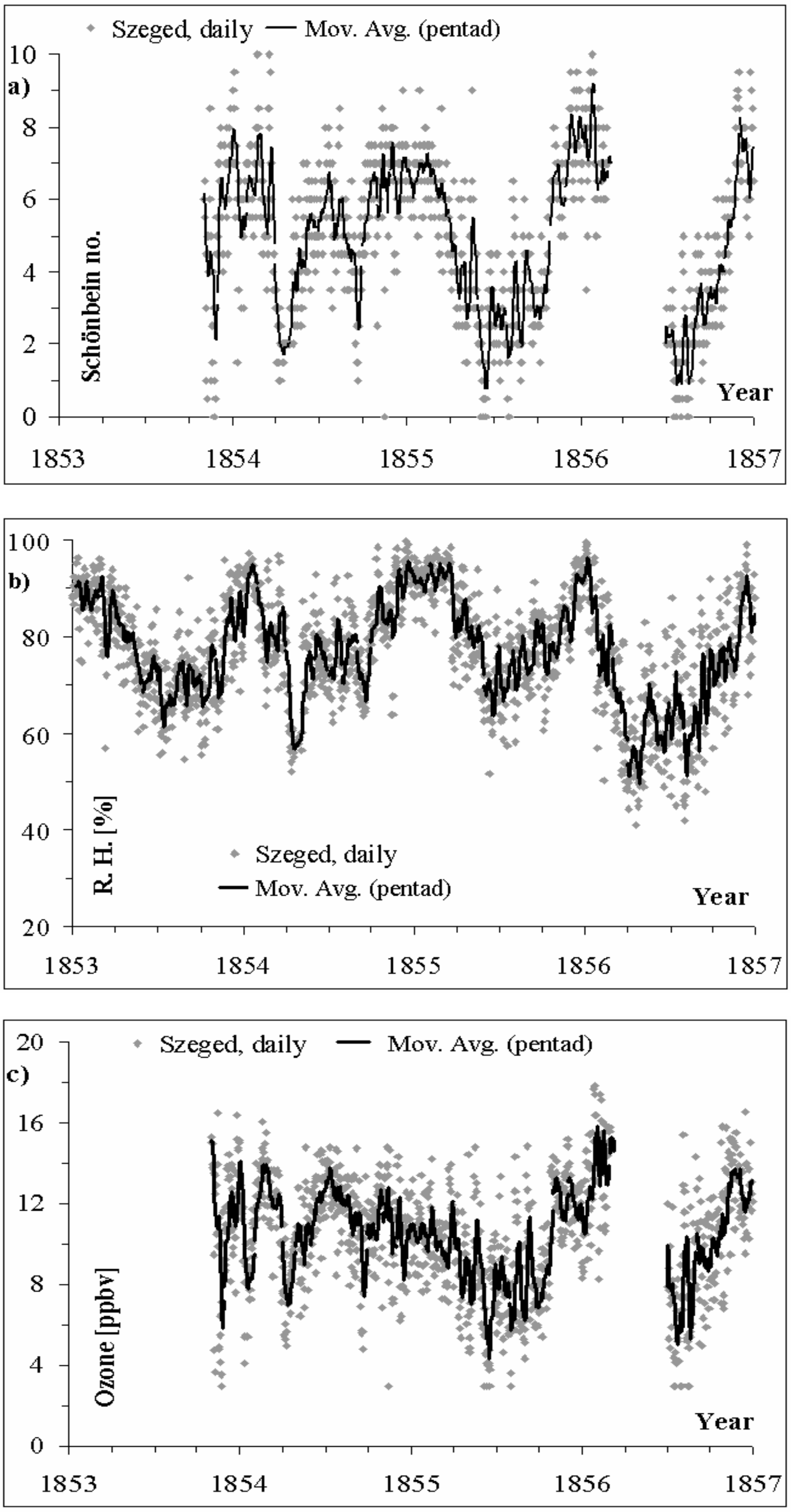

Figure 4. Schönbein number (a), relative humidity (b) and ozone concentration (c) in Szeged between 1853–1856. The moving averages were calculated over 10 days of data (pentad)

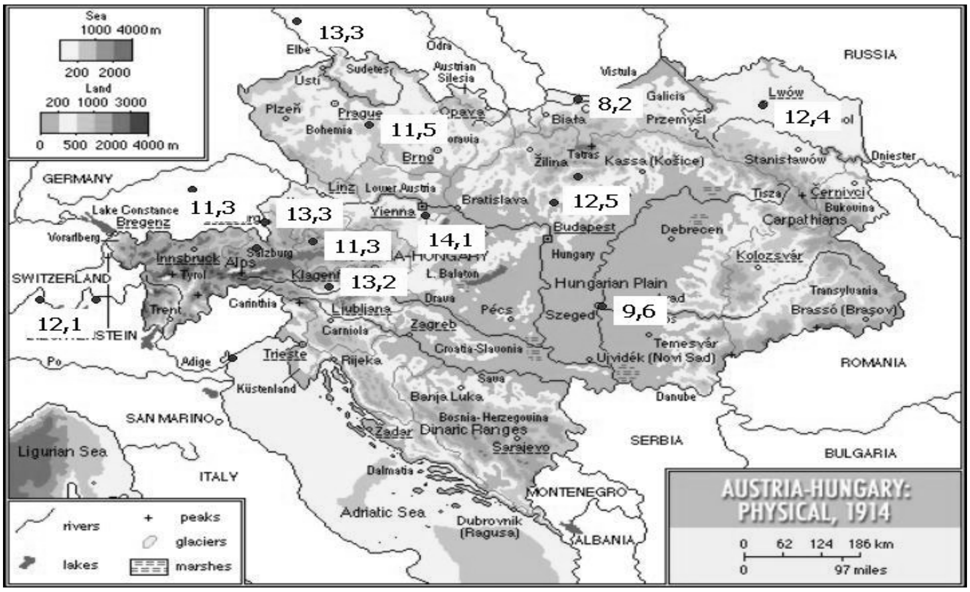

Figure 5. Annual average ozone concentration [ppbv] in the Habsburg Empire in 1855

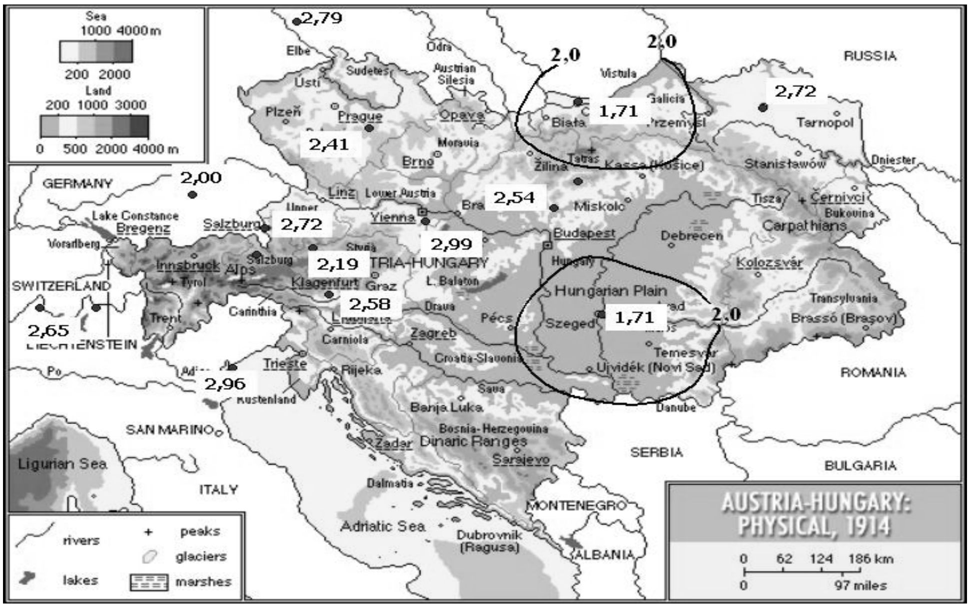

Figure 6. Ozone deposition [g/m^2] over coniferous forest during the vegetation growth season (April–October) on the Habsburg Empire in 1855, calculated on the basis of reconstructed ozone concentration and deposition velocity data measured during day- and nighttime in Nyírjes (Table 1) (The coniferous forest is an example. It is not autochthonous in the Hungarian Plain)

3.5 Ó-Gyalla Dataset (1893–1905)

The meteorological and geomagnetic observatory founded by Miklós Konkoly in Ó-Gyalla (now Hurbanovo, Slovakia) plays an important role in the history of Hungarian meteorology. Starting in 1900 it operated as the Observatory of the Meteorological and Geomagnetic Institute (Czelnai, 1995). Yearbooks of the Observatory contain ozone measurements (daytime and nighttime, on 0–10 Schönbein scale) besides meteorological and geomagnetic observations between 1897 and 1905. The relative humidity was measured three times a day similar to the former measurements at Szeged.

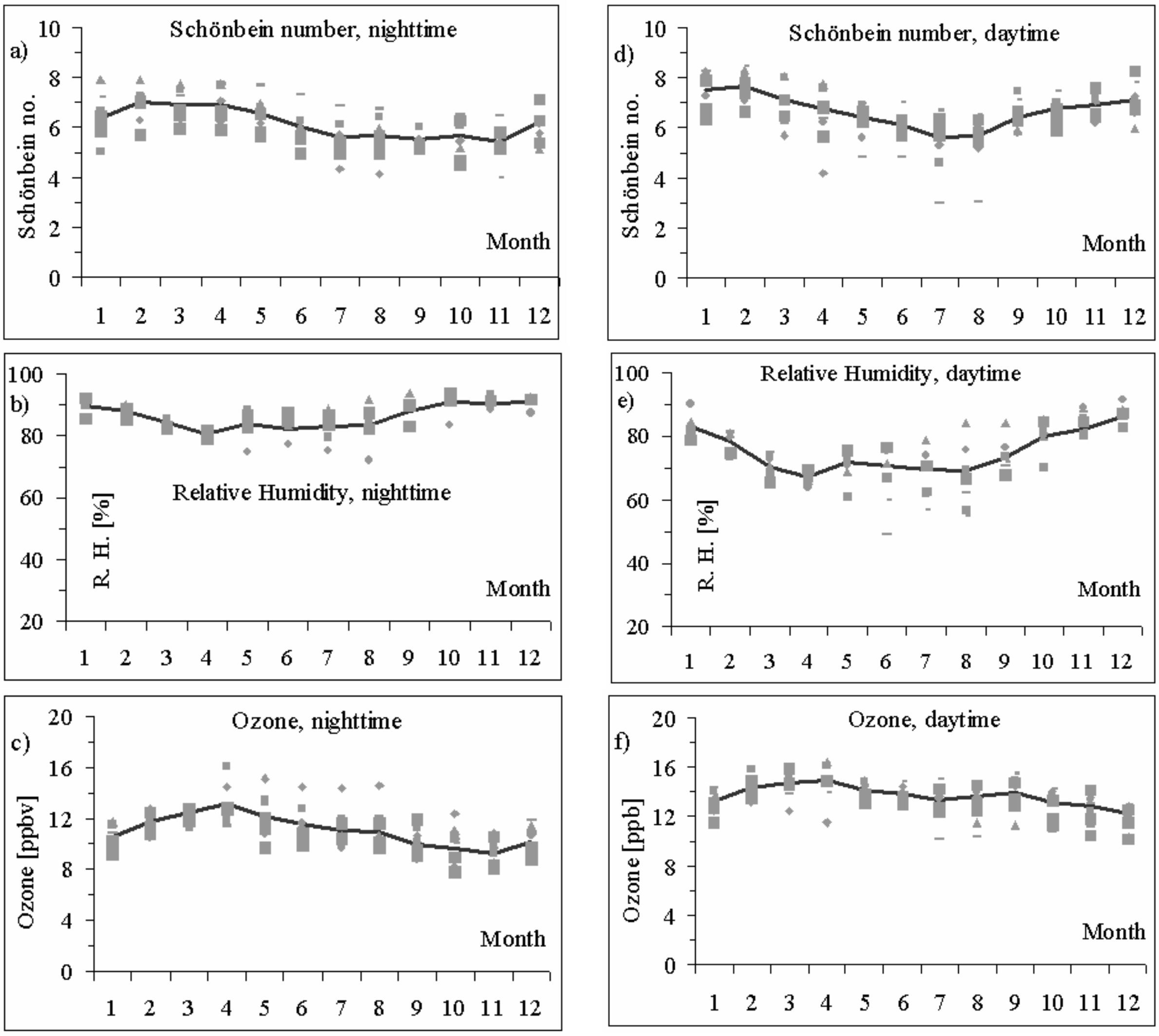

Figure 7. Monthly averages of nighttime and daytime Schönbein numbers (a, d), relative humidity (b, e) and ozone concentration (c, f) in Ó-Gyalla between 1893 and 1905

Figure 7 shows monthly averages for daytime and nighttime relative humidity, Schönbein number, and reconstructed ozone concentrations over a 13 year period. Average monthly values are indicated by continuous lines. Seasonal variation of ozone shows slight changes without summer maxima (not suitable anthropogenic effects compare with present). The daytime and nighttime average ozone concentrations – based on the Welch-test – are statistically different even at 99% significance level. Maximum values occurred in early spring (at daytime as well as nighttime), which are also found in the recent ozone dataset, explained by tropopause folding, which permits transfer to the surface (Sándor et al., 1994).

4 COMPARISON OF OZONE DATASETS AND FLUXES IN THE 19th AND 21st CENTURIES OVER URBAN AND RURAL AREAS

Daytime and nocturnal average ozone values are available for the stations located in the lower area of the Carpathian Basin for a period of over 150 years. In the evaluation ozone data measured at Szeged between 1854 and 1856, at Buda between 1871 and 1898 and at Ó-Gyalla between 1893 and 1905 were used.

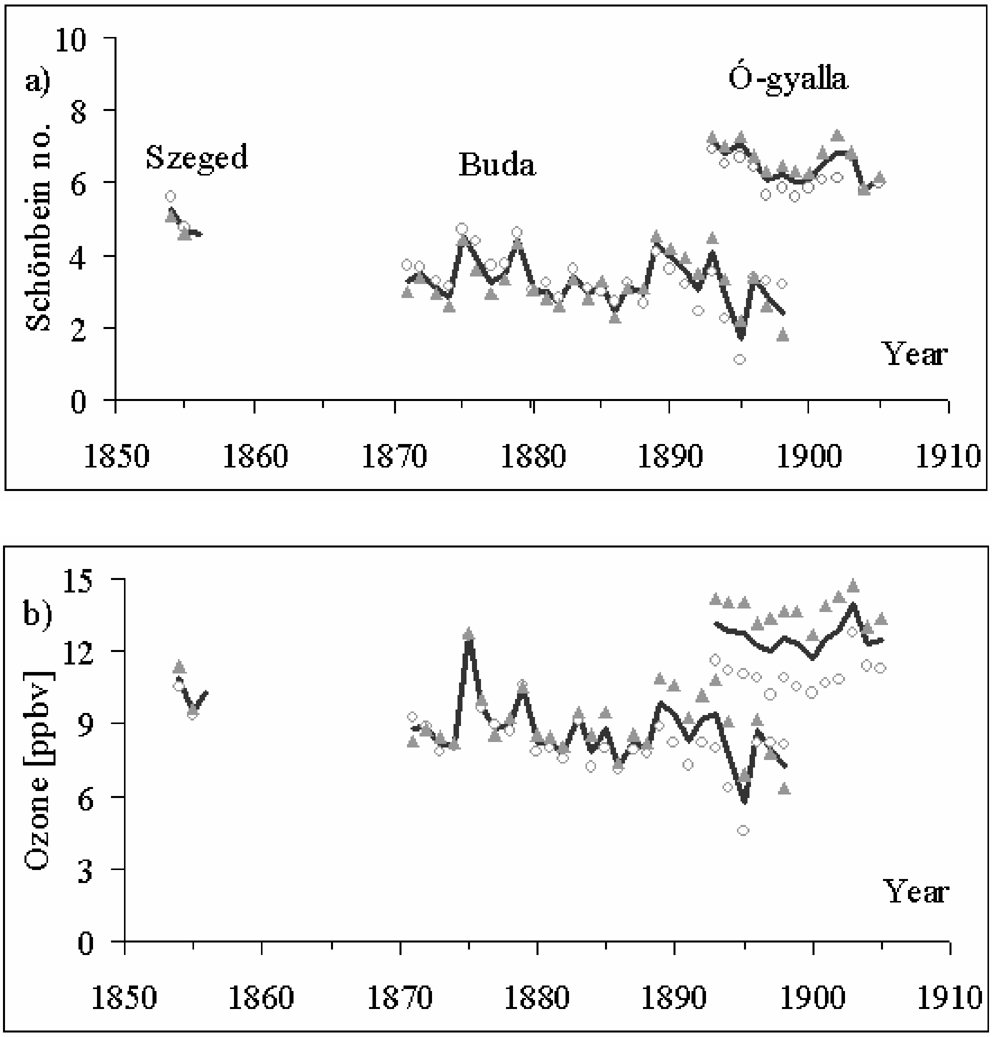

Figure 8. Annual averages of Schönbein number (a) and ozone concentration (b): daytime (grey triangles), nighttime (grey circles) and entire day (black line) measurements in Szeged, Ó-Gyalla and Buda between 1854–1904

The highest Schönbein value and ozone concentration are found in Ó-Gyalla and the lowest ones at Buda. The differences between ozone values at Buda and Szeged are very small. There are not significant trends in the ozone dataset in Buda. At the same time, measured ozone data in Ó-Gyalla (12–14 ppbv) and Buda (8–12 ppbv) indicate differences between urban and rural areas. This difference could be related to emissions of reducing gases such as SO_2 emitted in urban areas. Sulphate aerosol is formed in the atmosphere by the oxidation of sulphur dioxide. Ozone and the sulphate aerosol are interconnected to each other, since sulphate affects O_3 and the oxidant chemistry by providing a surface for the conversion of NO_x to nitric acid, limiting thus the formation of O_3 (Unger et al., 2006). On the other hand, reducing agents of the Schönbein paper – such as SO_2 and ammonia – can also lead to a lower ozone reading (Pavelin et al. 1999)

The daytime concentrations in spring and summer outpace in most cases the nighttime concentrations (*Figure 9*), which could be due to the effect of photochemical processes. In the majority of cases autumn and winter concentration at night is higher than in the daytime. Possible reasons are less daytime solar radiation, inactive period of vegetation and the effect of the coal burning in could seasons. The tendencies are more pronounced in the summer and spring, while smaller changes are found in winter and autumn.

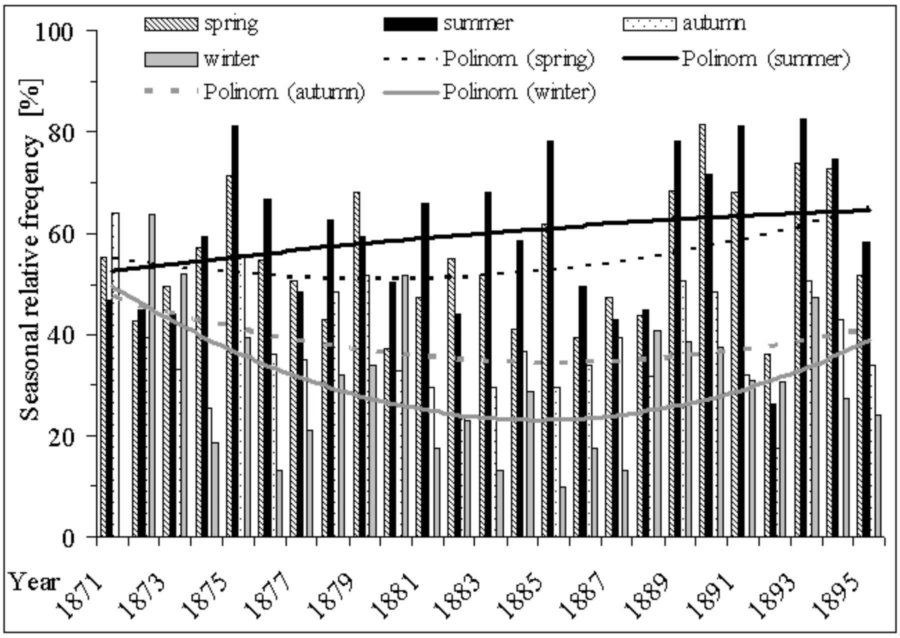

Figure 9. Relative frequency of days [%] when ozone concentrations are higher in the daytime (ΔC> 0) in different seasons observed in Buda between 1871 and 1895 (bars). Inter annual variation is demonstrated by fitted polynomial trend lines for each season (solid and dashed lines)

Taking into consideration of daily variation of ozone concentration from 1871 to 1895 in many days highest values were formed at nighttime, which are not common recently. For this reason these cases were treated separately. Long term variations of average differences were shown in *Figure 10* for winter and in *Figure 11* for summer. In winter smaller and in summer larger differences of concentrations can be found when the daytime concentrations are higher. It can be explained by photochemical reactions. Increasing trend can be found only in summer in this case.

The differences in ozone levels between urban and rural areas are increasing from beginning the observations until the present day. Differences between daytime and nighttime concentrations are also rising. Increasing emissions of nitrogen oxides and other trace gases playing important roles in ozone formation and the photochemical processes have been recognized (Mészáros 1997). Based on the measurements of the Hungarian Meteorological Service (for the period 1990–2008 as shown in *Figure 12*) increasing concentrations were found at both rural and urban areas until 1998. Since 1999 however, the concentrations are decreasing in both environments. Presently ozone levels are about three times higher than they were in the 19th century (compare *Figure 12* vs. *Figure 8*).

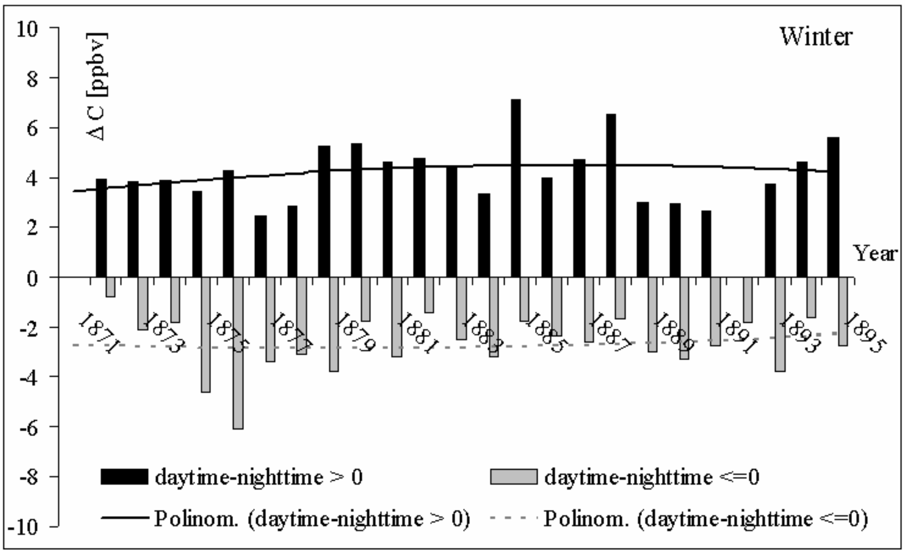

Figure 10. Average differences of daytime and nighttime measurements in Buda between 1871–1895 in winter for two cases i) for ozone concentration higher (dark) respectively ii) lower in daytime (gray). The variation between years is illustrated by trend lines

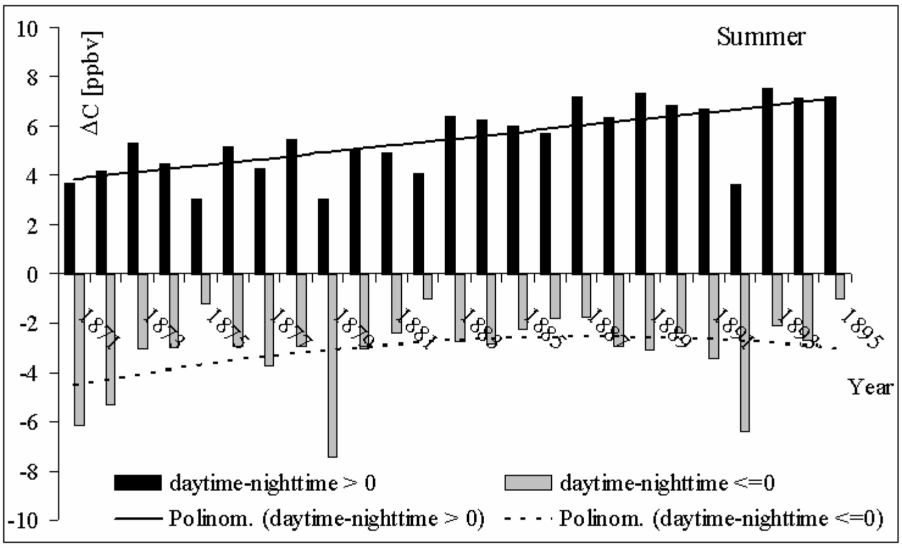

Figure 11. Average differences of daytime and nighttime measurements in Buda between 1871–1895 in summer for two cases i) for ozone concentration higher (dark) respectively ii) lower in daytime (gray). The variation between years is illustrated by trend lines

The change of ozone deposition from 19th to 21st century was illustrated over the coniferous forest for seven months (from April to October) of vegetation growth season *(Table 3).*

Table 3. Estimated ozone deposition [g/m^2] during the vegetation growth season (from April to October).

	Daytime	Nighttime	**Entire day**
Selmecbánya (1855)	2,2	0,3	**2,5**
Lemberg (1855)	2,4	0,3	**2,7**
Farkasfa (2008)	7,7	1,2	**8,9**
K-puszta (2008)	9,1	1,3	**10,4**
Nyírjes (2008)	9,5	2,0	**11,5**

Values almost three times higher were also found in later measurements cases than in earlier ones. In 1855, ozone deposition (*Figure 6.*) was 2.5 g/m^2 in Selmecbánya (Banska Štiavnica), while in Nyírjes 11.5 g/m^2 was calculated in 2008. Currently, differences of ozone deposition between two stations (Farkasfa and Nyírjes) are higher than the baseline deposition in the 19th century. In other words the spatial changes are larger than for the total deposition a century and a half ago. Due to anthropogenic activities, photochemical reactions play more important role at present. The differences between day and night values are increasing, and day to day variations in ozone concentrations are also increasing (see also Lagzi et al., 2004).

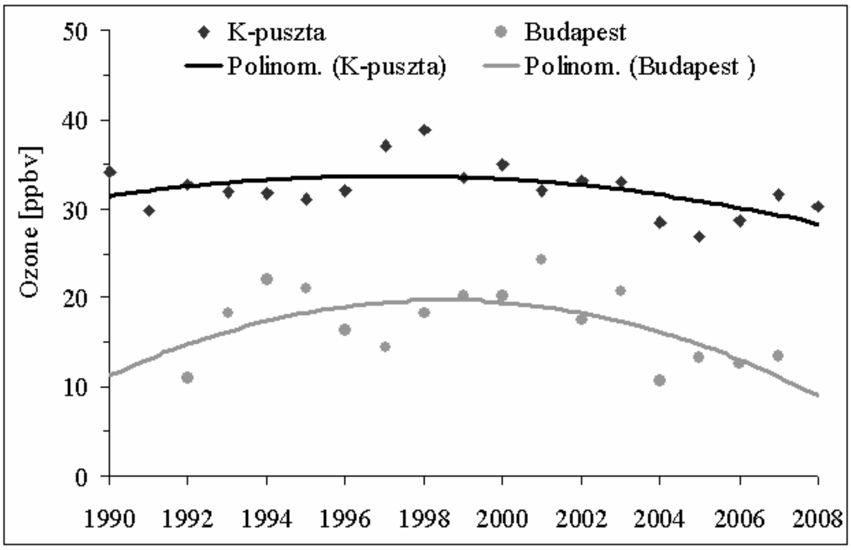

Figure 12. Annual averages of ozone levels between 1990 and 2008 in Budapest (urban site) and at K-puszta (rural site)

5 CONCLUSIONS

We present reconstructed ozone measurements and ozone deposition calculations based on these measurements (i) in the Habsburg Empire and in the Carpathian Basin in the middle of 19th century and the early 20th century; and (ii) in Hungary in the late 20th and the early 21st century. The Schönbein method is able to track the changes of concentration in the daytime and nighttime, and the seasonal changes as well. In summary:

- Reconstructed ozone concentrations in Central Europe are consistent with those deduced for measurements reported for other regions in the literature (i.e. generally in the range of 5 to 15 ppbv based on the widely accepted methodology of Pavelin et al. (1999).
- Although the data are subject to large uncertainties (~25% and possibly larger), they indicate that ozone concentrations were not likely to be substantially greater than this range and not as high as predicted by model calculations of pre-industrial background ozone.
- Small spatial variability of measurements over Central Europe between 1854 and 1905 for daytime, nighttime and daily values;
- Differences in ozone level between rural (Ó-Gyalla) and urban areas (Buda) were demonstrated;
- In Central Europe current ozone level and ozone deposition are about three times higher than in the 19th century.

Further investigations are planned on i) the effect of the wind speed, concentration of SO_2 and NH_3 for the ozone deposition according to the Schönbein paper, ii) uncertainty of the Schönbein method at high ozone concentrations and iii) the development of a multi-linear regressions model relating relative humidity and wind speed to Schönbein number based on the historical XIX century ozone measurements in Hungary.

Acknowledgments: We express our thanks, for providing deposition velocity data measured in Nyírjes between 1991 and 1993, to László Horváth (Hungarian Meteorological Service), Ernő Führer (Hungarian Forest Research Institute) and Robert Mészáros (Eötvös Loránd University), as well as to the Hungarian Meteorological Service for ozone data from the present dataset. Thank you very much to Joseph Pinto (US EPA) for useful comments during the preparation of the manuscript. Special thanks are due to the financial support of the project *UHI 3CE292P3* in Central Europe Program; *OTKA 75500*; *COST ES0804*; and the *TÁMOP 4.2.1./B-09/1/KMR-2010-0003* realized trough the common support of the European Union and the European Social Found.

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10.37045/aslh-2011-0003 *Acta Silv. Lign. Hung., Vol. 7 (2011) 39–47*

Seasonal Variability of Wind Climate in Hungary

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Abstract – One of the most important effects of climate variability and climate change may come from changes in the intensity and frequency of climatic extremes. Responding to the need of new climatologic analyses, complex wind field research was carried out to study and provide reliable information about the state and variability of wind climate in Hungary. First of all, special attention was paid on creation of a high quality, homogeneous data series. The research is based on 36-year-long (1975–2010) wind data series of 36 Hungarian synoptic meteorological stations. The means and extremes of near-surface wind conditions assist in estimating the regional effects of climate change, therefore a complex wind climate analysis was carried out. Spatial and temporal distribution of mean and extreme wind characteristics were estimated; wind extremes and trends were interpolated and mapped over the country. Furthermore, measured and ERA Interim reanalysis data were compared in order to estimate the effects of regional climate change.

wind climate / climatic extremes / regional tendencies / reanalysed data

Kivonat – A magyarországi szélklíma évszakos változékonysága. Napjainkban megnövekedett az igény a klímaváltozás globális és regionális hatásainak elemzésére, következményeinek becslésére. Az egyes meteorológiai paraméterek átlagos értékeinek elmozdulása mellett kiemelt figyelmet igényel a szélsőséges időjárási és éghajlati események esetleges gyakorisági változása is.

Kutatásaink során a hazai szinoptikus meteorológiai állomások 36 éves, 1975–2010-ig terjedő adatsorainak minőségi és mennyiségi ellenőrzése, feldolgozása után elemeztük a szélmező klimatológiai szempontból lényeges statisztikai jellemzőit. Az órás szélsebesség, szélirány és széllökés adatokat tartalmazó idősor felhasználásával becsültük a szélklíma legfontosabb paramétereinek és szélsőértékeinek évek közötti változékonyságát, azok térbeli és időbeli tendenciáit. Az ERA Interim reanalízis adatsor 10 méteres magasságra vonatkoztatott szélsebesség idősorán szintén elvégeztük a fent említett vizsgálatokat, melyek eredményét összevetettük egymással annak megállapítása érdekében, hogy a klímamodellek bemenő adataként széleskörűen alkalmazott ERA Interim adatsor klimatikus jellemzői mennyire esnek egybe a mért adatokból levezetett jellemzőkkel

szélklíma / klimatikus szélsőségek / regionális trendek / reanalízis

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1 INTRODUCTION

In view of global warming, changes of extreme climate events are considered a key issue nowadays. Usually it is impossible to connect directly specific weather events to global warming. Instead, global warming is expected to cause changes in the overall distribution and intensity of extreme events, such as changes in the frequency and intensity of heavy precipitation and wind storms.

Hungary occupies the low elevation areas of the Carpathian basin. The country is predominantly flat, two-thirds of the entire territory lies below 200 m and approximately 2% is above 400 m. The latitudinal extension of Hungary – less than three degrees (45° 45' – 48° 35' N) – does not cause significant climatic differences between northern and southern regions. The country was not the subject of extensive wind research in the last century. However, some studies were carried out analyzing the surface and upper-air wind records spanning several decades. The present study is a segment of complex wind climate research of the country, which uses statistical methods to analyze the measured wind records of the Hungarian meteorological stations (Péliné et al. 2008, Radics – Bartholy 2002, 2008, Radics et al. 2010).

Most scientists agree that special attention should be paid applying ERA-40 reanalysis data sets as a reference, e.g. for such model development and validation purposes where wind plays an important role (Punge – Giorgetta 2007). Considering the statistics of differences between observations and hindcasts, furthermore, the fact that no corrections were applied prior to 1980 in ERA-40 data sets (Haimberger 2005), spatially and temporally inhomogeneous wind speed data and reanalyzed data (ERA Interim, Berrisford et al. 2009) were compared for Hungary. In this study some preliminary results are presented demonstrating how the comparison of different datasets can improve the reliability of detected wind variability.

2 DATA SETS

2.1 Measured data

The research is based on 36-year-long (1975–2010) hourly wind data of 36 Hungarian synoptic meteorological stations provided by the HDF Geoinformation Service. The most important feature that has to be provided for the analysis of such long time series is the homogeneity. Generally, homogeneity of data bases is strongly affected by the method of measurements. Before 1997, meteorological observations were made manually in Hungary. Therefore, the data series was split into two parts: "manual data" (1975–1994) and "automatic data" (1997–2010) sets. The consistency of data sets was checked and the values were verified. However data gaps were not filled. In order to be able to compare wind speed data, vertical interpolation (to standard height of 10 metres above the ground) was carried out *(Table 1).* In this paper preliminary results are presented on the detailed analyses of the second time period (1997–2010).

The network of Automatic Weather Stations (AWS) was designed by the national meteorological service (Hungarian Meteorological Service – HMS) to provide real-time observations and measurements for forecasting, warning and information services, as well as to ensure high quality data for the national climate database. During AWS installation the main aim was to settle the stations according to World Meteorological Organisation standards (WMO 1996). Wind observations are most sensitive to shelter by high roughness or nearby obstacles. Hence, wind sensors should in general be located over open terrain, at standard height of 10 metres above the ground in accordance with WMO-Guidelines (WMO 1996). Finding the ideal exposure that produces representative measurements may be difficult to achieve. Therefore, it is a crucial issue to report on the site conditions, a technical description of the set-up and sensors' heights (metadata).

Due to changing circumstances, in few cases site, method and height of wind measurements have been altered or observations ceased. Therefore, a few stations were excluded from further analysis.

Table 1. Heights of wind instruments at the meteorological stations involved in the analysis

	Stations	Time series	Heights of wind instruments (m)
1.	Agárd	1997 – 2010	10,30
2.	Baja Csávoly	1997 – 2010	10,30
3.	Budapest/Lőrinc	1997 – 2010	14,68
4.	Debrecen	1997 – 2010	10,23
5.	Győr	1997 – 2010	10,17
6.	Jósvafő	1997 – 2010	9,99
7.	Kecskemét	**1998** – 2010	10,00
8.	Kékestető	1997 – 2010	25,07
9.	Miskolc	1997 – 2010	16,25
10.	Mosonmagyaróvár	1997 – 2010	16,99
11.	Nagykanizsa	1997 – 2010	13,69
12.	Nyíregyháza	1997 – **2003**	27,00/15,98
13.	Paks	1997 – 2010	9,80
14.	Pápa Nyárád	**2002** – 2010	12,05
15.	Poroszló	1997 – 2010	10,45
16.	Sármellék	**2001** – 2010	10,61
17.	Siófok	1997 – 2010	15,10
18.	Szécsény	1997 – 2010	10,40
19.	Szeged	1997 – **2004**	8,76/10,59
20.	Szentgotthárd	1997 – 2010	16,61
21.	Szolnok	1997 – 2010	10,00
22.	Szombathely	1997 – 2010	10,56
24.	Tata	1997 – 2010	19,30
25.	Záhony	1997 – 2010	16,71
26.	Zalaegerszeg	**1999** – 2010	10,40

2.2 Reanalysis of gridded data

ERA-Interim is the latest global atmospheric reanalysis data set produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). ERA-Interim data are available from January 1 1979 to June 30 2011. Gridded data on the data server are normally updated once per month, allowing a two-month delay for quality assurance and for correcting technical problems with the production, if any. The timeline in *Figure 1* summarises the sources of in situ observations used in ERA-Interim. Surface observations from land stations, ships, and drifting buoys were involved throughout the reanalysis period, as were reports from radiosondes, pilot balloons, dropsondes, and aircrafts. Wind profiler data of North American sites became available in 1994, European and Japanese profilers were added in 2002. Hourly METAR airport weather reports have been used since 2004. Pseudo-surface pressure observations, which were used in ERA-40, were not involved in ERA-Interim project (Dee et al. 2011)

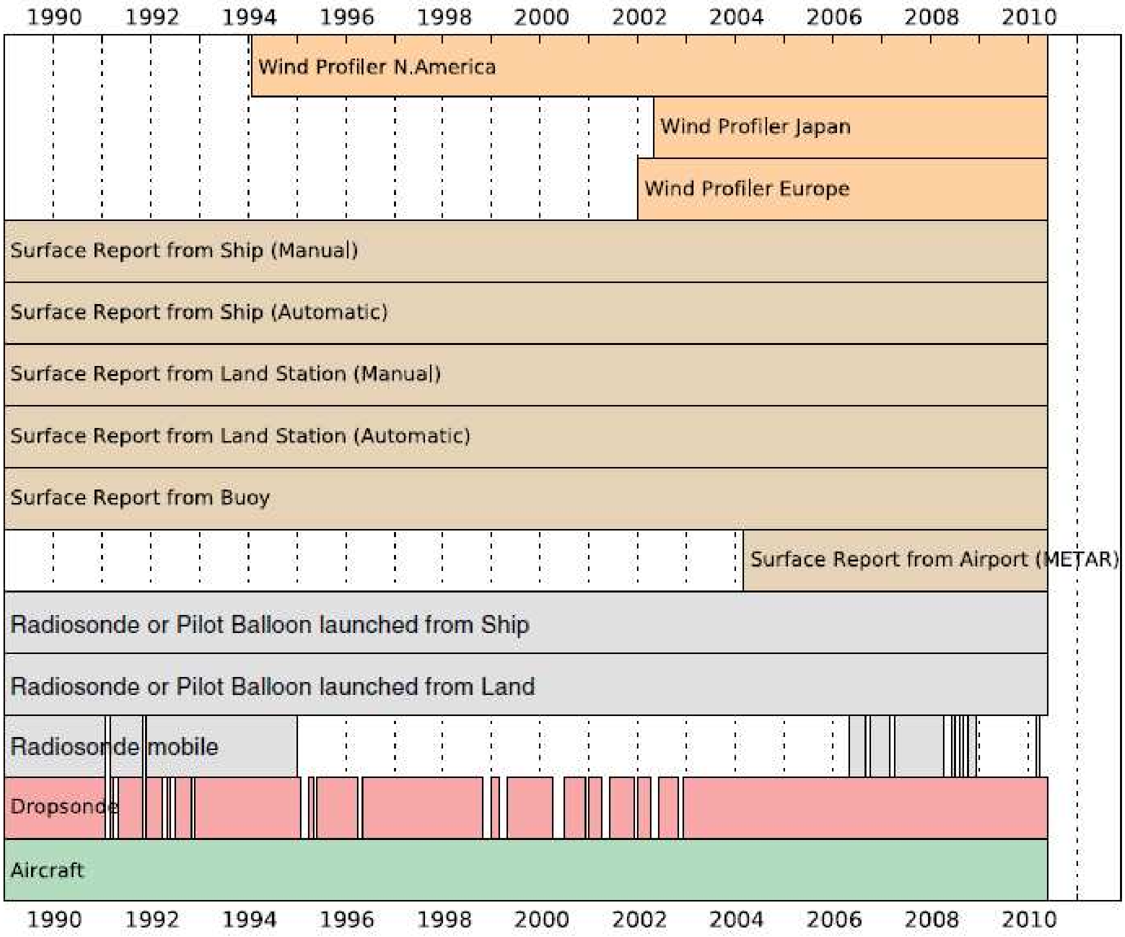

Figure 1. Timeline of conventional observations assimilated in ERA Interim (Dee et al. 2011)

Average wind (u, v) components (at 10 m height) were downloaded for the period 1997–2010 with 6 h temporal and 1.5°×1.5° spatial resolution from the ECMWF webpage (http://data-portal.ecmwf.int/data/d/interim_daily/) over Hungary *(Figure 2).*

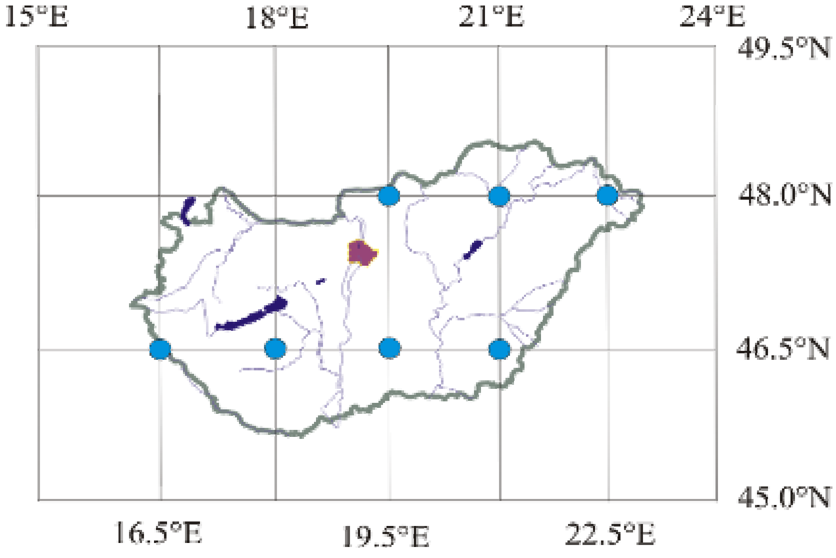

Figure 2. Geographical location of ERA Interim grid points over Hungary

3 ESTIMATIONS AND RESULTS

Hourly wind speed and wind gust data of Hungarian synoptic stations were analysed for the second subseries (1997–2010). Using monthly averages spatial distributions of fitted linear trends are presented in *Figure 3* where, red and blue colours demonstrate increasing and decreasing tendencies, respectively. The sizes of the circles indicate the quality of changes. Contrary to previous analyses (Radics – Bartholy 2008) monthly trends show significant decline in April, but slightly increasing tendencies appear in some stations during December, March and June. Regarding wind gust values, trend coefficients significantly decreased in April almost over the whole territory of Hungary, in January and November in the western part of Transdanubia, moreover in February and June in the middle of the country. In October, March and December wind gust averages show an increasing trend at some measuring sites.

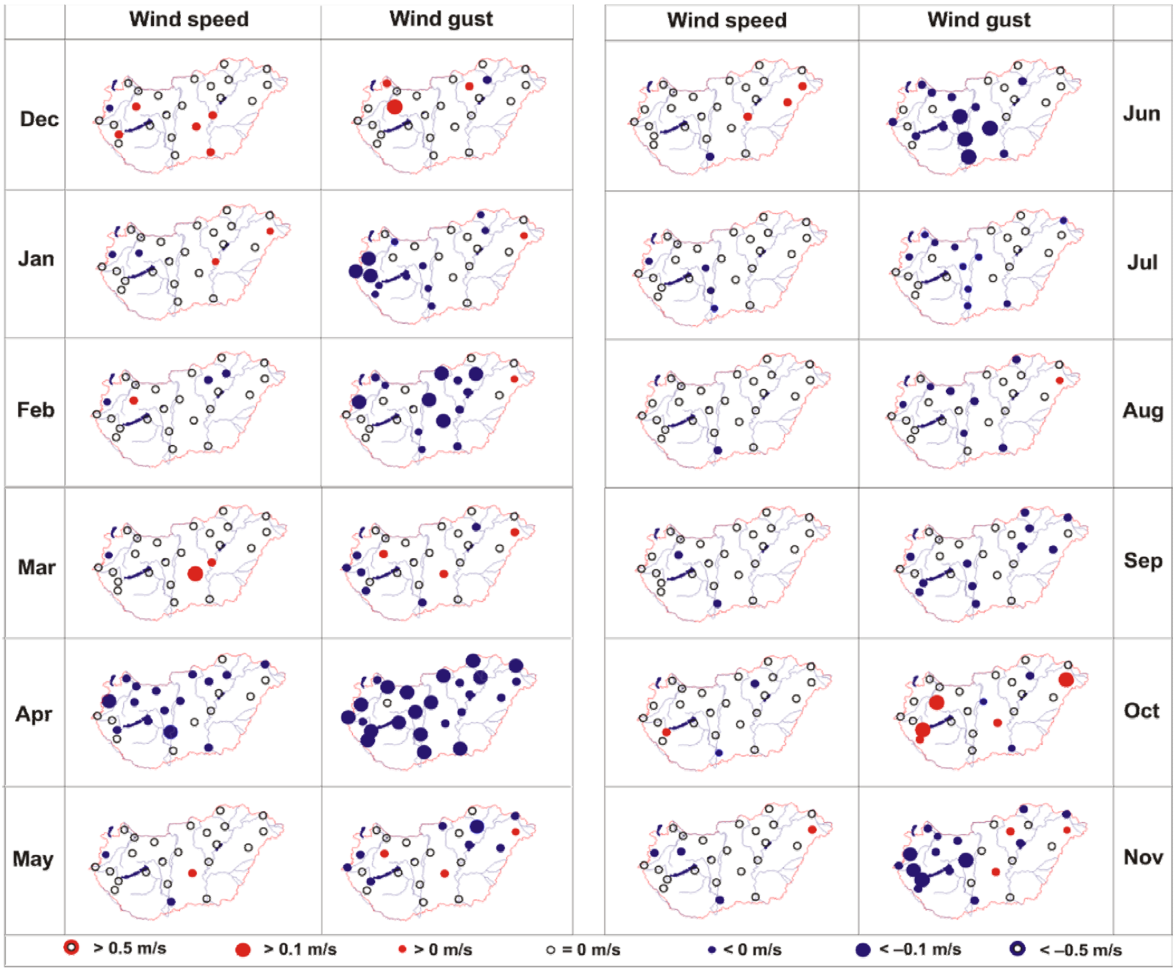

Figure 3. Spatial distribution of linear trends fitted on average wind speed and wind gust values over Hungary (1997–2010)

Similar analysis was carried out for different percentile values of the measured time series. Spatial distribution of trend coefficients of the linear trend fitted on the 0.9 and 0.99 percentile values is presented in *Figure 4* and *5*, respectively. Comparing *Figure 3*, *4*, and *5* it is observable that the higher the percentiles, the bigger the changes. Significant decreasing tendencies (blue dots) reappeared in April, while the number of positive trends (red dots) increased considerably.

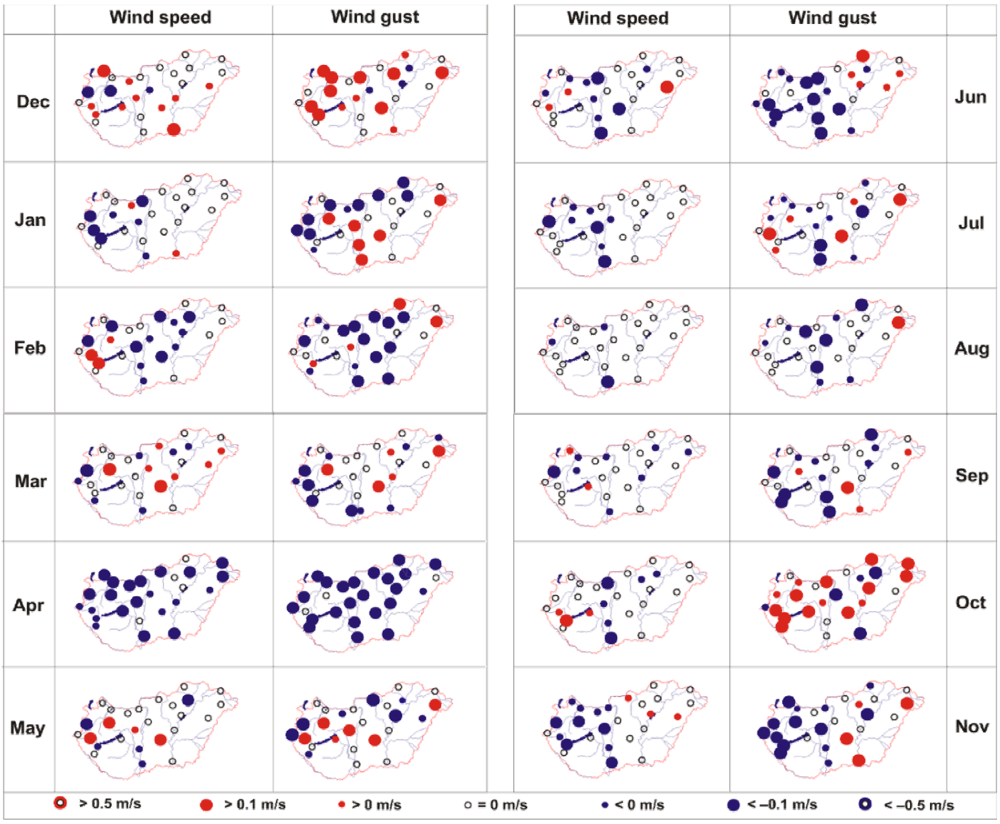

Figure 4. Spatial distribution of linear trends fitted on the 0.9 percentiles of wind speed and wind gust values (1997–2010)

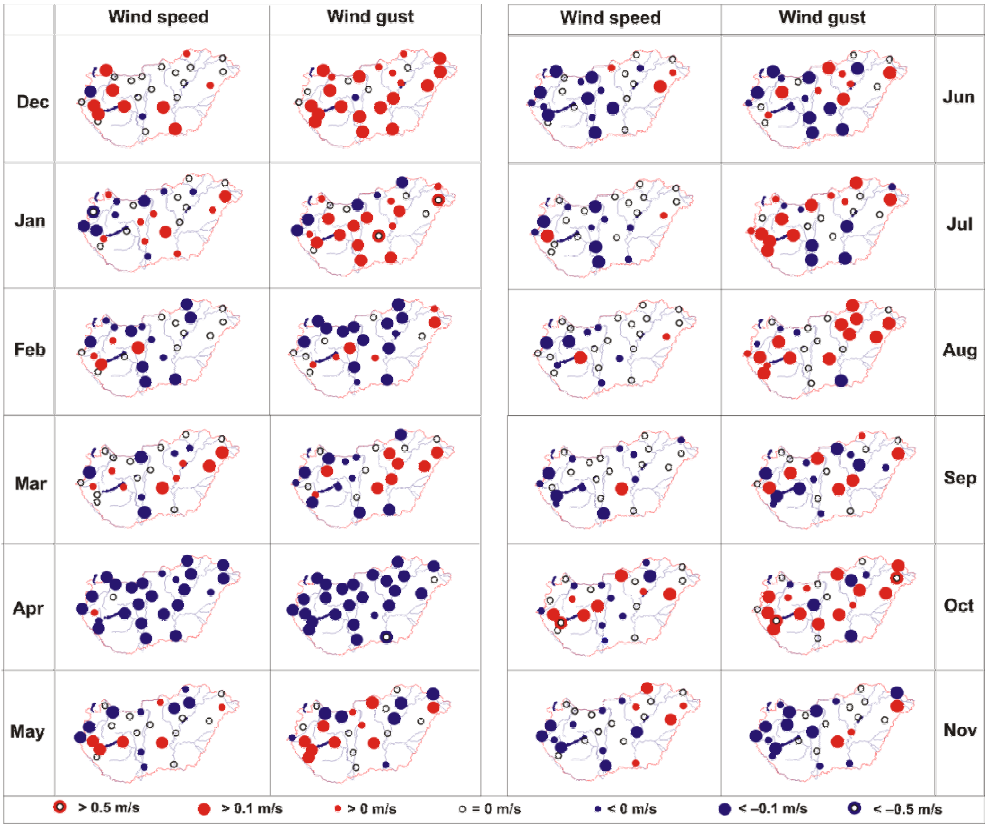

Figure 5. Spatial distribution of linear trends fitted on the 0.99 percentiles of wind speed and wind gust values (1997–2010)

Considering the main results of studies on statistics of differences between observations and hindcasts, spatially and temporally inhomogeneous measured wind speed data and reanalyzed data were compared for Hungary. ERA Interim reanalysis wind speed data were analysed (*Figure* 6 and *7*). Reanalysis data sets were controlled and in some cases corrected, so they can be considered homogeneous data series. In cause of the further study of ERA Interim, spatial distribution of wind speed extremes were analyzed (1997–2010) using three-year moving averages of different percentile values.

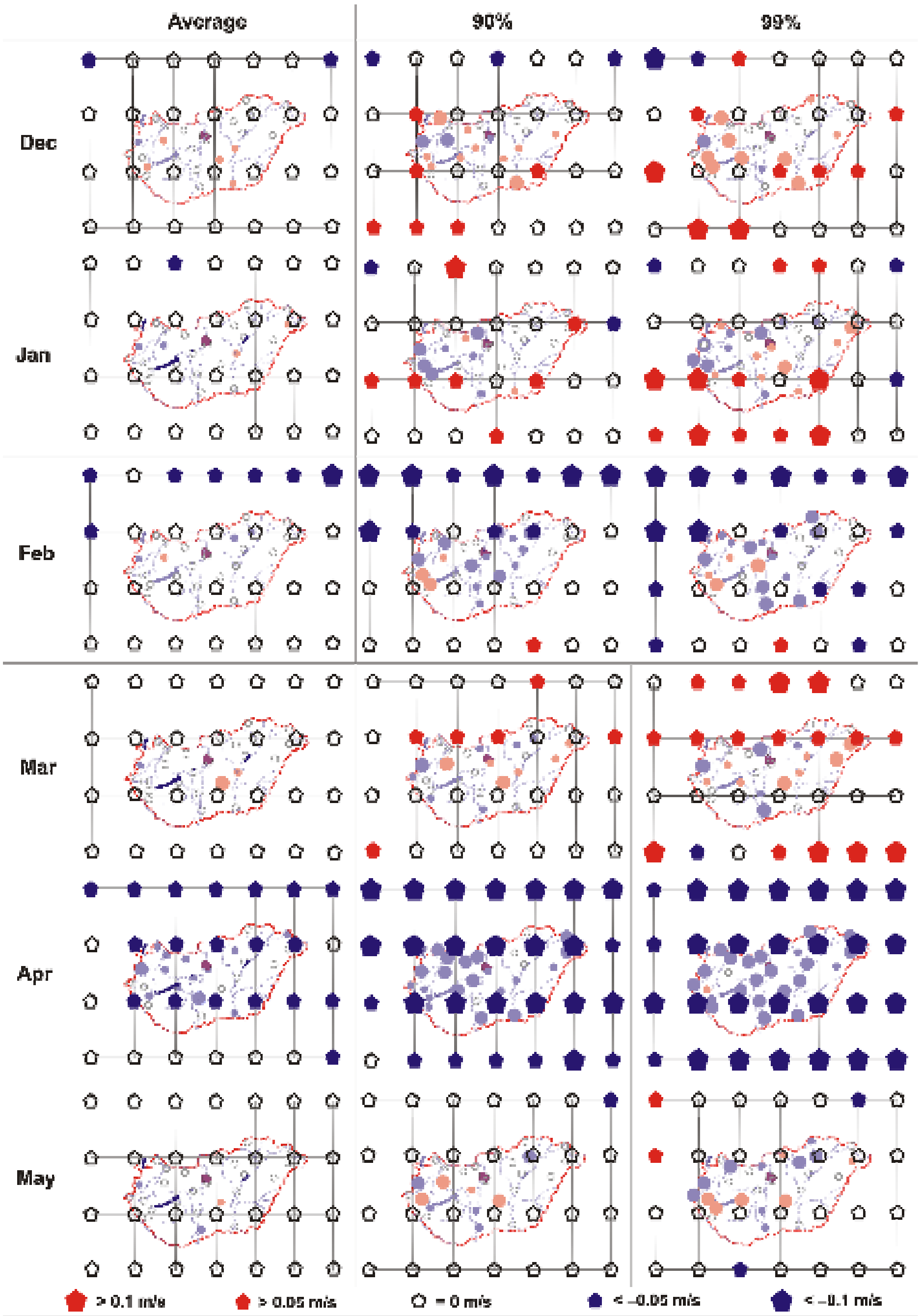

Figure 6. Spatial distribution of trend coefficients of the linear trends fitted on average and the different percentile values (90% and 99%) calculated from the yearly subseries of ERA Interim wind speed values between 1997 and 2010

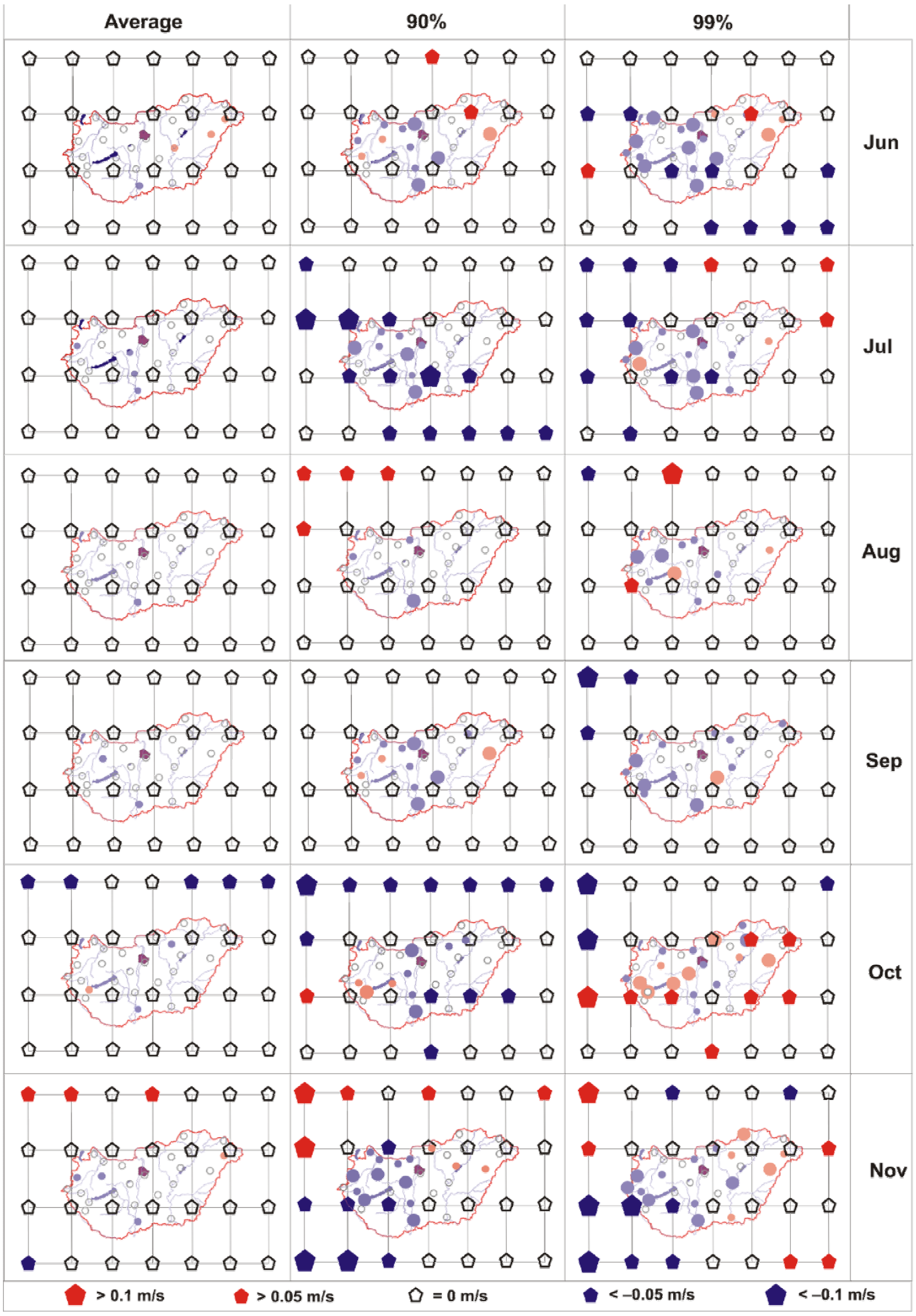

Figure 7. Spatial distribution of trend coefficients of the linear trends fitted on average and the different percentile values (90% and 99%) calculated from the yearly subseries of ERA Interim wind speed values between 1997 and 2010

In *Figure 6* and *7* pentagonal symbols were used to demonstrate the changes of wind conditions. Generally it can be stated again that the higher the percentiles, the bigger the changes. In close correspondence with the results of synoptic data, a decreasing trend was found in April, July and November over Hungary. Increasing trends appeared in some cases in January, March, October and December.

Summarizing the main results, the following conclusions can be drawn: (1) The preliminary results show strong relationships between the corresponding periods of ERA and the station data. (2) In order to estimate regional climate change effects, spatially and temporally homogeneous data series of ERA Interim seem to be an appropriate tool to substitute the measured data over Hungary. (3) Analysing 14-year long (1997–2010) average wind speed and gust values, generally decreasing tendencies were found. A significant trend appeared first of all in April. To answer the question whether the observed tendencies are effects of regional climate change or consequences of climate fluctuation, needs further studies.

Acknowledgements: Authors are grateful to the Geoinformation Service of the Hungarian Defence Forces for the wind databases of the Hungarian synoptic meteorological stations and to the Hungarian Meteorological Service for the ERA Interim data sets.

Research has been supported by the Hungarian Academy of Sciences under the program 2006/TKI/246 Adaptation to climate change, by the Hungarian National Science Research Fund under grants T-049824, K-67626, K-69164 and K-78125, and by the Hungarian Ministry of Environment and Water Management

Furthermore, the support of the János Bolyai Research Scholarship of the Hungarian Academy of Sciences is appreciated.

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10.37045/aslh-2011-0004 *Acta Silv. Lign. Hung., Vol. 7 (2011) 49–61*

Effects of Simulated Forest Cover Change on Projected Climate Change – a Case Study of Hungary

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Abstract – Climatic effects of forest cover change have been investigated for Hungary applying the regional climate model REMO. For the end of the 21st century (2071–2100) case studies have been analyzed assuming maximal afforestation (forests covering all vegetated area) and complete deforestation (forests replaced by grasslands) of the country. For 2021–2025, the climatic influence of the potential afforestation based on a detailed national survey has been assessed. The simulation results indicate that maximal afforestation may reduce the projected climate change through cooler and moister conditions for the entire summer period. The magnitude of the simulated climate change mitigating effect of the forest cover increase differs among regions. The smallest climatic benefit was calculated in the southwestern region, in the area with the potentially strongest climate change. The strongest effects of maximal afforestation are expected in the northeastern part of the country. Here, half of the projected precipitation decrease could be relieved and the probability of summer droughts could be reduced. The potential afforestation has a very slight feedback on the regional climate compared to the maximal afforestation scenario.

climate change / forest cover change / drought probability

Kivonat – A klímaváltozás hatáskorlátozásának esélyei erdőtelepítéssel Magyarországon. A magyarországi erdők klímaváltozás-hatáskorlátozó szerepét három felszínborítás-változási forgatókönyvre számszerűsítettük a REMO regionális klímamodell segítségével. A 2071–2100-as időszakra vizsgáltuk, hogy a feltételezett maximális erdőtelepítéssel (minden növényzettel borított felszín erdő), valamint a hazai erdőterületek gyeppel történő helyettesítésével milyen irányban és mértékben befolyásolhatók az előrevetített hőmérséklet- és csapadéktendenciák. A 2021–2025-ös periódusra a rossz adottságú és gyenge minőségű szántók helyére tervezett erdők éghajlati hatását elemeztük. A modellszimulációk eredményei alapján az erdőterület változás, amennyiben nagy kiterjedésű, összefüggő területeket érint, hatással van a regionális klímára. A feltételezett maximális erdőtelepítéssel a nyári hónapban a csapadékmennyiség növekszik, a felszínhőmérséklet csökken, melynek nagysága régiónként eltérő. A legnagyobb hatás az ország északkeleti részén várható, ahol a klímaváltozással járó csapadékmennyiség-csökkenés fele kiegyenlíthető lenne és az aszályos nyarak száma is csökkenhet. A potenciálisan megvalósítható, országos átlagban 7%-os erdőterület növekedésnek nincs jelentős hatása a regionális éghajlati viszonyokra, bár a lokális klimatikus hatások kedvezőek lehetnek. Az erdő-klíma kölcsönhatások számszerűsítése nem csak az erdők klímavédelmi szerepéről ad információt, hanem az éghajlatváltozás következményeinek megelőzését, enyhítését célzó stratégiák alapja is lehet.

klímaváltozás / erdőtelepítés / aszálygyakoriság

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1 INTRODUCTION

For Hungary, the projected warming and drying trend of summers is significant in the 21st century (Christensen 2005; Bartholy et al. 2007; Bartholy – Pongrácz 2007; Szépszó – Horányi 2008; Krüzselyi et al. 2011; Pieczka et al. 2011). Not only the climatic means but also the extremes are affected by climate change. The latter are more important from ecological point of view. Probability and severity of summer droughts are expected to be significantly higher, droughts might occur in every second summer for the period 2071–2100 (Gálos et al. 2007) that may have severe impact on agriculture and forestry. Forests are not able to adapt to rapid changes of climatic conditions. Especially zonal tree species are affected at their lower (xeric) limit of distribution (Mátyás et al. 2009). Regional impact studies show that recurrent droughts cause growth decline and mortality, e.g. in beech forests in Southwest Hungary (Berki et al. 2009; Lakatos – Molnár 2009). Ecological models of forest distribution expect the reduction of macroclimatically suitable areas for beech for the future and the possible disappearance of this species from Hungary (Mátyás et al. 2010; Czúcz et al. 2011).

In turn forests interact with climate through biogeophysical and biogeochemical processes. Focusing on the physical effects, they can alter the climate conditions, precipitation and temperature variability through their influence on surface energy fluxes and water cycle on various scales (e.g. Pielke et al. 1998; Pitman 2003; Betts 2007; Seneviratne et al. 2010; Móricz 2010). Changes of the land cover due to climatic conditions and human influence feed back to the atmosphere, can lead to the enhancement or reduction of the projected climate change signals (Feddema et al. 2005; Bonan 2008; Wramneby et al. 2010).

Climatic effects of forests are determined by various contrasting feedbacks (e.g. Hogg et al. 2000; Anav et al. 2010; Teuling et al. 2010). Results of model simulations agree quite well regarding biogeophysical effects in boreal and tropical forests (Dickinson – Kennedy 1992; Bonan 2008; Göttel et al. 2008). Whereas the magnitude of the net climate forcing and benefit of temperate forests and their role in the climate change mitigation is considered smaller or uncertain (Bala et al 2007; Jackson et al 2008), as model results are conflicting.

Hungary has been selected as study area because of

- large scale land use changes,
- high sensitivity of zonal forest belts of the lowlands (Mátyás – Czimber 2004; Jump et al. 2009),
- serious consequences (i.e. forest cover loss) of climate change at xeric limit.

In Hungary, large scale afforestations were carried out in the last 50 years, which is planned to continue also in the near future. Results of mesoscale model studies showed that land use change in the 20th century already altered weather and climate (Drüszler et al. 2010). So far however, climatic effects of forest cover change in Hungary have not been investigated for longer future time periods on regional scale. Information about the forest-climate interaction is essential both for the assessment of mitigating effects, and for the development of future adaptation strategies.

Case studies have been carried to investigate

- climatic influences of maximal afforestation, deforestation and potential afforestation and its regional differences,
- magnitude of the climate change mitigating effects of maximal afforestation with special focus on precipitation and drought probability.

2 MODEL AND METHODS

2.1 The regional climate model REMO

The climate change driven by emission change and land cover change have been studied applying the REgional climate MOdel, REMO (Jacob 2001; Jacob et al. 2001; Jacob et al. 2007). This is a regional three-dimensional numerical model of the atmosphere. The prognostic variables are calculated based on the hydrostatic approximation. Land cover is described by its physical properties in REMO: leaf area index and fractional vegetation cover for the growing and dormancy season, background albedo, surface roughness length of the vegetation, forest ratio, plant-available soil water holding capacity and volumetric wilting point. These properties are allocated in the global dataset of land surface parameters (Hagemann et al. 1999; Hagemann 2002) for each land cover type.

In the current model version biogeochemical processes and vegetation dynamics are not considered. Vegetation phenology is represented by the mean climatology of the annual cycle of leaf area index, vegetation ratio and background albedo (Rechid and Jacob 2006; Rechid et al. 2008a,b). The values of these vegetation characteristics are varying monthly throughout the year, the other land surface parameters remain constant in time.

For Hungary, REMO has been validated against observations for temperature, precipitation (Jacob et al. 2008; Szépszó – Horányi 2008) as well as for the occurrence and severity of droughts (Gálos et al 2007). It has been also applied to climate change projections (Szépszó – Horányi 2008; Szépszó 2008; Jacob et al. 2008; Gálos et al. 2007; Radvánszky – Jacob 2008; Radvánszky – Jacob 2009) and land use change studies (Gálos et al. 2011) for the Carpathian basin.

2.2 Experimental setup

The simulation domain covers Central Europe *(Figure 1)* with 0.176° horizontal grid resolution. The model has been initialized and driven by REMO 0.44° simulations, applying a double nesting procedure.

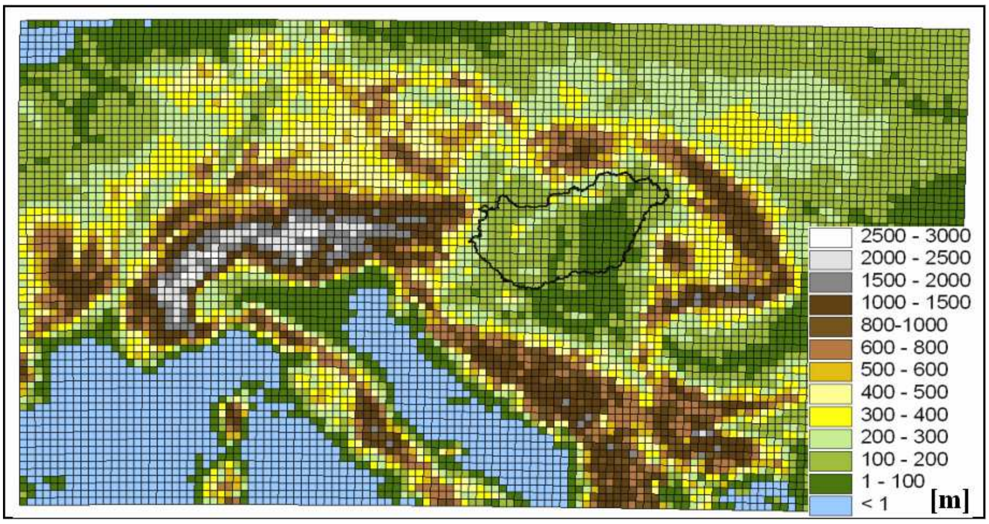

Figure 1. Simulation domain

The following model simulations have been performed and analyzed *(Table 1):*

- *Reference simulation* for the past (1961–1990) with present forest cover based on the CORINE Land Cover vector database[1] for Hungary.

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[1] http://dataservice.eea.eu.int/

- *Climate change simulations* for the future (2021–2025, 2071–2100) with present land cover applying the A1B IPCC-SRES[2] emission scenario (IPCC 2007) serving as reference simulations for the land cover change experiments.
- *Forest cover change simulations* for the future, under enhanced greenhouse gas conditions (A1B IPCC-SRES emission scenario):
  a) *Maximal afforestation simulations* for 2021–2025 and 2071–2100 with the assumption that the whole vegetated area of Hungary will be forest *(Figure 2)* and the new afforestations will be carried out with deciduous species;
  b) *Deforestation simulation* for 2071–2100 replacing the whole forested area in Hungary with grassland *(Figure 2)*;
  c) *Potential forest cover simulation* for 2021–2025 based on a survey of ecological potential for afforestation in Hungary (Führer 2005). For the 50 forest regions, this afforestation plan suggests to increase forest cover on marginal agricultural land *(Figure 3).* This means a 7% increase (6.5% deciduous and 0.5% coniferous) of the present 20% share of forests until the 2030s. The exact location of the additional forest area within the region is not determined. Considering the spatial distribution of the agricultural land, the potential increase of deciduous and coniferous forests has been allocated to all model gridboxes *(Figure 3).*

Table 1. Experiment characteristics and time periods

Experiment	*Reference*	*Deforestation*	*Maximal afforestation*	*Potential forest cover*
Characteristics	Present forest cover unchanged	Grassland over all forested area	Forests covering all vegetated area	Some agricultural areas replaced by forest
Time period	1961–1990 2021–2025 2071–2100	2071–2100	2021–2025 2071–2100	2021–2025

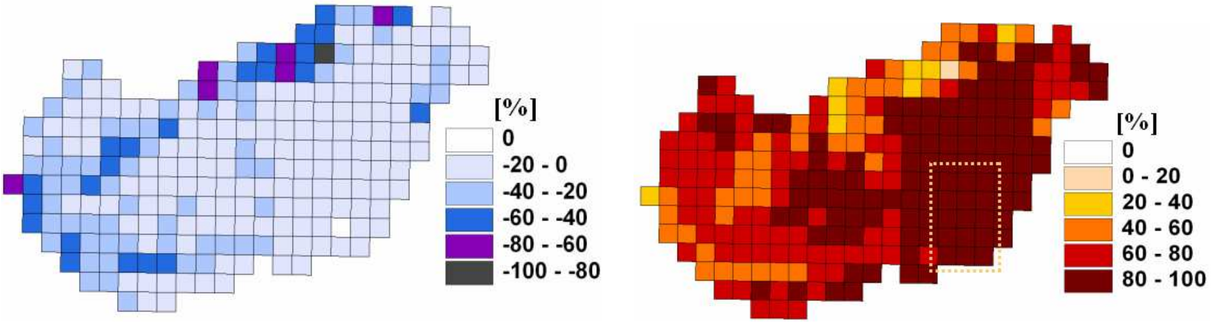

Figure 2. Change of the forest cover for deforestation (left) and maximal afforestation (right) compared to the reference. The region in Southeast Hungary with the largest increase of forest cover is marked

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[2] A1: very rapid economic growth, global population peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system; A1B means a balance across all sources.

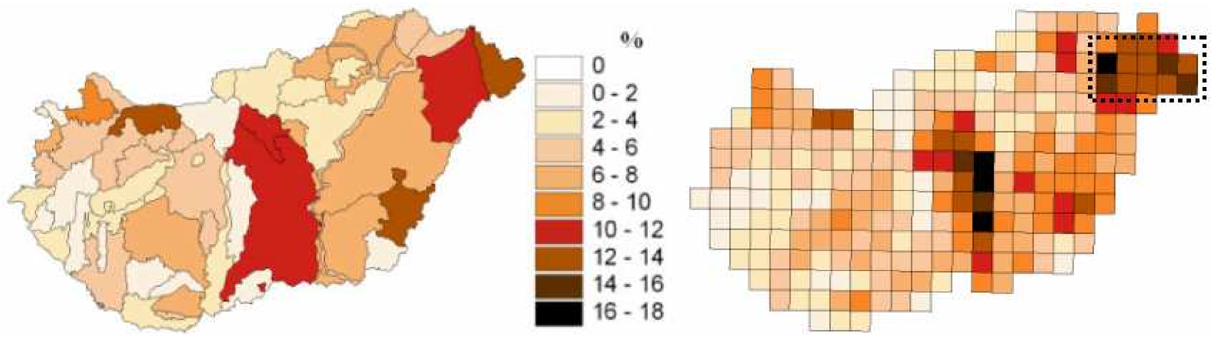

Figure 3. Potential increase of forest cover for the 50 forest regions (left; Führer 2005) and its appearance on the model grid (right). The region in with the largest increase of deciduous forests is marked

Within the simulation domain, land cover has been changed only in Hungary. For each forest cover change scenario a new land surface parameter set has been calculated. Afforestation leads to the increase of the leaf area index and roughness length and to the decrease of the surface albedo, whereas deforestation has opposite effects (not shown in detail). The changes of these parameters correlates linearly to the magnitude of the forest cover change in the grid boxes.

2.3 The main steps of the analyses

Because of the special focus of the study on summer droughts, simulation results for May, June, July and August have been selected for analyses and considered '*summer*'. In these months water availability is especially important in Hungary for forest growth (e.g. Czúcz et al. 2011). The leaf area index reaches its maximum, which has a strong influence on the land-atmosphere interactions.

First, *climate change driven by maximal afforestation and deforestation* have been assessed comparing simulated evapotranspiration, surface temperature and precipitation with and without forest cover change for the time period 2071–2100. The theoretical options of maximal afforestation and deforestation provide information about the maximal climatic effects of forest cover change in the model. Secondly, feedback of the potential afforestation on transpiration and precipitation has been investigated for the near future (2021–2025).

Third, the magnitude of the effect of maximal afforestation on precipitation as well as on the probability and severity of droughts has been analyzed relative to the magnitude of the climate change signal for the end of the 21st century. Simulations without any land cover changes for 2071–2100 vs. 1961–1990 served as reference. *Climate change driven by emission change and maximal afforestation* has been determined comparing the results of the maximal afforestation experiment (2071–2100) to the reference study of the past (1961–1990). For the detailed analysis of the regional differences, sub-areas (the region with the largest increase of forest cover, the region most affected by warming and drying, the area in which the precipitation increasing effect of maximal afforestation is simulated to be the largest) have been selected.

Meteorological droughts have been defined and classified based on Gálos *et al* (2007): for each investigated year the relative precipitation anomaly has been calculated taking mean summer precipitation sum in the period 1961–1990 as reference. Weather conditions were considered as drought if the relative precipitation decrease was larger than 15% of the reference. For more severe precipitation anomalies, further severity classes have been determined. A Mann-Whitney U-Test (Mann – Whitney 1947) has been applied to investigate the significance of the climatic effects of forest cover change. This ranking test does not assume a normal distribution.

3 RESULTS

3.1 Climate change driven by maximal afforestation and deforestation

The spatial correlation between the magnitude of forest cover change and its climatic effects has been investigated including all Hungarian grid boxes. In the case of the *maximal afforestation simulation*, the higher leaf area index and roughness lengths of forests support the enhanced ability of evapotranspiration. For the time period 2071–2100 the 30-year mean of the summer evapotranspiration rate may be up to 20% higher than with the unchanged forest cover *(Figure 4)*. The changes are statistically significant at 95% confidence level. Due to the cooling effect of the enhanced evapotranspiration, surface temperature might be reduced by up to 0.7 °C. The 30-year mean of the summer precipitation sum may increase by 15% relative to the reference *(Figure 4)*. Based on the results of the Man-Whitney-U-test, the change is significant at 85% confidence level in all grid boxes where precipitation increase due to maximal afforestation exceeds 10%. This confidence level indicates high interannual variability of precipitation within the investigated time period.

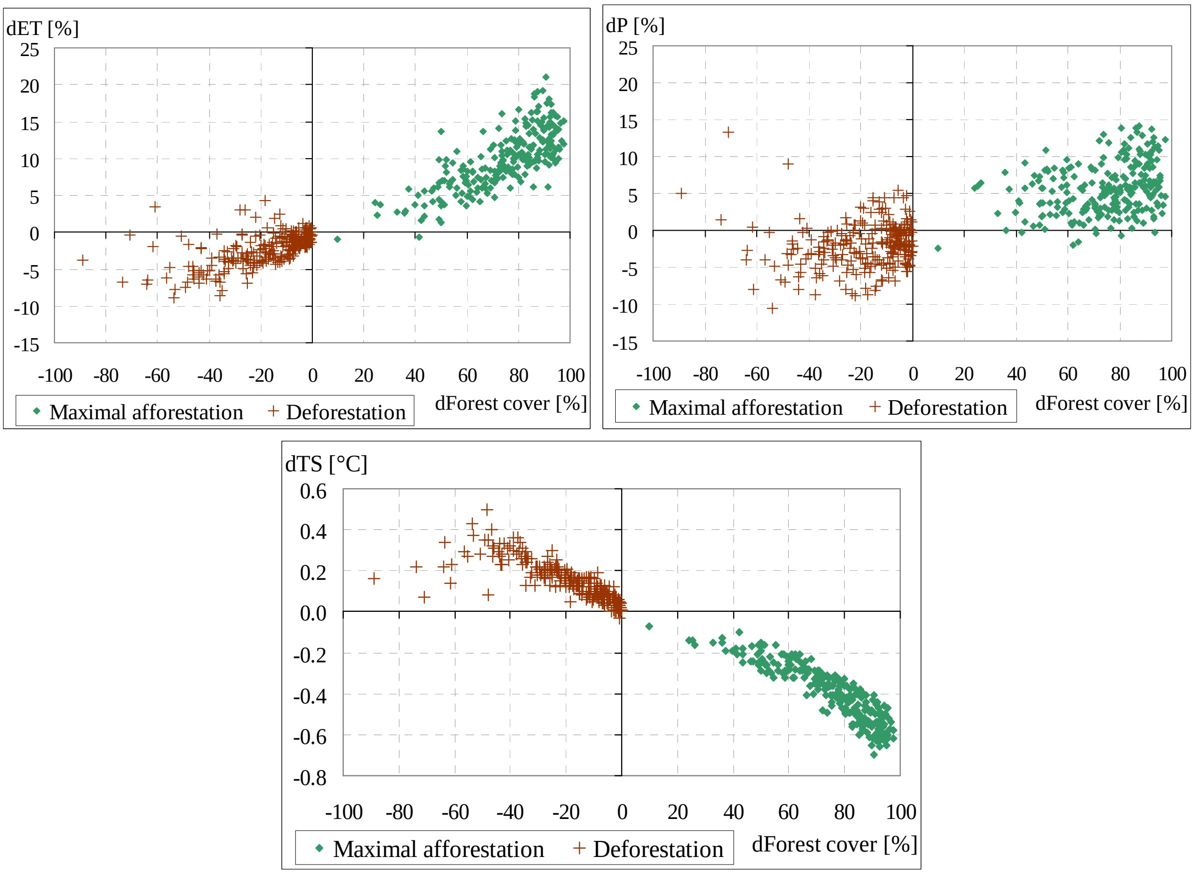

Figure 4. Correlation between the change of forest cover and the change of evapotranspiration (dET; top left), surface temperature (dTS; bottom), and precipitation (dP; top right) for all grid boxes in Hungary in the period 2071–2100

The opposite climate feedbacks can be observed in the deforestation sensitivity study, although the effects are less spectacular than for maximal afforestation. This is explained by the spatial distribution of the forested area in Hungary, which is mostly in small fragments rather than in larger contiguous forest blocks. The fraction of forests in the gridboxes, which could be replaced by grasslands was consequently small. Evapotranspiration rate may decrease by up to 10% and surface temperature may increase by up to 0.5 °C in the grid boxes where larger forest cover decrease has taken place *(Figure 4*). Whereas maximal afforestation resulted in wetter conditions for almost all Hungarian gridboxes, for deforestation the opposite signal is not so clear *(Figure 4).* Climate change signal of deforestation shows weaker statistical significance than the one of maximal afforestation.

The larger the increase/decrease of the forested area in the gridbox, the stronger the feedbacks on evapotranspiration and thereby on surface temperature (*Figure 4*). Changes of these two variables are determined primary by local processes. Precipitation formation is influenced also by large-scale circulation therefore it cannot be directly correlated with the local forest cover change.

3.2 Climatic effects of potential afforestation

For the time period 2021–2025 the climatic influence of the proposed afforestation program has been analyzed for Hungary, comparing the results of the emission scenario simulations with and without forest cover change.

Regarding to the proposed afforestation program the relatively small increase of forest cover (7%) led to significantly smaller changes for all land surface parameters than the maximal afforestation scenario (not shown). In the investigated time period, these modifications of the physical properties of the land surface have no clear effects on the average summer climate.

The largest potential forest cover increase (13%) is proposed for the northeastern region of Hungary *(Figure 3).* This region has been selected and studied more in detail. Due to the higher leaf area index and roughness length of deciduous stands relative to agricultural crops, local increase of transpiration rate (2.5%) has been detected *(Figure 5).* Summer precipitation does not change significantly due to the proposed afforestation, whereas its amount would increase by 5% in the analysed region assuming maximal afforestation *(Figure 5).* In the latter case transpiration would be 12% higher than with the unchanged forest cover.

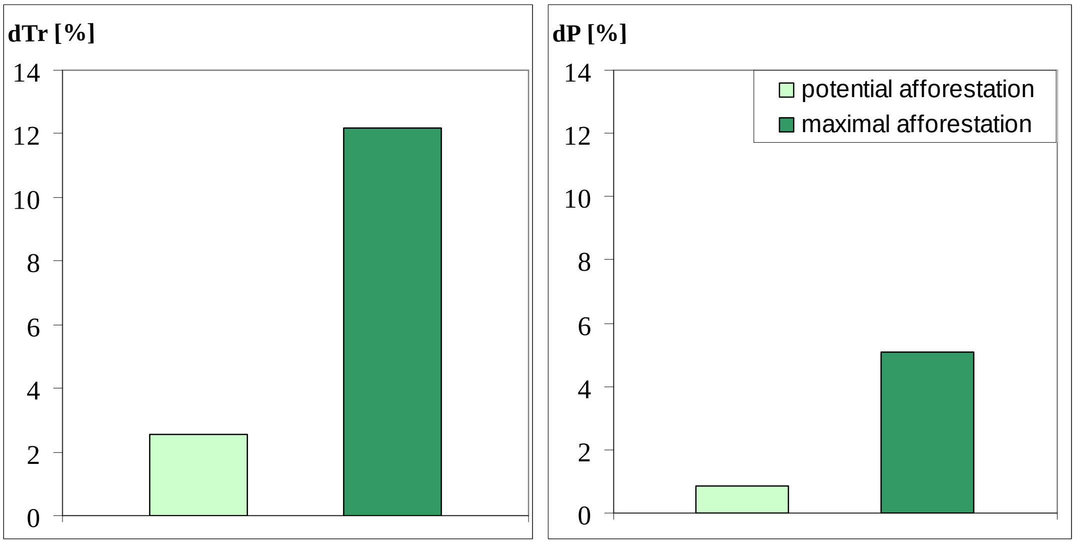

Figure 5. Effect of potential and maximal afforestation on transpiration (dTr; left) and precipitation (dP; right) for the period 2021–2025

Summing it up, the proposed afforestation, dispersed across the country would not alter the climate on a regional scale, although its effects on the local climate might be favourable.

3.3 Climate change driven by emission change and maximal afforestation

First, climate change without any land cover change has been analyzed for temperature and precipitation in the 30-year period at the end of the 21st century (2071–2100) with reference to the 30-year climate period in the 20th century (1961–1990). The simulation results indicate that the southwestern part of Hungary is affected most by warming and drying (Gálos et al. 2011). Here, the projected increase of the temperature may be larger than 3.5 °C (not shown) and the decrease of the summer precipitation sum may exceed 25% *(Figure 6)*.

Second, the region has been determined, where maximal afforestation has the largest effect on precipitation in the period 2071–2100. *Figure 6* shows that the increase of the summer precipitation sum due to maximal afforestation is the largest in the northeastern part of the country, which does not correspond to the area with the largest amount of afforestation. Possible reasons for it can be the more humid air over mountains and the easier precipitation formation due to the orographic uplift as well as the characteristic large scale circulation patterns in summer.

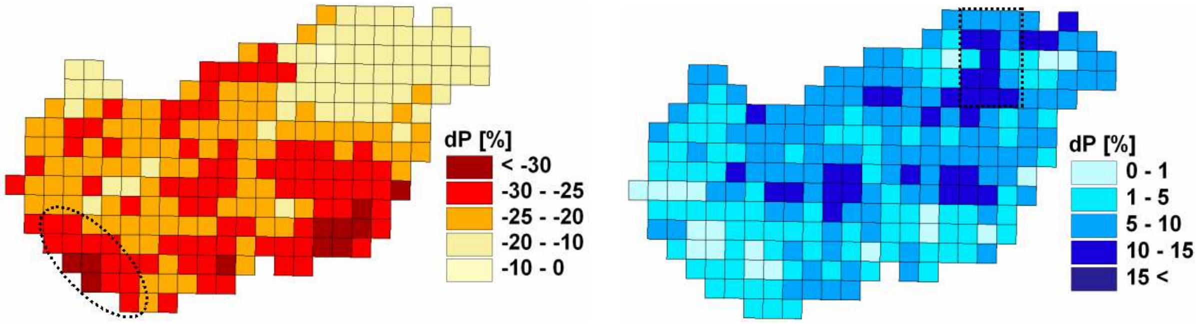

Figure 6. Change of summer precipitation (dP) due to climate change (2071–2100 vs. 1961–1990; left) and modulated by maximal afforestation (2071–2100; right). The two regions selected for detailed analyses (Southwest and Northeast Hungary) are marked

These results were the motivation to study the spatial differences of the possible climate change mitigating effects of forest cover for the country mean (Hungary) and for the following three regions:

- Southwest Hungary (SWH): the region most affected by warming and drying (*Figure 6*),
- Southeast Hungary (SEH): the region with the largest increase of forest cover (*Figure 2*),
- Northeast Hungary (NEH): the area in which the precipitation increasing effect of maximal afforestation is simulated to be the largest (*Figure 6*).

Figure 7 clearly shows that in all three regions and for whole Hungary the projected decrease of precipitation caused by emission change can be reduced by the increase of forest cover. The magnitude of the feedback of maximal afforestation on precipitation differs among regions. In the area most affected by climate change (SWH), precipitation increase due to maximal afforestation is relatively small. In Southeast Hungary, the significant decrease of summer precipitation can be weakened through the increase of the forested area. In the partly mountainous region of Northeast Hungary, the projected tendency of drying is the mildest, where the simulated increase of the summer precipitation sum due to maximal afforestation is the largest (9%). Here, more than half of the projected climate change signal for precipitation could be relieved with enhanced forest cover *(Figure 7)*.

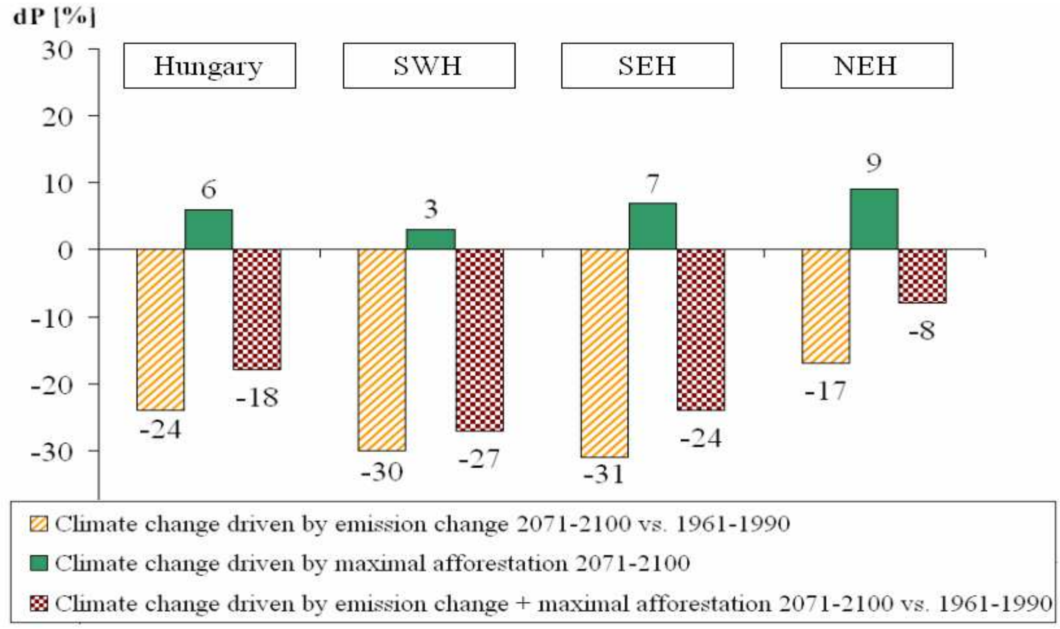

Figure 7. Change of the summer precipitation sum (dP) driven by emission change (2071–2100 vs. 1961–1990), by maximal afforestation (2071–2100) and by emission change + maximal afforestation in whole Hungary and in the three investigated regions (SWH: Southwest Hungary, SEH: Southeast Hungary, NEH: Northeast Hungary) Adapted from Gálos et al. 2011

For the end of the 21st century the significant decrease of the mean summer precipitation sums result in more frequent dry summers compared to the second half of the 20th century *(Table 2)*. The influence of maximal afforestation on the increase of the probability and severity of droughts has been studied for the selected regions. The spatial differences in the effect of the maximal afforestation are observable also for droughts (*Table 2*). For country mean and for Southwest Hungary, the enlarged forest area has almost no effect on the increase of drought probability (*Table 2*). In Southeast Hungary the total number of dry summers would be reduced by the increase of the forest cover. The largest effects of maximal afforestation would be expected in Northeast Hungary. Here, the increase of the total number of droughts would be reduced by 4 (*Table 2*) that corresponds to the number of the moderate droughts. The probability of the severe droughts above 40% precipitation decrease would not be diminished in this region. Thus, the simulations indicate that afforestation may influence moderate droughts but cannot eliminate severe droughts.

Table 2. Number of droughts in Hungary, Southwest Hungary (SWH) Southeast Hungary (SEH) and Northeast Hungary (NEH) in the period 1961–1990 and projected changes due to climate change and maximal afforestation. dP: relative precipitation decrease

Region		Number of dry summers 1961–1990	Change of the number of dry summers 2071–2100 vs. 1961–1990	
			due to emission change	due to emission change + maximal afforestation
Hungary	Total number of droughts (15% < dP)	12	+6	+5
SWH		13	+8	+7
SEH		11	+11	+8
NEH		8	**+10**	**+6**
	15% < dP ≤ 25%	3	+2	+2
	25% < dP ≤ 40%	4	**+5**	**+1**
	40% < dP	1	+3	+3

4 CONCLUSIONS

A case study has been carried out for Hungary to investigate the chances for mitigating climate change effects through afforestation. Applying the regional climate model REMO, the theoretical option of maximal afforestation resulted in an increase of evapotranspiration (10–15%) and precipitation (up to 10–15%) as well as in a decrease of surface temperature (up to 1 °C). The cooler and moister conditions could mitigate the projected climate change for the entire summer period. The mitigating effect differs among regions. It is simulated to be the largest in the Northeast (where 50% of the projected precipitation decrease could be set off), whereas it is the smallest in the southwestern region. In Northeast Hungary, projected increase of the total number of summer droughts would be significantly reduced (from 10 to 6). Climatic effects of deforestation are weaker, less significant and have the opposite sign than those of maximal afforestation.

The results have to be interpreted in the context of the initial conditions of the studied region, situated in a drought-threatened, ecologically vulnerable part of the closed forest zone at the xeric limits. Projected forest cover and forest composition shifts triggered by climate change, i.e. the expected reduction of the forested area and mass mortality in the drought threatened areas (Berki et al. 2009; Mátyás et al. 2010; Czúcz et al. 2011) and changes from coniferous to deciduous species, have not been taken into account in the simulations, so far.

The climatic benefits of the investigated potential afforestation dispersed across the country (7% increase in country mean) are surprisingly negligible. The survey shows that climatic conditions cannot be influenced meaningfully by potential afforestation on regional scale. Although even practically unrealistic increases of forest cover could not offset the projected climate change, the ecologic significance of indicated effects of land cover changes should not be underestimated. Certain services and local scale benefits of forest cover are highly valued even though their mitigating effect is presently not represented in atmospheric regional climate models.

For Hungary, results of these analyses represent the first regional scale assessment of the climatic role of forests for long future time periods and their role in adapting to climate change. Analyses of the spatial differences in the climate change mitigating effects of afforestations can help to identify the areas, where forest cover increase is the most beneficial and should be primarily supported to reduce the projected tendency of drying. Based on the deforestation scenario, certain regions can be identified, where decrease of forested area enhances the climate change signal. Here, the existing forests should be maintained to avoid the additional warming and drying of the region. Results concerning the climatic feedbacks of forest cover change and its spatial distribution for the 21st century should be an important basis of the future forest policy. Study results may also improve the public awareness of ecological services of forest cover and its role in adapting to climate change.

Acknowledgements: The climate model simulations have been carried out in the Max Planck Institute for Meteorology (MPI-M), Hamburg. The authors give special thanks to the Regional Modelling Group of the MPI-M for fruitful scientific discussions about the simulation results. We thank to Dr. Kornél Czimber for assistance in converting the model grid into GIS. This research was financially supported by the EC-FP7 project CC-TAME (www.cctame.eu; grant agreement n° 212535) and the TÁMOP 4.2.2-08/1-2008-0020 and 4.2.2.B-10/1-2010-0018 joint EU-national research projects.

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Numerical Validation of a Diurnal Streamflow-Pattern-Based Evapotranspiration Estimation Method

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Abstract – The evapotranspiration (ET) estimation method by Gribovszki et al. (2010b) has so far been validated only at one catchment because good quality discharge time series with the required high enough temporal resolution can probably be found at only a handful of watersheds worldwide. To fill in the gap of measured data, synthetic groundwater discharge values were produced by a 2D finite element model representing a small catchment. Geometrical and soil physical parameters of the numerical model were changed systematically and it was checked how well the model reproduced the prescribed ET time series. The tests corroborated that the ET-estimation method is applicable for catchments underlain by a shallow aquifer. The slope of the riparian zone has a strong impact on the accuracy of the ET results when the slope is steep, however, the method proved to be reliable for gentle or horizontal riparian zone surfaces, which are more typical in reality. Likewise, errors slightly increase with the decrease of riparian zone width, and unless this width is comparable to the width of the stream (the case of a narrow riparian zone), the ET estimates stay fairly accurate. The steepness of the valley slope had no significant effect on the results but the increase of the stream width (over 4m) strongly influences the ET estimation results, so this method can only be used for small headwater catchments. Finally, even a magnitude change in the prescribed ET rates had only a small effect on the estimation accuracy. The soil physical parameters, however, strongly influence the accuracy of the method. The model-prescribed ET values are recovered exactly only for the sandy-loam aquifer, because only in this case was the model groundwater flow system similar to the assumed, theoretical one. For a low hydraulic conductivity aquifer (e.g. clay, silt), root water uptake creates a considerably depressed water table under the riparian zone, therefore the method underestimates the ET. In a sandy, coarser aquifer the flow lines never become vertical even bellow the root zone, so the method overestimates the ET rate, thus the estimated ET values need to be corrected. Luckily the prescribed and estimated ET rates express a very high linear correlation, so the correction can be obtained by the application of a constant, the value of which solely depends on soil type.

numerical model / baseflow / groundwater/ riparian vegetation

Kivonat – A vízhozamok napi ingadozásán alapuló párolgásbecslési módszer vizsgálata numerikus modellezéssel. A vízfolyásmenti vegetáció (elsősorban erdők) párolgásának becslésére Gribovszki et al. (2010b) kifejlesztett eljárást, amely a vízfolyások vízhozamának napi ingadozásán alapul eddig csak egy vízgyűjtő lefolyási adatain sikerült tesztelni. Sajnos a módszerhez szükséges nagy időbeli felbontású, pontos vízhozammérések csak igen kis számban fellelhetőek és ezek

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hozzáférhetősége is kérdéses. Egy vízgyűjtő hidrológiai körfolyamatának numerikus modellezés azonban lehetőséget nyújt szintetikus vízhozam idősorok előállítására. A vizsgálat során a minta vízfolyás egy átlagos keresztszelvényében 2D numerikus modellezést végeztünk. A modell-paramétereket egy kezdeti értékhez képest szisztematikusan változattuk és vizsgáltuk a beadott párolgási idősor visszanyerhetőségét. Az eredmények alapján a kimunkált módszer a patakmederben vagy nem sokkal alatta elhelyezkedő vízzáró réteg, ún. sekély víztartók esetén alkalmas a becslésre. A vízfolyás menti zóna lényeges (10% fölötti) meredeksége jelentősebb eltéréseket is okozhat a párolgásbecslésben, annak akár közel vízszintes volta azonban csak kis mértékben módosítja az eredményeket. Ugyancsak erősen befolyásolja a módszer eredményeit a vízfolyásmenti zóna keskeny volta, ugyanakkor a jelentősebb szélessége nincs ilyen mértékű hatással a számításra. A vízfolyásmenti zónán kívüli terep meredeksége ugyancsak nem bír meghatározó befolyással a módszerre. A vízfolyásmeder szélességének növelése, mintegy 4m-es szélességnél már erősen befolyásol, így az új metódus csak kisvízfolyások felső szakaszain alkalmazható. Ugyancsak kis befolyással bír a párolgás nagyságrendjének változatása a becslésre. A leginkább befolyásolják a módszer eredményeit a talajfizikai paraméterek. A vízfolyásmenti zóna környezetében kialakuló áramkép és a módszer hipotetikus áramképének megfelelősége a gyökérzónában sandy clay loam fizikai féleségű talajok estében nyújt pontos eredményt. Az alacsony vízvezetőképességű (pl. agyag, iszap) víztartó esetében a vízfolyásmenti zóna alatt egy jelentős depressziós tölcsér alakul ki, a módszer alulbecsli a párolgást. A homokos, durvább szövetű talajoknál pedig a gyökérzónában az áramlási vonalak nem válnak függőlegessé, hanem közel vízszintesek maradnak (mivel a szükséges vízigény szinte mindig kielégíthető az utánpótlódással), így a módszer felülbecsül. Ez utóbbi esetekben nem teljesül a módszer egy-egy alapfeltételezése, tehát korrekcióra szorul. Szerencsére a modellben beadott és az új módszerrel kapott párolgási értékek lineáris korrelációja igen magas, így a korrekció egy talajtípustól függő konstans szorzó bevezetésével megtehető.

numerikus modell / alapvízhozam / talajvíz / vízfolyásmenti vegetáció

1 INTRODUCTION

Small streams and the neighbouring riparian zone groundwater table generally have characteristic diurnal fluctuations in the baseflow period (*Figure 1.* Gribovszki et al. 2010a). Almost all researchers consider evapotranspiration as the primary inducing factor of the growing-season diurnal signal in streamflow and in shallow groundwater level, and some apply the observed diurnal fluctuations for evapotranspiration estimation methods (White 1932; Meyboom 1964; Reigner 1966; Bauer et al. 2004; Nachabe et al. 2005; Gribovszki et al. 2008; Loheide 2008).

A new, baseflow-fluctuations based groundwater ET estimation algorithm is described by Gribovszki et al. (2010b) but validated only at one catchment *(Figure 1)*. The significant advantage of the method over other existing ones is that it requires only very basic geometric properties (i.e., length and width) of the riparian zone and the stream channel width.

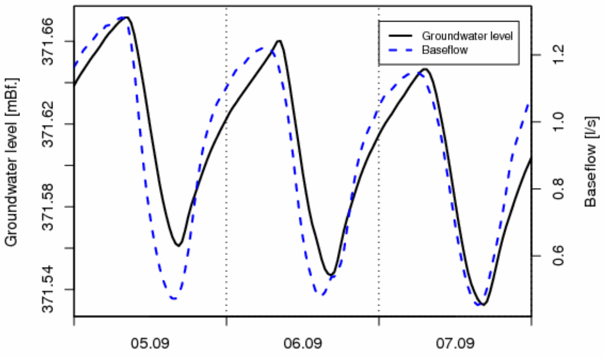

Figure 1. ET-induced diurnal fluctuations in groundwater level and baseflow rates, Hidegvíz Valley experimental catchment near Sopron, Hungary, 2005

2 DERIVATION OF THE BASEFLOW-BASED ET ESTIMATION

The water table within the riparian zone is generally close to the surface and vegetation water uptake during rainless periods comes directly or indirectly from the groundwater. This water use may depress the groundwater table which thus, via an enlarged hydraulic gradient, induces an enhanced seepage from the valley side (and not rarely from the stream as well) toward the riparian zone. *Figure 2* schematically depicts the daily change of the riparian-zone groundwater table and the general groundwater flowpaths in a rainless period of the growing season.

The riparian groundwater hydrograph is a cumulative curve, the result of the dynamic interplay of replenishment as source term and groundwater evapotranspiration as a sink term (Troxell 1936, Gribovszki et al. 2008a). Since in dry periods stream baseflow predominantly originates from the saturated zone, the baseflow hydrograph has a similar shape and characteristics (disregarding of the short temporal shift observable in *Figure 1*) as the groundwater level curve.

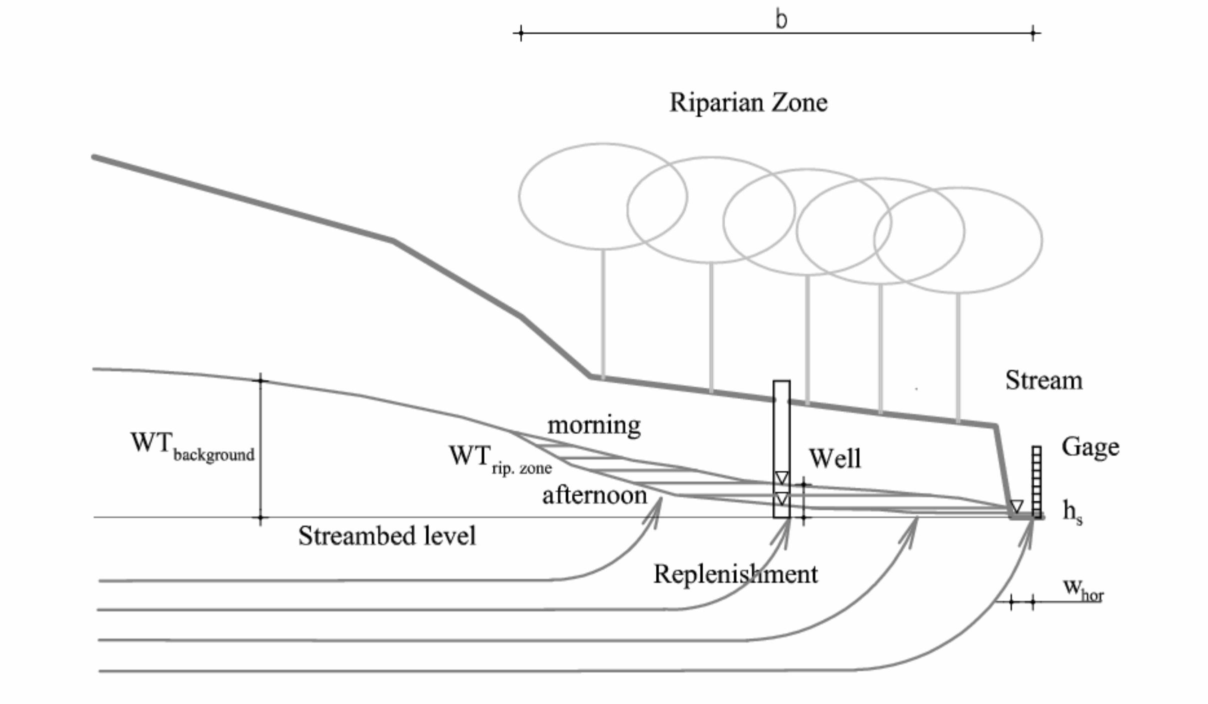

Figure 2. Schematic model of the water table (WT) diurnal change in the riparian zone

The riparian-zone groundwater ET estimation method of Gribovszki et al. (2008a), based on the diurnal fluctuations of the groundwater levels, can be reformulated for the baseflow signal through the employment of a linear transformation, similar to Loheide (2008). The physical interpretation of the linear transformation is that of a linear reservoir for the riparian zone.

Accordingly, the streamflow-based ET-estimation method presented by Gribovszki et al. (2010b) employs the linear reservoir and water balance equations (written for the saturated zone), the latter as

$$\frac{\partial S_r}{\partial t} = S_y(t, WT)\frac{\partial WT}{\partial t}A_{rip} = Q_i - Q_o - ET_{gw}\cdot A_{rip} = Q_{net} - ET_{gw}\cdot A_{rip} \tag{1a}$$

where dS_r / dt [L^3T^{-1}] is the time-rate of change in riparian groundwater storage (S_r), WT [L] the average groundwater level (above reference) in the riparian zone, S_y the specific yield, Q_i, the incoming discharge [L^3T^{-1}] to the riparian zone, and Q_o, the outgoing discharge from the riparian zone to the stream [L^3T^{-1}]. The net supply/replenishment rate is the difference of the incoming and outgoing discharges to and from the riparian zone, $Q_{net} = Q_i - Q_o$, [L^3T^{-1}]. ET_{gw}, is evapotranspiration (directly or indirectly) from the groundwater, $A_{rip} = l \cdot 2b$ [L^2] is the area of the riparian zone, with b denoting the average half-width of it, and l [L], the length of the stream valley (and not the stream), where the riparian vegetation (phreatophytes) is located.

In order to obtain the net supply rate (Q_{net}), let's write Eq. 1a for the late night/early morning hours when ET_{gw} is negligible

$$\frac{\partial S_r}{\partial t} = Q_i - Q_o = Q_{net} \tag{1b}$$

The linear storage equation for Q_0 is

$$Q_o = \frac{1}{T^*} S_r \tag{2}$$

where, T^* [T], is the average residence time of water within the riparian zone.

Eqs. (1b) and (2) yield

$$T^* \frac{\partial Q_o}{\partial t} = Q_i - Q_o \tag{3}$$

Q_o results from stream discharge measurements, while Q_i is obtained from Darcy's law (Gribovszki et al., 2010b), assuming a continuous flow system for the watershed (Tóth, 1963). Due to groundwater evapotranspiration, groundwater streamlines intersect the riparian zone, as illustrated in Fig. 2. Obviously, the density of the streamlines that intersect the riparian zone varies with the actual water demand of the riparian vegetation forming a considerable upward hydraulic gradient during rainless/drought periods of the growing season resulting in near-vertical streamlines directly below the root-zone.

Instead of using the real physical parameters (Gribovszki et al. 2010b), Eq. 3 can be written in a form that only a theoretical relationship (the most simple is linear) is assumed between the water balance components, e.g. $Q_i=f(Q_o)$, yielding regression equations. In this case one does not need a preliminary knowledge of the flow system, because the value of the resulting regression parameter indicates its type. Unfortunately, ET cannot be estimated directly in this way, however the reliability of a physically based method (Gribovszki et al. 2010b) under different conditions can still be tested. The assumed linear relationship between in and outflows, for a unit width of the riparian zone can thus be written as

$$q_i \approx a_1 + m_1 \cdot q_0 \tag{4}$$

where $q_i = Q_i/(2 \cdot l)$ and $q_o = Q_o/(2 \cdot l)$.

In this way Eq. 3 can be written in finite difference form as

$$T^* \frac{\Delta q_o}{\Delta t} = a_1 + m_1 \cdot q_0 - q_o = a_1 - (1 - m_1) \cdot q \tag{5}$$

Rearrangement for q_o yields

$$q_o = \frac{a_1}{1-m_1} - \frac{T*}{1-m_1}\frac{\Delta q_o}{\Delta t} \tag{6}$$

Eq. 6 is of a linear (i.e., $y=a+m\cdot x$) form, where $y = q_0$, $x = \Delta q_0 / \Delta t$, $m = T* \cdot (1 - m_1)^{-1}$, and $a = a_1 \cdot (1 - m_1)^{-1}$. The constant parameters (a and m) of Eq. 6 can be obtained from streamflow measurements in the late night/early dawn period of the day by fitting straight lines to the $\Delta q_0 / \Delta t$ and q_0 data pairs (Gribovszki 2010b). Fig. 3 illustrates the correlation of these data pairs (as a result of the numerical model).

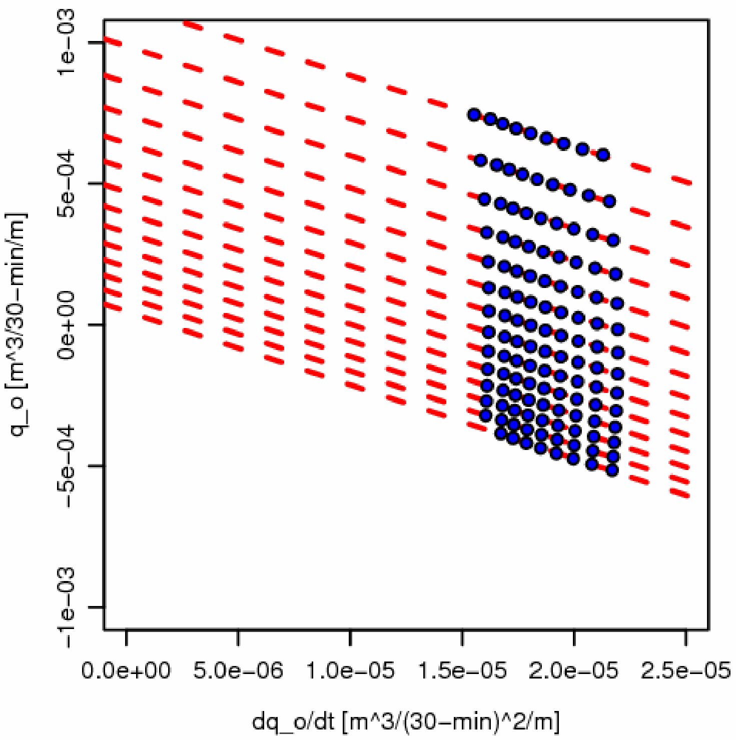

Figure 3. Numerical model data for a loamy aquifer. The dq_0/dt *vs* q_0 *values (dots) with the fitted first-order polynomials (one line per day) from the late-night hours*

Now apply Eqs. 1a, 1b and 2 for the estimation of ET_{gw} ($ET_{gw}\cdot 2b = ET_{gw}\cdot A_{rip} / l$), which, using Eqs. 5 and 6, can be transformed into

$$ET_{gw} \cdot 2b = q_{net} - T*\frac{\partial q_o}{\partial t} \approx a_1 - q_o(1-m_1) - T*\frac{\Delta q_o}{\Delta t} \tag{7}$$

where $q_{net} = q_i - q_o$.

Figure 4 demonstrates the new ET estimation method applied with the synthetic outflow values of the numerical model.

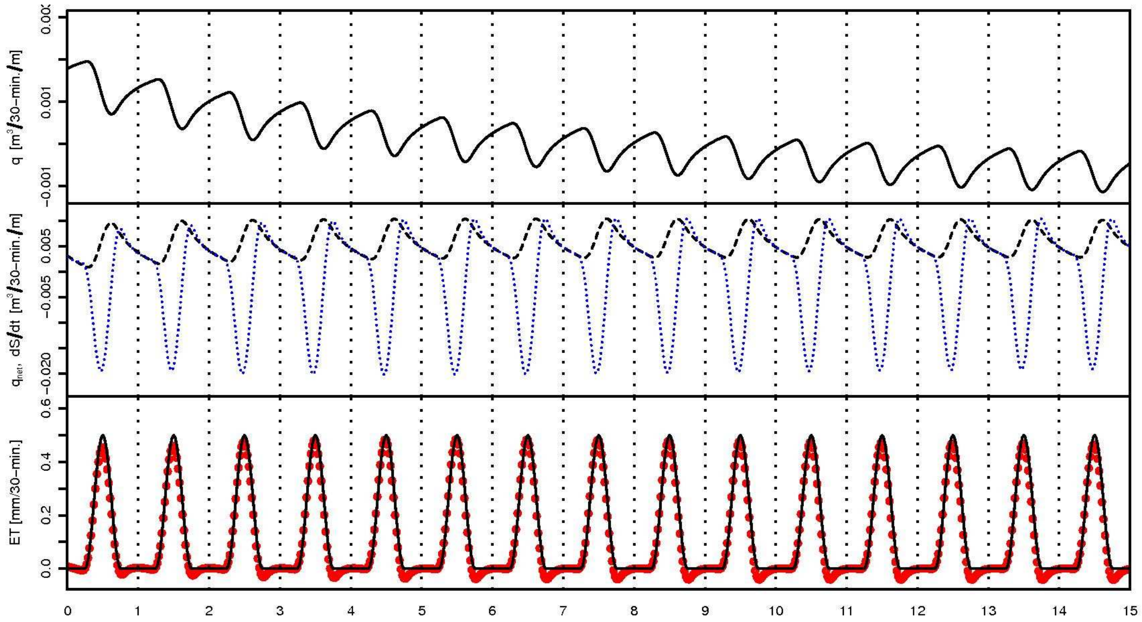

Figure 4. Components of the groundwater evapotranspiration estimation method based on diurnal fluctuations of streamflow (numerical model result without model spin up days in case of loamy aquifer). Top panel: q, measured streamflow; Middle panel: q_{net}*, estimated net groundwater supply (broken line);* dS_r / dt*, estimated groundwater storage change of the riparian zone (punktuated). Bottom panel:* ET_{gw}*, the ET rates estimated by the new method (solid line);* ET_s*, prescribed model ET rates (points)*

The $-m_1$ parameter value is the same as *b/(2w)* in Gribovszki et al. (2010b). So one can check if the $-m_1$ values calculated from the late night regression of the numerical discharge are equal or not with the *b/(2w)* constant values. If they are, one obtains the same ET rates as the prescribed ET time series values. If not, the model does not follow the pre-supposed flow system, therefore the method under the corresponding boundary conditions cannot be applied directly, only with some further modification.

The relationship between the replenishing and the outgoing groundwater discharge may be not linear. This nonlinearity can only be tested on a longer time series, so a 20-day interval was chosen as the time span of modelling. A 20-day time-period is long enough to exceed the model spin-up period significantly. So after omitting these spin up days, one is still left with a sufficient number of values to perform statistical analyses if needed.

3 THE NUMERICAL MODEL SETUP

To test the validity of the new ET estimation method, an adaptive, finite element 2D numerical model was employed for integrating the extended Richards equation (Lam et al., 1987, Szilágyi et al. 2008) vertically

$$\frac{\partial}{\partial x}\left(K(\Psi)\cdot\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K(\Psi)\cdot\frac{\partial h}{\partial y}\right)+s=m\cdot\chi\cdot\frac{\partial h}{\partial t} \tag{8}$$

where K [LT^{-1}] is the hydraulic conductivity (a function of the pressure head, Ψ); h [L] is the hydraulic head; m is the slope of the water retention curve which becomes the coefficient of volume change in the saturated zone; s is the sink term which represents ET [LT^{-1}] in this model; γ is the unit weight of water; and *x*, *y* [L] and t [T] are the horizontal, vertical and temporal coordinates.

First, this numerical model with geometrical and physical model parameters similar to that of Vadkan-valley (the test catchment in Gribovszki et al., 2010b) was used for generating an outflow flux (discharge) series. The numerical outflow values were then used to "back-calculate" the prescribed ET rates in the model.

Figure 5 describes the geometry of the model setup. Each simulation lasted for 20 days with a 30-minute time-step between outputs. The initial condition of the model was a horizontal groundwater level (1.5 m above the streambed) at t=0, equalling the water level in the adjacent stream. Stream-level then was dropped to a fixed elevation (i.e. 0.05 m) for t>0 to induce drawdown of the aquifer. The initial aquifer geometry is similar to Vadkan-valley, for which Gribovszki et al. (2010b) have already employed measured streamflow values for validation of the present method. The riparian aquifer width (*b*) is 20 m, the ground surface (*mf_rip*) has a gentle (1:20) slope, the impermeable layer is horizontal and found at *d* meter (*d* = 1 m) below the streambed. Prescribed horizontal extent (*wr*) of the watershed beyond the riparian zone is 50 m, with a valley-slope (*mf*) of 0.3. The *wr* value for the test catchment is about four-times greater (i.e., ~200 m), but in order to reduce the model run-time it was changed to 50 m. Sensitivity of the method to *wr* has been tested and was found that *wr* = 200 m gave practically the same ET estimates as *wr* = 50 m. Basic aquifer geometric parameters are listed in *Table 1*.

Table 1. The basic parameter-set of the model

b	=	20 m	{one side (half) width of the rip zone }
w_{hor}	=	1 m	{half of the stream width}
wr	=	50 m	{watershed boundary distance from rip. zone side}
d	=	1 m	{depth to the impermeable layer from stream bottom}
mf	=	0.3	{surface slope outside the rip. zone}
mf_rip	=	0.05	{surface slope of the rip. zone}
gyz	=	1 m	{depth of the root zone}
m	=	0	{slope of the impermeable layer}
h_0	=	1.5 m	{starting stream water level at t=0}
h_s	=	0.05 m	{stream water level at t>0}

Aquifer drainage rate was obtained by integrating the horizontal component of the Darcy-flux vectors at $x = b$ along the vertical stream bank and the vertical component of the Darcy-flux vectors where $b < x < (b+w)$ along the horizontal stream bed (w_{hor}). In order to obtain a correct value for *w*, the extent of the vertical seepage face with the corresponding seepage rate had to be considered and it had to be added to the half stream width (w_{hor}). The active vertical extent of the seepage face was determined by the ratio of the horizontal to vertical seepage rates and on average gave an additional 0.5 m (standard deviation ±0.10 m) to the horizontal half stream width.

The $b/2w$ values are listed in Tables 3 and 4 (with corresponding errors relative to the value of $-m_1$), calculated with both a constant 0.5-m long vertical seepage face and also with a seepage face whose length has been estimated by weighting the vertical and horizontal fluxes.

Figure 5 illustrates the setup of the model domain.

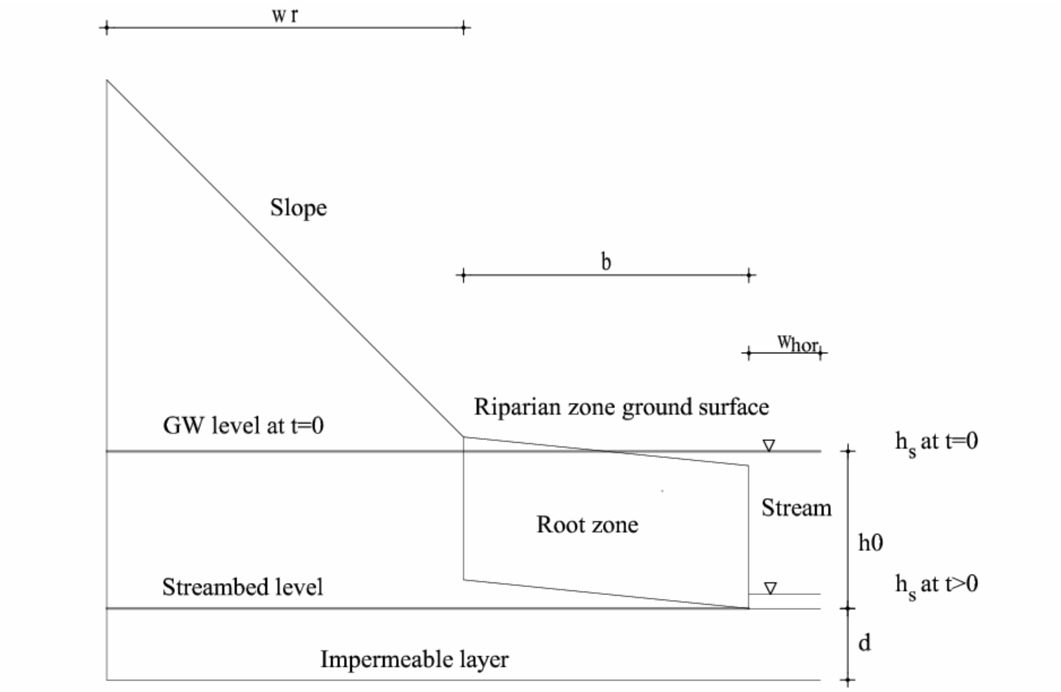

Figure 5. Schematic vertical cross-section of the aquifer employed in the numerical model. The left-side of the aquifer represents no-flow conditions (wr distance from the side of the riparian zone), and the stream (h_s is stream stage) is on the right-side of the riparian aquifer. The x_0, y_0 ($x=0$, $y=0$) coordinates of the model is set where the vertical riparian-zone boundary reaches the streambed level.

Prescribed aquifer material properties are listed in *Table 2.*

Table 2. Hydraulic properties of the model aquifer (after Campbell, 1974; as well as Clapp and Hornberger, 1978)

Hydraulic property	Value/equation	Explanation
φ [–]	Sand=0.395, Loamy sand=0.410, Sandy loam=0.435, Silt loam=0.485, Loam=0.451, Sandy clay loam=0.42, Silty clay loam=0.477, Clay loam=0.476, Sandy clay=0.426, Silty clay=0.492, Clay=0.482	φ – total porosity
K_s [cm/min]	Sand=15.21, Loamy sand=13.51, Sandy loam=3.00, Silt loam=0.622, Loam=0.600, Sandy clay loam=0.544, Silty clay loam=0.147, Clay loam=0.212, Sandy clay=0.187, Silty clay=0.089, Clay=0.111	Ks – saturated hydraulic conductivity
Ψ_{ae} [kPa]	Sand=1.21, Loamy sand=0.90, Sandy loam=2.18, Silt loam=7.86, Loam=4.78, Sandy clay loam=2.99, Silty clay loam=3.56, Clay loam=6.30, Sandy clay=1.53, Silty clay=4.90, Clay=4.05	Ψ_{ae} – air-entry pressure
$\Psi(\Theta)$	$\lvert\Psi_{ae}\rvert\cdot(\varphi/\Theta)^b$	Θ – volumetric water content [–]
$K(\Theta)$	$K_s(\Theta/\varphi)^{2b+3}$ *b*: Sand=4.05, Loamy sand=4.38, Sandy loam=4.90, Silt loam=5.30, Loam=5.39, Sandy clay loam=7.12, Silty clay loam=7.75, Clay loam=8.52, Sandy clay=10.4, Silty clay=10.4, Clay=11.4	b – pore size distribution index

The 1-m thick root zone considered in the model starts at the surface and lies parallel with the sloping ground surface. The water consumption of riparian vegetation is represented by the term *s* (a sink for groundwater and soil moisture, respectively, depending whether the root zone is saturated or not) in (8), restricted to the root zone only. Diurnal water use fluctuation is described by (Szilágyi et al., 2008)

$$s = -c \cdot \sin^2\left(\frac{\pi \cdot t}{12}\right), \ldots 0 \le \mathrm{mod}\left(\frac{t}{24}\right) < 12 \tag{9a}$$

$$s = 0, \ldots 12 \le \mathrm{mod}\left(\frac{t}{24}\right) < 24 \tag{9b}$$

where *c* (=2.4 10^{-3}) is a constant and *mod* is the modulus of division with time measured in hours. Eqs. 9a and 9b ensure that for one-half of the day water uptake by the vegetation from the root zone is zero, and follows a sine-like curve for the other half, taking only positive values.

The basic prescribed value (used in most model validation scenario) of *c* yields a daily mean ET of 6 mm, which is close to the growing season daily mean ET value reported by Gribovszki et al. (2010b). The fixed value of the stream level for $t > 0$ in the model allowed for possible induced recharge during the drawdown.

4 RESULTS

The effect of geometry and ET magnitude

First, sensitivity of the new method to the geometry of the riparian zone and to the magnitude of the prescribed evapotranspiration rate for a loamy aquifer (similar to that of Vadkan Valley) was tested. Table 3 displays the results of the sensitivity test. The first column lists the parameters whose values were modified while keeping the rest of the parameters unchanged and listed in Table 1.

Table 3. ET-estimation sensitivity to geometry and prescribed evapotranspiration magnitude

Parameter	$b/2w/{-m_1}$ if *w* used as a constant	$b/2w/{-m_1}$ if *w* calculated from num. model	$-m_1$	R (Corr. coef.)	Error (%) (*w* as a constant)	Error (%) (*w* as a result of num. model)
w_hor=1 m, *d*=1 m	1.31	1.31	5.08	0.991	–	–
w_hor=0 m, *d*=0 m	1.14	1.14	10.95	0.979	–13.0	–13.0
w_hor=2 m , *d*=1 m	0.78	0.66	5.12	0.991	–40.5	–49.4
w_hor=1, *d*=2	1.69	1.93	3.94	0.997	28.9	47.3
mf=0.01	1.22	1.17	5.47	0.992	–7.1	–10.7
mf=0.1	1.27	1.13	5.27	0.991	–3.6	–13.7
mf=1	1.36	1.46	4.89	0.99	3.9	11.5
mf_rip=0.025	1.45	1.35	4.61	0.989	10.2	3.1
mf_rip=0.1	1.10	0.85	6.04	0.992	–15.9	–35.1
b=40 m	1.02	1.00	13.06	0.993	–22.2	–23.8
b=10 m	2.30	2.44	1.45	0.991	75.2	86.3
ET=2 mm	1.48	1.50	4.49	0.992	13.1	14.5
ET=10 mm	1.11	1.13	5.99	0.99	–15.2	–13.7

Error means the estimated ET value’s deviation from the prescribed ET rate.

The following conclusions can be drawn from *Table 3.*

1) The increase (over 4m) of the horizontal streambed width ($2\cdot w_{hor}$) strongly influences the ET estimation. The new method is stable in the range of a 0–2 m width, so it can only be used reliably for small headwater catchments.
2) If the riparian aquifer is deeper than 2 m below the streambed, considerable (30–50%) errors can be detected, so the method can only be applied for fully or near-fully incised streams.
3a) The steepness of background watershed surface (*mf*) influences the evaporation estimate only slightly. Even a slope of 100% does not lead to a significant error in the ET estimates.
3b) Changing the slope of the riparian zone surface (*mf_rip*) does not cause any significant change, but if the slope is over 10%, the error becomes significant. A flat valley bottom assumption, however, is relevant in most natural cases.
4) Even a two-fold increase in the riparian zone width (from 20 to 40 m) does not induce significant errors in the results of the method, but on the other hand its decrease (narrowing) influences the evaporation estimate more significantly. The errors become substantial only under a width of 10 m, but this situation is rare even on headwater catchments. It is so because a narrow vegetation stripe cannot induce significant upward gradients in a considerably wide zone, as required by the method.
5) Applying an ET range of 2 to 10 mm/d on rainless days of the growing season as lower and upper envelope values, the method gives +13–15% and –14–15% errors, respectively. Small ET rates were slightly overestimated, while large ET values were slightly underestimated by the method.

The effect of soil physical parameters

The prescribed ET values are recovered only for the sandy-loam aquifer, because it corresponds best to the theoretical groundwater flow system *(Table 4)*. Only in this case will the *b/(2w)* ratio be about equal with the $-m_1$ constant in Eqs. 4–7.

Table 4. Results of the soil parameter sensitivity tests

1	Soil texture	*k* (m/d)	*b/2w/–m1* if *w* used as a constant (1.5m)	*b/2w/–m1* if *w* calculated from num. model	*–m1*	*R* (Corr. coef.)	Error (%) (*w*=1.5m as a constant)	Error (%) (*w* as a result of num. model)
2	Sand	15.21	2.89	3.09	2.31	0.976	188.6	209.0
3	Loamy sand	13.51	2.04	2.26	3.27	0.943	103.9	126.0
4	Sandy loam	3.00	2.26	2.36	2.95	0.984	126.0	136.0
5	Silt loam	0.62	2.19	1.97	3.04	0.968	119.3	97.0
6	Loam	0.60	1.31	1.31	5.08	0.991	31.2	31.0
7	Sandy clay loam	0.54	1.02	0.96	6.54	0.999	1.9	–4.0
8	Silty clay loam	0.15	0.55	0.52	12.2	0.999	–45.4	–48.0
9	Clay loam	0.21	0.81	0.81	8.25	0.998	–19.2	–19.0
10	Sandy clay	0.19	0.38	0.41	17.55	0.993	–62.0	–59.0
11	Silty clay	0.09	0.55	0.81	12.14	0.997	–45.1	–19.0
12	Clay	0.11	0.60	0.576	11.12	0.996	–40.0	–42.4

Error means the estimated ET value’s deviation from the prescribed ET rate.

For low hydraulic conductivity aquifers (e.g. clay, silt), root water uptake induces a considerably depressed water table under the riparian zone. The streamlines will be perpendicular to the surface of the depression cone and not to the bottom of the root zone. In this case $b/2w < -m_1$, so the method underestimates the prescribed ET rate. Interestingly, the error of the estimation as a function of the physical soil type is not linear, but roughly oscillates around an average value of –50%.

For coarse aquifer type (loam, loamy sand, sand) the flow lines do not become vertical below the root zone because the decreasing day-time storage can be readily replaced via the high conductivities. Thus the water demand of the vegetation is almost immediately met via the main horizontal gradients. In this case $b/2w > -m_1$ so the method overestimates the ET rate. It is also remarkable that the error does not change linearly with the change of the hydraulic conductivity, but rather (except for sand and loam types), it oscillates around +100–130%.

In summary, it can be stated that a strong linear relationship exists in all model settings between the prescribed and estimated ET values (the model spin up period excluded). The correction-factor values valid for the linear relationships changed only minutely during the 20-day modelling period (Fig. 4).

Since the model results depend strongly on the soil physical characteristics, the method requires a correction. Fortunately, the correlation between prescribed and estimated ET rates is very high (generally R = 0.98–1.00) and linear, accordingly the required correction by introducing a constant multiplier as a function of the soil type, can be achieved and remains the task of the future to be tested on natural catchments.

Acknowledgements: This research has been supported by funds from the ERFARET, OTKA (F 046720 and NN 79835), TÁMOP 4.2.1/B-09/KONV-2010–0006, TÁMOP-4.2.2.-08/1-2008–0020 projects and by an MTA Bolyai scholarship.

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10.37045/aslh-2011-0006 *Acta Silv. Lign. Hung., Vol. 7 (2011) 75–85*

Effect of Litter Fall on Soil Nutrient Content and pH, and its Consequences in View of Climate Change (Síkfőkút DIRT Project)

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Abstract – In the DIRT (*Detritus Input and Removal Treatment*) field experiments established at the Síkfőkút Site (North Hungary) in October 2000, an experiment was initiated to study the long-term effects of litter quality and quantity on pH and nutrient content (organic carbon, N forms, PO_4^{3-}, K^+, Mg^{2+}, Ca^{2+}) of soil in a *Quercetum petraeae-cerris* forest. An eight-year litter manipulation demonstrated a close connection between the changes in pH and Mg^{2+} and Ca^{2+} concentration. The decline of litter production, the decrease of the soil pH due to lower Mg^{2+} and Ca^{2+} input lead to consequent reduction of soil buffering capacity. The acidification interferes with the decomposition process of litter and humus compounds. Our results suggest decreases in organic matter content, total N, Ca^{2+} and Mg^{2+} concentrations in the soil as a consequence of decline in forest litter production induced by climate change and a resulting degradation of the soil over a longer period.

oak forest / DIRT / Sikfokut Project / litter production / soil nutrient

Kivonat – Az avarhullás hatása a talaj tápanyagtartalmára és pH-jára, a klímaváltozás fényében. A Síkfőkúti cseres-tölgyes erdőben beállított szabadföldi avarmanipulációs kísérletünkben (Síkfőkút DIRT Project) azt a kérdést vizsgáltuk, hogy az avarprodukció összetételének megváltozása, csökkenése vagy növekedése, várhatóan milyen hatással lesz a talaj szerves szén-, teljes nitrogén-, PO_4^{3-}-, K^+-, Mg^{2+}- és Ca^{2+}-tartalmára, valamint pH-jára.

Az eddigi kutatási eredményeink azt mutatják, hogyha a klímaváltozás hatására csökkenne az erdő avarprodukciója, ez hosszabb távon a talaj szerves szén-, összes-N-, Ca^{2+}- és Mg^{2+}-tartalmának csökkenését eredményezné, ami a termőhely leromlásához vezetne. A vizsgálatainkból levonható továbbá az a következtetés is, hogy az avarprodukció hosszú távú csökkenése a talaj pH csökkenését, elsavanyodását eredményezi, mivel az avarbomlás során keletkező savas intermediereket, humuszanyagokat, a csökkenő avarinput miatt a csökkenő Ca^{2+}- és Mg^{2+}-bevitel nem képes pufferolni. Ezt alátámasztja az is, amely szerint a talaj Ca^{2+}- és Mg^{2+}-tartalma és pH-ja között pozitív szignifikáns összefüggést mutattunk ki.

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Abban az esetben, ha klímaváltozás hatására növekedne az avarprodukció, ez hosszabb távon a talaj szerves szén-, összes-N-, Ca^{2+}- és Mg^{2+}-tartalmának, továbbá a talaj pH-jának a növekedését eredményezné, ami kedvező hatással lenne a talaj termőhelyi tulajdonságaira. A Síkfőkút Projecten végzett avarprodukcióval kapcsolatos hosszú távú vizsgálataink eddigi eredményei azt mutatják, hogy az avarprodukció csökkenő tendenciájú, ami hosszabb távon kedvezőtlen hatású a talajra.

tölgyerdő / DIRT / Síkfőkút Project / avarmanipuláció / talaj elemtartalom

1 INTRODUCTION

The long-term ecological research Síkfőkút Project was started in 1972 as a part of IGBP (International Geosphere-Biosphere Program), and later it continued within the MAB (Man and Biosphere) program. The study site was designated to investigate dynamics of a temperate-zone *Quercetum petraeae-cerris* forest which is typical for Hungary (Jakucs 1973). The study area is situated 6 km northeast of the city of Eger in the foothills of the Bükk Mountains (47°55’ N and 20°46’ E) in an elevation of 320–340 m above sea level. Ensuring undisturbed research conditions the total region of forest which includes the Síkfőkút site was declared a nature reserve by the Hungarian Nature Conservation Bureau (Enactment No. 8/1976). As a consequence of lacking silvicultural management in the past decades the Síkfőkút forest is assumed to approach the state of close to natural forest. Based on the data acquired from the intensive and long-term ecological research in the past 37 years, effects of climate change (warming, drought) on forest species composition, structure and fitness are well characterized.

As a result of the climate change, species composition and other structure in the Síkfőkút *Quercetum petraeae-cerris* forest changed considerably. This was shown by the strong decline of Sessile oak (*Quercus petraea*) abundance while a progression of Turkey oak (*Quercus cerris*) and *Acer* species (Kotroczó et al. 2007). This shift in tree species composition lead to qualitative and quantitative alteration of leaf litter production and clearly affected related soil properties (Tóth et al. 2008). Considering the phenomena described above, the present study focuses on how alteration of litter production under the condition of climate change modifies physical, chemical and biological soil properties. To answer this question, the approach of DIRT (*Detritus Input and Removal Treatment*) (Neilson and Hole 1963) was applied when field experimental plots were set up for determining the effects on soil by changing amounts and quality of litter in the long-term perspective. By contributing to DIRT, the Síkfőkút Project is an associated member of the ILTER (International Long-Term Ecological Research) DIRT Project which consists of four American (Harvard Forest, Bousson Forest, Andrew Forest and Michigan Forest) and two European (University of Bayreuth and Síkfőkút) LTER sites establishing an international and intercontinental research network. We have shown similar results already in our previous litter decomposition experiments in which we found effects in the soil water dynamics, changes in bacterial end fungal flora enzyme activities (Fekete et al. 2011) and soil respiration (Kotroczó et al. 2008, Tóth et al. 2007a, 2007b, 2008). The aim of the present study demonstrates and analyzes respective effects by experiments on litter decay particularly on the chemistry of soil organic matter, nitrogen (N -NO_3^-, NH_4^+, organic N, and total N), mineral nutrients and soil pH. This paper is dedicated to the evaluation of litter decay experiments regarding nutrient dynamics and soil-pH with special regard of sampling in the framework of DIRT after eight years duration.

2 MATERIALS AND METHOD

Inside the Síkfőkút forest stand, 7×7 m permanent experimental plots were set up 2000 in accordance with the protocol used in the USA DIRT plots too (*Table 1*).

Table 1. The applied treatments in open-field experiment (Síkfőkút, Hungary).

Treatments	Description
Control (C)	Normal litter inputs. Average litter amount typical to the given forest site
No Litter (NL)	Aboveground inputs are excluded from plots. Leaf litter was totally removed by rake. This process was replayed continuously during the year.
Double Litter (DL)	Aboveground leaf inputs are doubled by adding litter removed from NO LITTER plots.
Double Wood (DW)	Aboveground wood debris inputs are doubled by adding wood to each plot. Annual wood litter amount was measured by boxes placed to the site and doubbled amount of that was applied in case of every DW plots.
No Roots (NR)	Roots are excluded by inserting impenetrable barriers in backfilled trenches to the top of the horizon C. Root resistant plastic foil was placed into the plot in the depth of 1 m hindering the roots developing outside of the plot to get into the NR plot. Trees and shrubs were eradicated when the plot was established, and plant roots decayed in time
No Inputs (NI)	Aboveground inputs are excluded from plots, the belowground inputs are provided as in NO ROOTS plots. This treatment is the combination of NR+NL treatments.

During the experiment six different treatments were applied: Control (C), No Litter (NL), No Root (NR), No Input (NI), Double Litter (DL) and Double Wood (DW) (Kotroczó et al. 2010). Every treatment was conducted in three replicates. Sample of 100 g were taken randomly on each plot from 0–5 and 5–15 cm depths using an Oakfield soil sampler (G model). Soil extracts were prepared by using two different solvents. Ammonium-lactate/-acetic acid buffer solution (0.1 M; pH=3.7) was used for extraction of soluble and easily exchangeable nutrients (Egnér et al. 1960). Calcium-chloride (0.01 M CaCl2) was used for extraction of easily soluble nutrients (Houba et al. 1990). Aliquots of 5 g air-dried, sieved and homogenized soil were extracted with 100 cm3 of the buffer solution or with 50 cm3 calcium-chloride solutions respectively during 2h shaking and filtering.

Concentrations of Ca2+ and Mg2 in the extracts were determined by means of atomic absorption spectrophotometer (AAS) (SpectrAA-20 Plus, Varian Australia Pty Ltd). Concentration of phosphorus was measured spectro-photometrically by the phospho-molibdovanadate method (VIS SP-850 Plus spectrophotometer, Metertech, Taiwan). Nitrogen species were determined spectro-photometrically by continuous flow analyzer (CFA) system (SA-2000 type Skalar photometer, Breda, The Netherlands). Soil organic matter content was determined after dry combustion (VARIO EL CNS elementary analyzer, Vario, Germany) according to Nagy (2000). Soil pH was determined in 0.01 M CaCl2 suspensions (EBRO

PHT 3140 digital pH meter with a combined glass electrode). Results were statistically analyzed by Sigma Stat software (v3.1.) using one-way variance analysis.

3 RESULTS AND DISCUSSION

3.1 Soil carbon content

The effect of removed litter on the carbon content of soil was larger than the effects of double litter input. In comparison with the Control plots (0–5cm: 5.19%; 5–15cm: 3.25%), carbon content of the soil decreased by leaf litter withdrawal in both two soil depth while Double Litter (0–5cm: 6.73%; 5–15cm: 3.12%) treatments caused increased carbon content only in the depth of 0–5 cm. In the deeper soil layers (5–15 cm) Double Litter treatment did not cause carbon accumulation during the first 8 years of study. Only the carbon content of the upper soil layer increased by the surplus litter input (*Figure 1*).

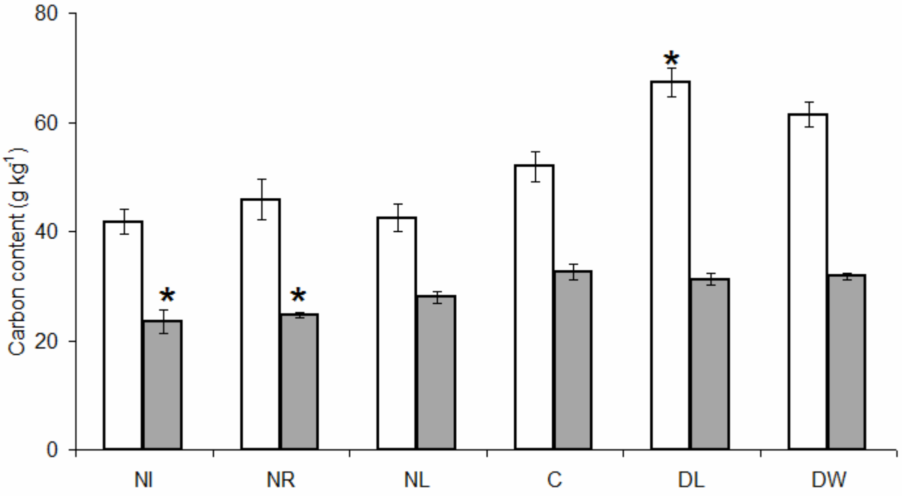

Figure 1. The effects of litter input manipulation on soil carbon content.
NI: No Input, NR: No Root, NL: No Litter, C: Control, DL: Double Litter, DW: Double Wood,
white column: 0–5 cm soil depth, grey column: 5–15 cm soil depth,
**: significantly different from Control ($p < 0.05$)*

These results suggest two hypotheses: 1) a decrease in litter production induced by climate change might result in declining organic matter content of soil over a longer period which can impair the soil water, temperature and nutrient storage capacity. 2) if climate change enhances litter production the resulted increase of soil organic matter content would gradually improve the former soil properties (temperature insulation, humus and cation content).

Our results (Tóth et al., 2007b; Fekete et al. 2008) indicate decreased litter production as a consequence of climate change. This supports the first hypothesis for the soil of Síkfőkút site. However, it should be added that generalization is not easy since warming climate might result in higher wood and leaf litter production as well in case of more humid ecosystems (Varga et al., 2008; Kotroczó et al. 2008; Krakomperger et al. 2008).

3.2 Nitrogen forms

In 0–5 cm depth the highest and the lowest NO_3^--N contents were measured in DL and NI plots, respectively (*Figure 2*). Other types of litter manipulation treatments, however, had no defined effects on soil's NO_3^--N content. Such lack of tendentious relationship is not surprising as nitrate is highly soluble and mobile and beside the seasonal fluctuations its momentary concentration in soil is strongly influenced by several factors such as nitrification, denitrification, uptake by plants and leaching. NH_4^+-N content in the upper 0–5 cm of soil decreased in plots where litter was excluded and increased in plots with double litter (*Figure 3*). The highest values were measured in DL plots. In the 5–15 cm soil layer only the DW treatment resulted in measurable change compared to control values (*Figure 3*). All types of litter exclusion treatments resulted in significant decrease in organic-N content in 5–15 cm depth and a non-significant decrease in the depth of 0–5 cm (*Figure 4*). In 0–5 cm depth litter addition increased the organic-N in DL plots and slightly decreased it in DW plots. Both treatments induced decrease in organic-N of 5–15 cm depth (*Figure 4*). Concerning total-N contents effects of litter manipulation treatments were only detectable in the upper 0–5 cm, while there were no differences at 5–15 cm depth (*Figure 5*).

Recently formed litter pools assimilate more NO_3^- than NH_4^+ under ambient N deposition, but may lose capacity to assimilate NO_3^- relative to NH_4^+ under potential future increases in N deposition (Micks et al. 2004). Global atmospheric composition and climate change effects on plant carbon to nitrogen ratios are thus likely to become important when predicting possible second-order impacts of the enhanced greenhouse effects (Kunz et al. 1995).

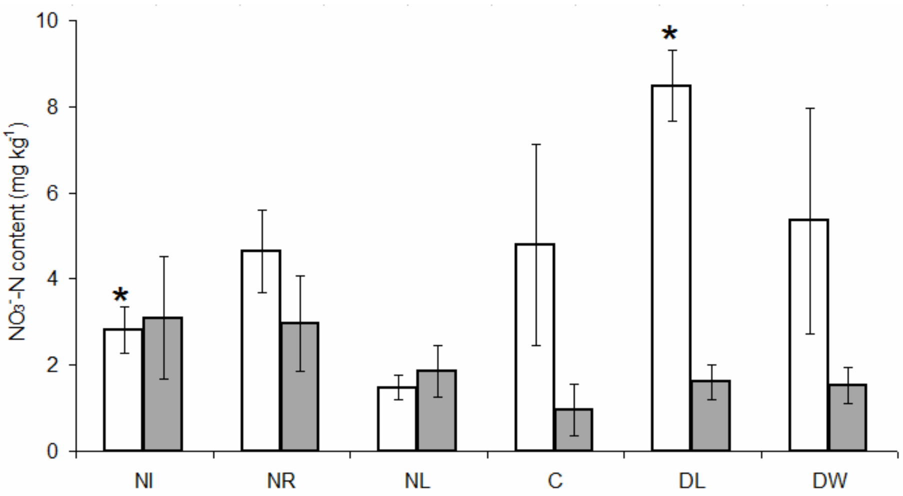

Figure 2. The effects of litter input manipulation on soil NO^{3-}-N content. Explanations are as in Fig. 1

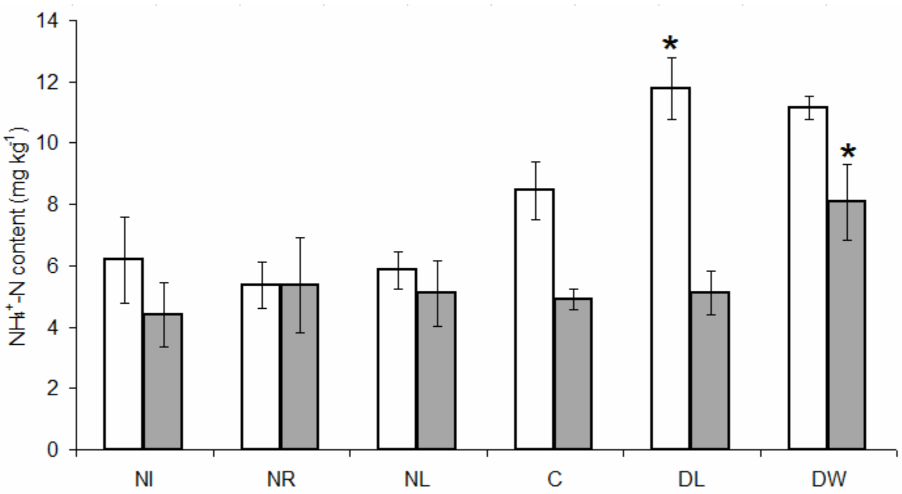

Figure 3. The effects of litter input manipulation on soil NH_4^+-N content. Explanations are as in Fig. 1

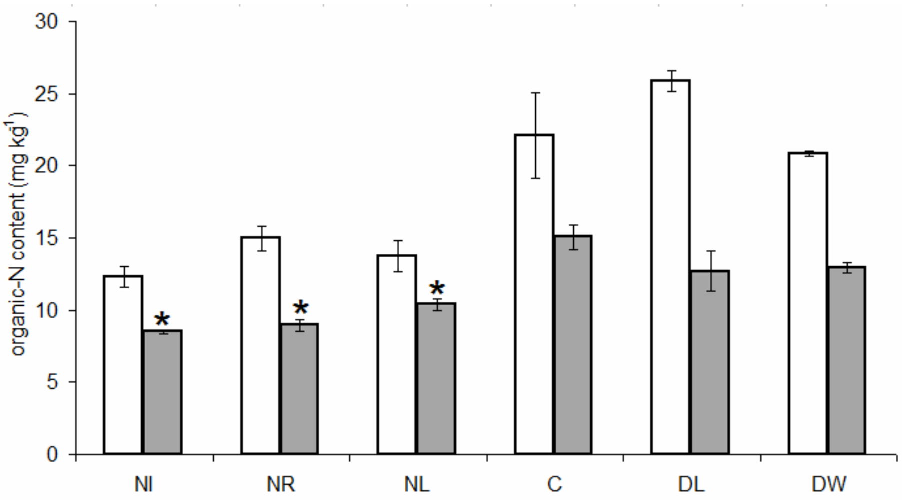

Figure 4. The effects of litter input manipulation on soil organic-N content. Explanations are as in Fig. 1

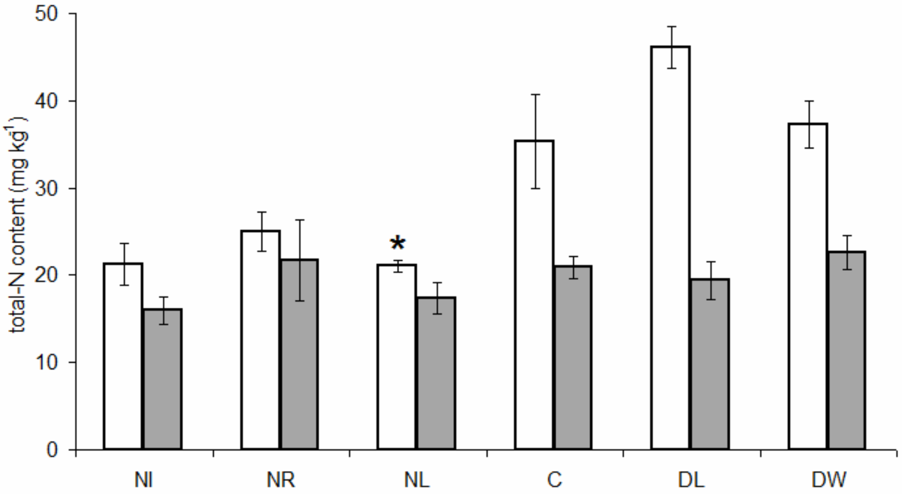

Figure 5. The effects of litter input manipulation on soil total-N content. Explanations are as in Fig. 1

3.3 Extractable phosphorus content

The upper 0–5 cm of soil contained remarkably more phosphorus than the 5–15 cm layer in plots irrespectively of the applied litter management (*Figure 6*). Surprisingly P-content in both depths increased as a result of litter exclusion while there were no significant differences in plots with doubled litter as compared to control values (*Figure 6*).

Higher P contents in plots with litter exclusion could be attributed to several factors such as: 1) in NI and NR treatments uptake of P by plants did not influence the P status of soil. 2) due to similar reasons the activity of phosphatase enzyme was also lower (Fekete et al. 2007; Fekete et al. 2008) allowing P in these plots to remain organically bound. 3) higher soil acidity in plots with litter exclusion (see later in this work) might enhance the possibility of precipitation of P in form of Fe- and Al-phosphates.

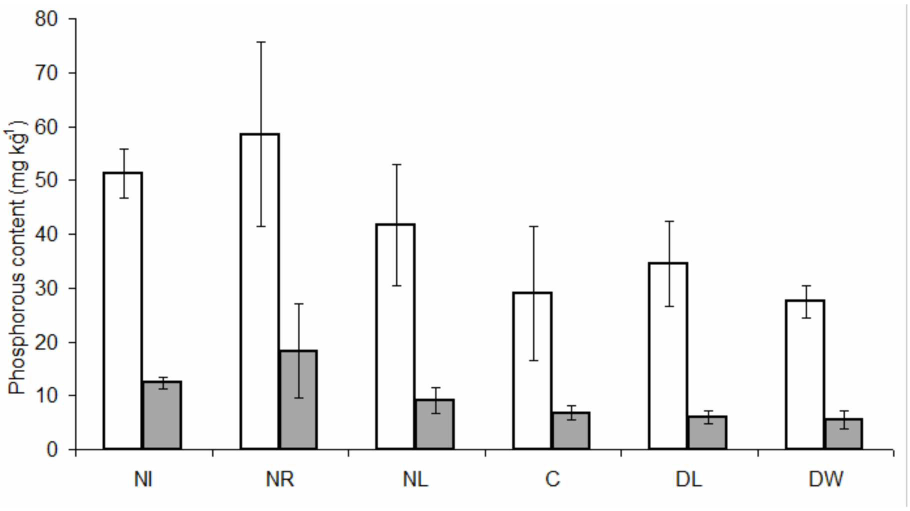

Figure 6. The effects of litter input manipulation on soil phosphorus content. Explanations are as in Fig. 1

3.4 Extractable Ca^{2+} content

Calcium content of soil declined in both depths as a result of litter exclusion. This decrease proved to be significant in NI and NL plots (*Figure 7*). Litter addition had an opposite effect since it increased the Ca^{2+}-content in the upper 0–5 cm (significantly in DL plots, *Figure 8*). In the 5–15 cm layer, however, an increase was not detectable (*Figure 7*). It can be hypothesized that potential decrease of litter production due to climate change might lower the Ca^{2+} content of soil and as a consequence reduce buffering capacity and increase the risk for acidification of the soil. In case of enhanced litter production this process might tend to enhance Ca^{2+} content and therefore improve the buffering capacity of soil.

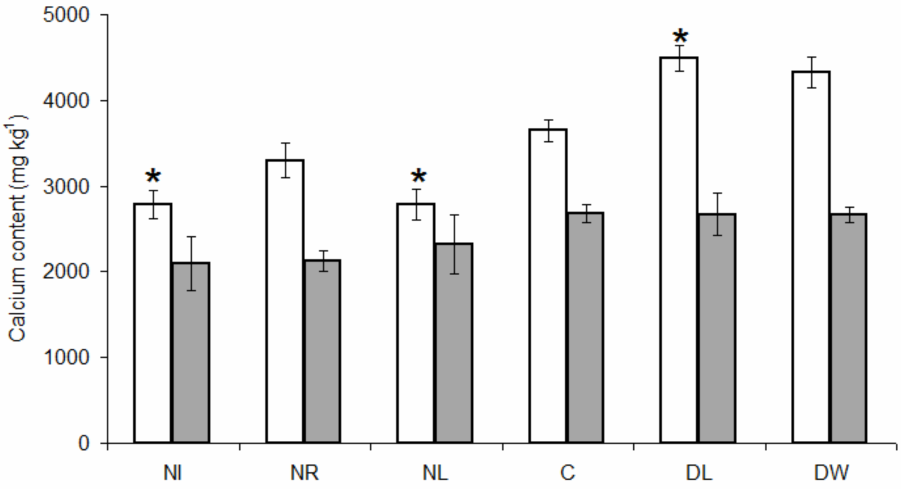

Figure 7. The effects of litter input manipulation on soil Ca^{2+} content. Explanations are as in Fig. 1

3.5 Mg^{2+} content

Magnesium content of soil decreased in both 0–5 and 5–15 cm depths due to litter exclusion treatments and differed significantly in 0–5 cm of all three treatments as compared to control (*Figure 8*). Litter addition increased Mg^{2+} content only in the 0–5 cm layer of DL treatments (*Figure 8*).

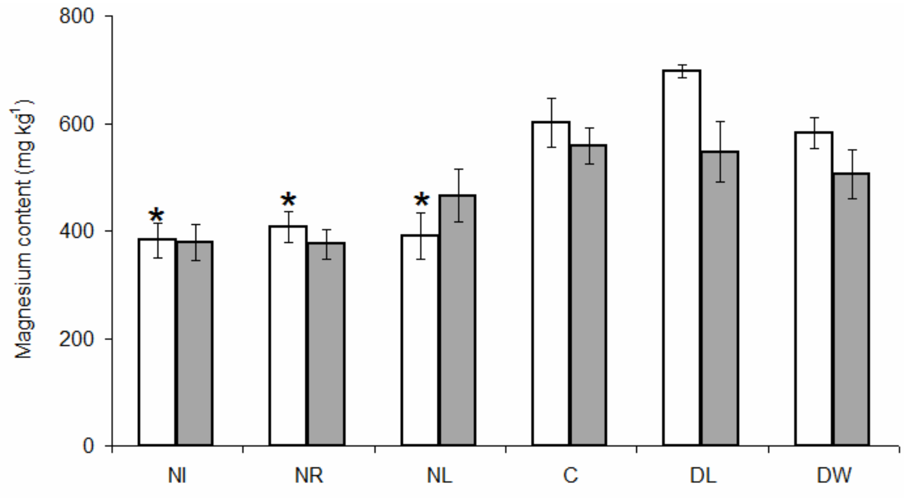

Figure 8. The effects of litter input manipulation on soil Mg^{2+} content. Explanations are as in Fig. 1

3.6 Soil pH

As a consequence of reduced litter input soil pH had decreased (*Figure 9*). This could be attributed to the depleted buffering capacity due to restricted Mg^{2+} and Ca^{2+} input which cannot compensate the acidifying effect of acidic intermediates and humus compounds. Increase of litter input resulted in higher soil pH since it also enhanced Mg^{2+} and Ca^{2+} input and improved buffering capacity (*Figure 9*). Soil pH, Mg^{2+} and Ca^{2+} concentrations in the soil changed in close positive correlation (*Figure 10 and 11*). Finzi et al. (1998) reported similar results. They found highly significant positive correlations between soil pH and extractable Ca^{2+}. In our site at 5–15 cm depth the pH is more acidic as at 0–5 cm depth. The Ca^{2+} has stronger alkaline effect as Mg^{2+}. At 0–5 cm soil depth high litter Ca^{2+} concentration coupled with a large quantity of leaf litter could increase the quantity of exchangeable Ca^{2+} on the surface (0–5 cm) (Finzi et al. 1998). These results suggest that the properties of litter in a given forest could fundamentally influence the soil pH and consequently the nutrient mobility.

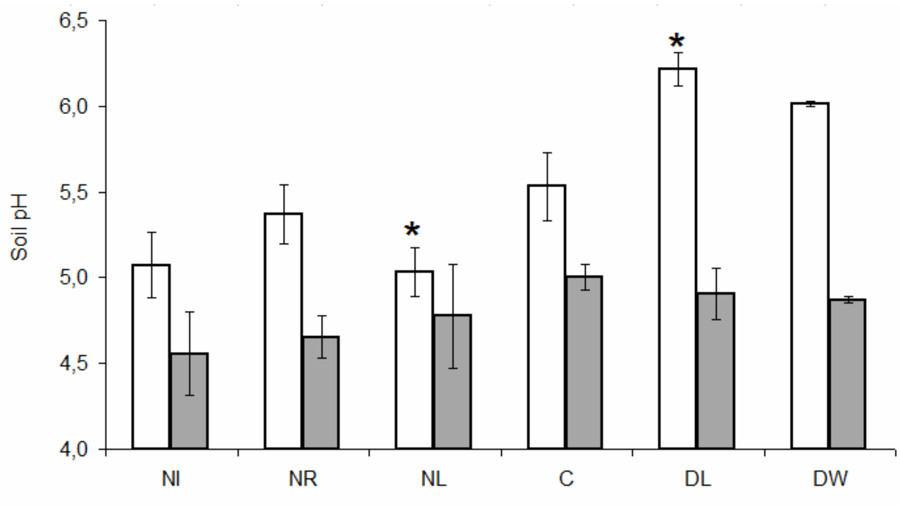

Figure 9. The effects of litter input manipulation on soil pH. Explanations are as in Fig. 1

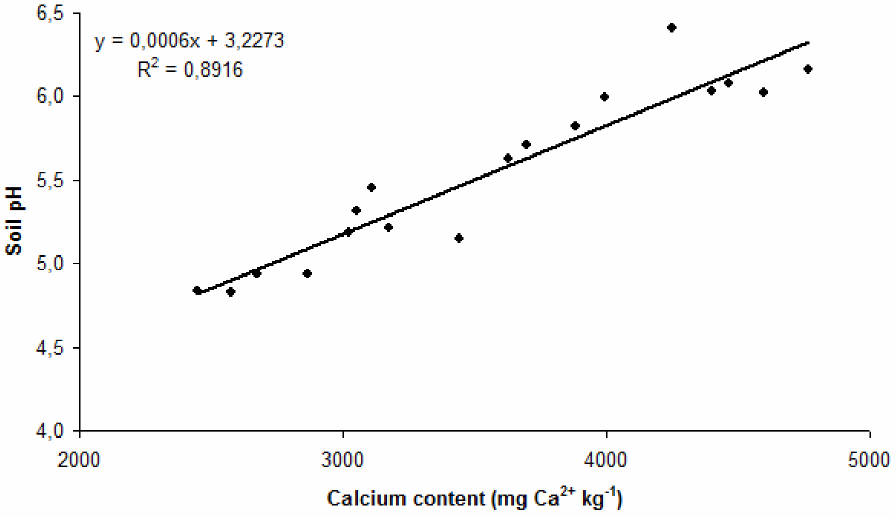

Figure 10. Results of regression analysis between soil Ca^{2+}- content and soil pH under conditions litter input manipulation (R^2=0.89)

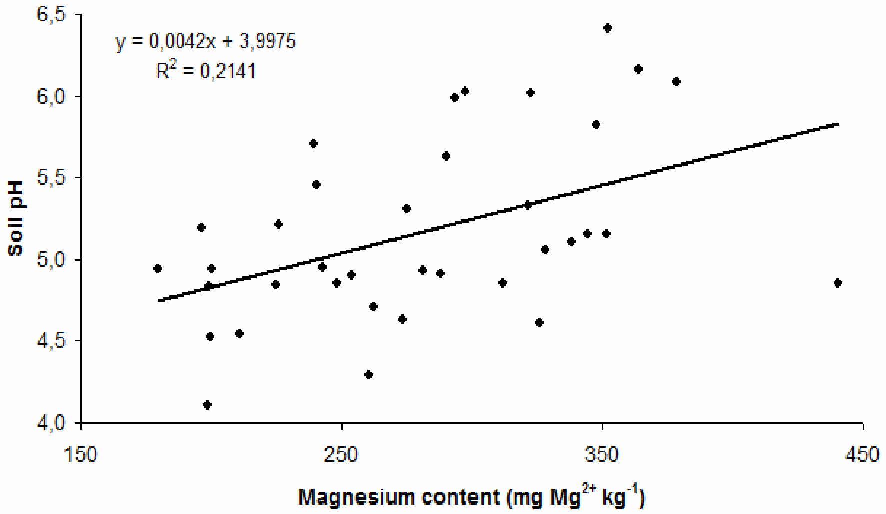

Figure 11. Results of regression analysis between soil Mg^{2+}- content and soil pH under conditions of litter input manipulation (R^2=0.21)

4 CONCLUSION

The effect of litter removal on the carbon content of soil was larger than the effects of double litter input. Carbon content of the soil decreased by leaf litter removal in both soil layers, while Double Litter treatments caused increased carbon content only in the depth of 0–5 cm. In the deeper soil layer (5–15 cm) Double Litter treatment did not cause carbon accumulation during the first 8 years of study.

We point out that organic nitrogen content of the soil decreased in both soil depths under the influence of litter withdrawal. In case of the depth of 5–15 cm, all three litter removal treatments (NI, NR, NL) caused significant decrease in N content. Double Litter treatment increased the organic N content of the upper 0–5 cm soil layer, while decreasing concentrations could be detected in the depth of 5–15 cm.

The effects of treatments on the total nitrogen content could be detected only in the upper 0–5 cm soil layer, however only the No Litter treatment was significantly different from the

Control. Considering the lower soil layer, there are no significant differences among the various treatments. In case of decreased litter production this process might tend to decrease Ca2+ content and therefore deteriorate the buffering capacity of soil and this leads to the acidification of the soil.

Acknowledgements: Bruce Caldwell, Richard D. Bowden and Kristin Wanderbilt American cooperative researchers of ILTER DIRT Project are thankfully acknowledged for their kind and wide-ranging help in the Síkfőkút DIRT Project.

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10.37045/aslh-2011-0007 *Acta Silv. Lign. Hung., Vol. 7 (2011) 87–95*

The Effects of Detritus Input on Soil Organic Matter Content and Carbon Dioxide Emission in a Central European Deciduous Forest

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Abstract – A major objective of our research was to survey soil biological activity and organic matter content reduction in a Central European oak forest during treatments of various detritus inputs within the Síkfőkút DIRT (*Detritus Input and Removal Treatments*) Project. Beside the control, three detritus removal and two detritus duplication treatments were applied. Our examinations have proven that soil organic matter content declined relatively fast in detritus removal treatments. The reduction was especially remarkable in root detritus removal treatments, where – due to the lack of transpiration – soils were moister during the whole year than in the other treatments. The higher moisture content, despite of the reduction of detritus input, produced an intense soil respiration. This can be explained by the fact that decomposing organisms have increased the use of soil organic matter. Detritus input reduction had a significantly greater effect on soil respiration and organic matter content than detritus input duplication of the same extent. The latter did not cause any significant change compared to the control.

litter manipulation / soil respiration / DIRT Project / humus content / climate change

Kivonat – Az avarinput hatása a talaj szerves anyag tartalmára és szén-dioxid kibocsátására egy Közép-európai lombhullató erdőben. Kutatásaink egyik fő célkitűzése az volt, hogy a Síkfőkút DIRT (*Detritus Input and Removal Treatments*) Project keretében, felmérjük egy közép-európai tölgyerdőben a különböző avarinputot kapó kezelések talajainak biológiai aktivitását és szerves anyag tartalom csökkenését. A kontroll mellett háromféle avarelvonásos és kétféle többletavart kapó kezelést alkalmaztunk. Vizsgálataink azt bizonyították, hogy a csökkentett avarinputot kapó kezelések esetén a talaj szerves anyag tartalma viszonylag gyorsan csökken. Különösen erős csökkenést tapasztaltunk a gyökéravar elvonásos kezeléseknél, ahol a hiányzó transpiráció miatt egész évben nedvesebbek a talajok, mint a többi kezelésnél. A magasabb nedvesség tartalom hatására a szerves anyag input csökkenés ellenére is intenzív talajlégzést tapasztaltunk. Ezt azzal magyaráztuk, hogy a lebontó szervezetek a talaj szerves anyag készletét fokozottabban használják fel tápanyagként, a kieső avar mennyiség helyett. Az avarinput csökkentése szignifikánsan nagyobb hatást gyakorolt a talajlégzésre és a talaj szerves anyag tartalmára, mint az avarinput ugyanolyan mértékű növelése, mely a kontrollhoz képest nem okozott szignifikáns változást.

avarmanipuláció / talajlégzés / DIRT Project / humusztartalom / klímaváltozás

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1 INTRODUCTION

A major part of carbon dioxide getting into carbon cycle comes from respiration, weathering of rocks and volcanic activity, while industrial activities are responsible only for 5–15% of it. Forest destruction and burning, area increase and degradation of agricultural lands, melting of permafrost soils and the enhancement of soil respiration also contribute to the growing carbon dioxide emission deriving from the combustion of fossil fuels. Although the extra carbon dioxide in the atmosphere is primarily due to the combustion of fossil fuels, a considerable proportion is caused by soil organic matter content reduction through forest destruction and utilizing lands for agriculture or constructions (Wild 1988). Batjes and Sombroek (1997) estimate the organic carbon matter of soil within the upper 1 m to be 1200–1600 Gt, while Batjes (1996) thinks that there is 2376–2456 Gt carbon in the upper 2 m. According to the estimations, soil stores two and a half times more carbon as plants, and twice as much as the atmosphere (Batjes 1998). According to Buringh (1984) the present soil organic matter content is merely 75% of that before the start of agriculture. According to Raich and Schlesinger (1992) decomposing detritus (including roots) provides about 70% of total carbon output of soils which is 68 Gt/year. Soil chemical and biological processes influence global climate change by increasing the quantity of greenhouse gases. Global warming will supposedly influence the decomposition of soil organic matters, thus the global carbon cycle of the biosphere. Several researchers assume that decomposition processes are induced more strongly by temperature rise than by anabolic processes (Jenkinson et al. 1991; Schimel et al. 1994; Kirschbaum 1995), which may lead to increased atmospheric carbon dioxide content (Townsend et al. 1992; Schimel 1995; Kaye and Hart 1998; Cox et al. 2000). The enhanced soil respiration as well as the reduction in detritus production can entail the decrease in soil organic matters, thus soil degradation.

Several examinations have already revealed that a higher carbon dioxide content causes lower nitrogen concentration in plant tissues (Cotrufo et al. 1998; Norby et al. 1999, 2000). Beside nitrogen concentration decrease, the quantity of less decomposable secondary (phenols, tannins and lignin) increases (Norby et al. 2001). The qualitative parameters of detritus, such as nitrogen concentration, carbon-nitrogen ratio and lignin-nitrogen ratio, considerably influence the composition and activity of microbes (Hu et al. 2001), thus the velocity of decomposition (Swift et al., 1979; Aerts 1977). Sulzman et al. (2005) carried out researches in an old-growter Douglas-fir (*Pseudotsuga menziesii*) forest at H. J. Andrews DIRT Site (USA, Oregon) and found that the increasing detritus input with a high carbon to nitrogen ratio accelerates the decomposition of soil organic matters. So the growth of detritus production rather entails the increase of atmospheric carbon dioxide content (Norby et al. 2002) than soil carbon supply. Pendall et al. (2004) think that the high carbon to nitrogen ratio in soil increases atmospheric carbon dioxide content. Detritus decisively influences soil nutrient supply, microbial activity and humus content. The quantitative and qualitative changes in detritus production together with their effects on soil life have already been treated in several studies and research papers (Sayer et al. 2006; Pandey et al. 2007).

DIRT experiments (Detritus Input and Removal Treatments) are long-term studies of soil organic matter formation and derived from a project launched in forest and grassland ecosystems at the University of Wisconsin in 1957 (Nielson-Hole 1963). This international project’s goal is to assess how rates and sources of above- and belowground plant inputs control the accumulation and dynamics of organic matter and nutrients in forest soils over decadal time scales. The significant effects of manipulations on mineralization and respiration suggest that microbial activity was influenced by DIRT treatments (Nadelhoffer et al. 2004). Our experimental site, Síkfőkút DIRT Project, is member of the DIRT intercontinental project organized by the ILTER (International Long-Term Ecological Research) network. Síkfőkút site was established by professor P. Jakucs. Our research constitutes an important part of a long term international project that involves five more experimental sites (Nadelhoffer et al. 2004) in USA (Andrews Experimental Forest, Bousson Experimental Forest) and Germany (Universität Bayreuth, BITÖK).

A major objective of our research was to examine soil respiration and organic matter content during treatments of various detritus inputs, thus revealing the effects of changes in substrate quantity available for decomposing organisms and in soil moisture content on soils.

The extent of carbon dioxide emission is an important indicator of the intensity of organic matter decomposition and related microbial activity (Gerenyu et al. 2005). The extent of soil respiration is influenced by several factors, such as vegetation, the quantity and quality of plant residues, the quantity and activity of decomposing microorganisms, soil structure, soil pH, the quantity of available nutrients, as well as soil temperature and moisture content that are influenced by climate change to the greatest extent (Swift et al. 1979; Pántos-Derimova 1983; Rustad et al. 2000).

2 SITE DESCRIPTION

The Síkfőkút site was established in 1972 for the long-term study of forest ecosystems. The area covering 27 ha is located in the south part of the Bükk Mountains in Northeast Hungary at 325 m altitude. GPS coordinates are N 47^{o}55’ E 20^{o}28’. Annual precipitation amounts to 550 mm and annual average temperature is 10 ^{0}C. According to the FAO Soil Classification, the type of soil is cambisol. Soil pH ranges between 4.85 and 5.50 depending on the plots (Tóth et al. 2007). The forest is a semi-natural stand (*Quercetum petraeae-cerris* community) without forest management, and since 1976 is part of the Bükk National Park.

Experimental plots were established in November 2000. Following the example of American DIRT Sites, six treatments were set up in three replications. These 18 plots were arranged randomly. The treatments are: Double Litter (DL), Control (C), No Litter (NL), No Root (NR), Double Wood (DF), No Input (NI) Each plot is 7m wide and 7m long (49 m^2) (Fekete et al. 2007).

3 METHODS

Random soil samples were taken from five test holes at each plot. The test holes with a diameter of 13 mm were 15 cm deep. Sampling was carried out with Oakfield auger (Oakfield Apparatus Company, USA). Samples were homogenized and stored in a refrigerator at 4°C. Laboratory examinations were implemented within a week after sampling.

For detecting soil temperature, an ONSET, StowAway TidbiT-type data-logger (Onset Computer Corporation, USA) was placed into the middle of each plot at 10 cm depth. Data-loggers were programmed to measure soil temperature every hour. Soil tempretaure was measured continuously from 8th March 2001. Data were downloaded at set intervals generally once a year. Soil moisture content was determined after drying in oven at 105°C for 24 hours. Soil organic matter content was determined by the Tyurin method (Buzás 1988). Soil respiration was measured by examining the carbon dioxide efflux of samples according to Jenkinson and Powlson’s (1976) method.

Experimental data were statistically evaluated by *Statistica* version 7.0. We ensured randomness of sampling and the independence of each sampling element. *Kolmogorov – Smirnov* test helped determine the normal distribution of actual data. Homogenity of the variations was examined by F_{max}*-probe*. *One-way ANOVA* and *Tukey’s HSD* test were also performed.

4 RESULTS

The first sampling took place in April 2001, five months after plot establishment. At that time NR treatment revealed the highest organic matter content (3.61%); however, NI (3.26%) also surpassed the values of DL (3.19%) and C (3.08%) (*Figure 1*). The next sampling took place in December 2001. Then NR was ranked second, following DL. In 2002 the organic matter content of treatments involving detritus removal (NR, NI, NL) decreased compared to the other treatments. From 2003 till the end of examinations the samples of detritus duplicaton and control treatments revealed higher organic matter contents than the ones of detritus removal treatments (*Figure 2*). Comparing the means of 2001–2002 and those of 2003–2006, the following results were obtained: organic matter content increased by 3% in DL and DW, while decreased by 2% in C. These changes were not significant. However, detritus removal treatments revealed significant decreases (at P≤0.05): NL: 14%, NR: 17%, NI: 8%. The lowest mean value was measured in NR between 2003 and 2006.

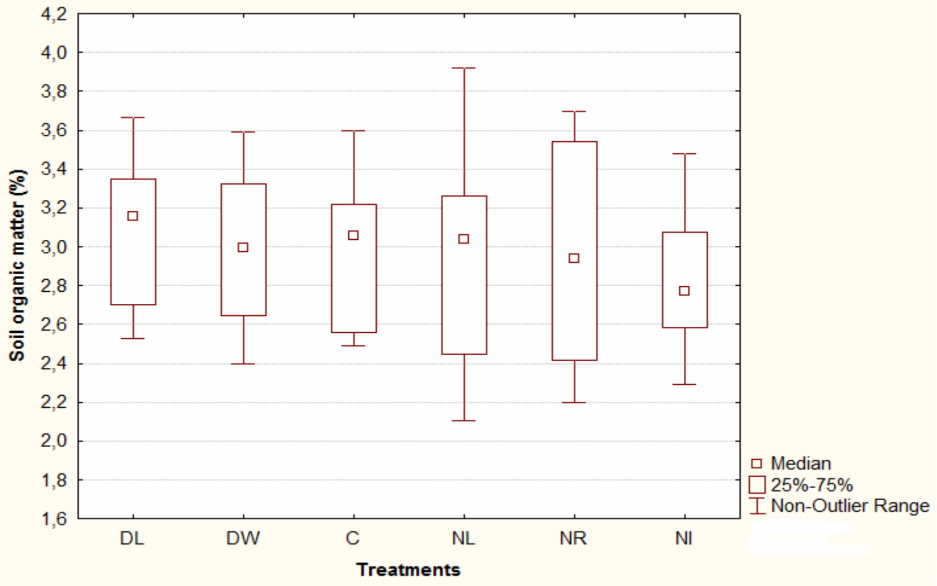

Figure 1. Mean values of soil organic matter content (n=12) in 2001 and 2002

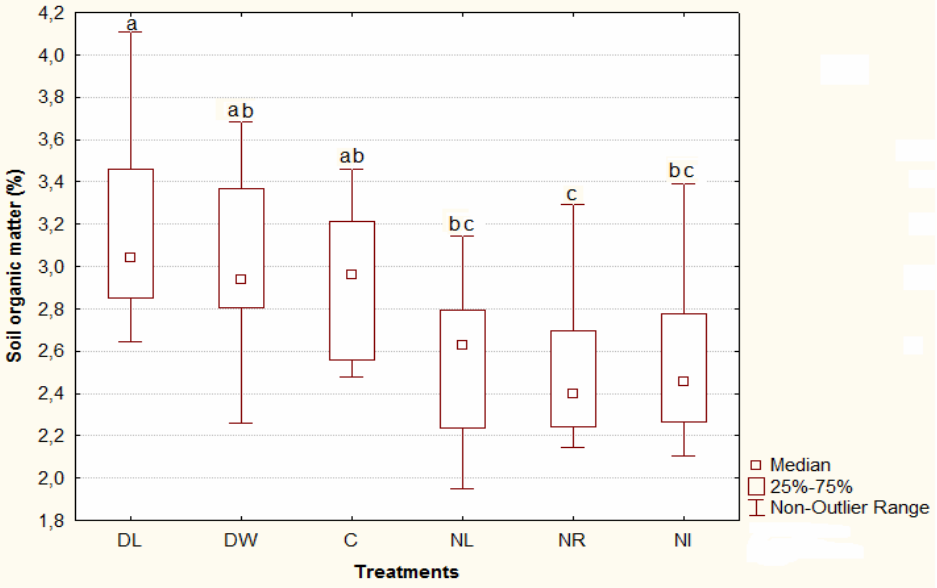

Figure 2. Effects of detritus manipulation on soil organic matter content (n=15) between 2003 and 2006. Different letters indicate significant differences according to Tukey's HSD test

Examining the organic matter content of the treatments between 2002 and 2006, ANOVA revealed significant differences between the groups ($F_{(5.36)}=6.26$; $p<0.001$). According to Tukey's HSD test, DL revealed significantly higher values than the three detritus removal treatments, as well as DW and C showed significantly higher values than NR ($p<0.05$). Regarding soil respiration, the highest mean values were measured in the detritus duplication treatments (DL, DW) and NR. These were followed by C and finally by the leaf litter removal treatments (NI, NL) (*Figure 3*). ANOVA did not reveal any significant difference between the groups ($p=0.1$) because of high variation and relatively low number of samples ($N=13$). However, considerable differences were observed between the treatments. Comparing the carbon dioxide emission of NL pairwise to the other treatments by t-test, all the treatments revealed significantly higher values than NL, except for NI.

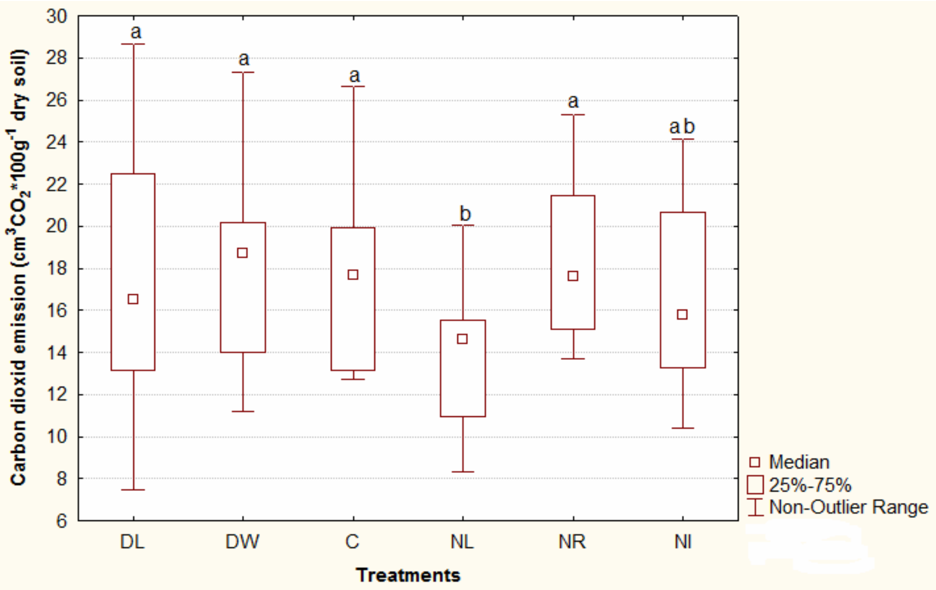

Figure 3. Mean values of carbon dioxide emission between 2004 and 2007 Double Litter (DL), Control (C), No Litter (NL), No Root (NR), Double Wood (DF), No Input (NI). Different letters indicate significant differences according to t-test

5 DISCUSSION

Carbon dioxide emission of NI surpassed that of NL, while NR exceeded both C and DW. These results – taking into consideration the extent of detritus input in the treatments – need further explanation.

Root respiration had no influence on carbon dioxide emission in NL, C, DW, DL, as the soil samples did not contain any living roots. Altough roots were removed from both NR and NI samples before the examinations, at the establishment of NR and NI plots roots had not been removed, they were let there to decompose.

Therefore, these dead roots were able to contribute to increasing soil respiration for a certain period of time. This effect could be observed in the case of certain enzymes' activities (phosphatase, phenoloxidase) and the changes in soil organic matter content (Fekete et al. 2007; Varga et al. 2008).

The higher than expected carbon dioxide emission of NR and NI can be explained primarily with the higher soil moisture content, due to the fact that plants were regularly removed, so there was no transpiration loss at all. Statistical analyses revealed that carbon dioxide emission correlates strongly with soil moisture content (Kotroczó et al. 2008).

The effects of soil moisture content and detritus input were proven by the fact that in the two sample series showing the highest soil moisture content (above 30% in all treatments) DL, C and DW samples revealed 32% carbon dioxide emission higher than NR and NI. This is because DL, C and DW plots had greater nutrient supplies, which – under appropriate circumstances, e.g. optimal moisture content for decomposing organisms – increase the intensity of soil respiration (Wan-Luo 2003; Berryman et al. 2010). Such nutrients were root exudates as well as organic compounds resulting from the decomposition of leaf litter. All these or a part of them were missing from the plots of detritus removal treatments. This fact further supports the observation that litterfall and root detritus play an important part in nutrient and carbon cycling (Sayer 2006). A further difference was that there were no plants in NR plots, detritus could only originate from the surrounding trees. The major part of leaf litter from the bushes fell to the ground outside the NR plots. According to Tóth et al. (2007), shrubs provide only 9% of the total leaf litter production at the Síkfőkút site. Thus, the quantity of aboveground detritus is lower in NR than in the other three detritus duplication treatments.

The effects of leaf litter manipulation was shown by the fact that CO_2 emission in NL was significantly lower than in treatments of aboveground detritus input (DL, C, NR, DW). CO_2 emission in aboveground input treatments was also higher than in NI; however, the difference was not significant. This can be explaned by the higher soil moisture content. In this experiment the effects of soil temperature were not relevant, as the examinations were carried out in laboratory at controlled temperature. However, in field investigations soil temperature is a crucial factor (Kotroczó et al. 2008). Comparing our results with those of the Andrews DIRT Site, we can observe the same trend sin DL, NL, C, and DW treatments (Sultzman et al. 2005). In both experiments C revealed the lowest CO_2 emission. Nevertheless, in the Andrews DIRT experiment there was a significant difference between DL, DW and C, while the difference was not significant in Síkfőkút. In 2001 NR and NI revealed higher organic matter content, which was due to the decomposing capillary roots. Living roots constantly enrich soil with their excretions (Gregory, 2006). Organic matter content was the highest in DL, C, DW since 2003 (Varga et al. 2008), although the increase was slight, however the values of NR and NI decreased by 30 and 18% between 2002 and 2006. NL also revealed a decreasing trend (22.3% between 2002 and 2006), which can be explained by the lack of leaf litter supply (Zhang et al. 2008).

This decomposition of organic matter was more intense in NR and NI, so soil CO_2 emission was higher as well. However, DL revealed the highest values regarding both CO_2 emission and organic matter content. This can be explained by the leaf litter duplication resulted in an extra amount of litter that could not be mineralized. It raised soil organic matter content. Nevertheless, during the field examination C and DW showed higher CO_2 emission than DL (Kotroczó et al. 2008). As for enzyme activity, similar tendency was observed (Fekete et al. 2011).

6 CONCLUSION

Our results have proven that additional detritus input influenced organic matter content in undisturbed soils under natural vegetation to a less extent than detritus removal for several years. The decrease in detritus input entailed the decrease in humus content relatively fast. At the Síkfőkút DIRT site detritus manipulation caused significant changes in soil organic matter content within five years. In drier conditions the increase of moisture content entailed a more intense soil respiration. If detritus input does not provide a sufficient amount of substrate for decomposing organisms, the mobile components of organic matter will be used for metabolic processes.

Acknowledgments: Special thanks to Dr. Bruce Caldwell, Dr. Kate Lajtha (Oregon State University, Corwallis, USA) for establishing the experiment. We wish to return thank to Ms Ildiko Huba for the English version of the article. The laboratory assistance of Ms Kovács Lászlóné is highly appreciated.

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10.37045/aslh-2011-0008 *Acta Silv. Lign. Hung., Vol. 7 (2011) 97–108*

Diurnal and Seasonal Changes in Stem Radius Increment and Sap Flow Density Indicate Different Responses of Two Co-existing Oak Species to Drought Stress

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Abstract – Using continuous monitoring of stem radius combined with sap flow measurements we assessed the effects of environmental conditions on tree radial growth and water status of two co-existing oak species (*Quercus petraea* and *Quercus cerris*) at high resolution time in growing seasons of 2008 and 2009. The forest (95–100 yr) is situated in a xeric site in the transition zone between forested and forest-steppe regions in north-eastern Hungary, Bükk mountains (47°90'N, 20°46'E, elevation 320–340 m a.s.l.). Weather conditions in the growing season of 2008 (total rainfall 354 mm, mean daily temperature 17.0 °C) was less extreme than in 2009 (total rainfall 299 mm, temperature 17.9 °C). Rainfall strongly determined the course of radial growth increment in trees. Radial growth of trees was limited in 2009 due to the drought in spring. The maximum radial increment of both species was achieved three weeks earlier (4th week of June) than in 2008 (4th week of July). We used dendrometer monitoring data for estimation of stem (tree) water deficit (ΔW) by measuring water-related changes in stem radius (Zweifel et al. 2005). The magnitude of tree water deficit variation (ΔW) was always smaller in *Q. cerris* than in *Q. petraea*. In contrast, *Quercus cerris* always exhibited larger daytime averages and maxima of sap flow density. In August of 2009 when drought became severe there were larger increases in tree water deficit (ΔW) (50–55 %) in both species compared to July as it could be expected from the extent of decreases in sap flow density (24–28%). Our data suggested that due to the low SWC the transpiration was supported mainly from the inner water storage of trees during prolonged drought which resulted in high stem water deficit (ΔW).

drought / forest/potential evapotranspiration / Quercus petraea / Quercus cerris / stem (tree) water deficit

Kivonat – Két zonális tölgyfaj törzsnövekedésének és nedváramlásának napi és szezonális dinamikája. A tanulmányban összefoglalt eredmények részét képezik a Bükk-hegységi Síkfőkút Project LTER kutatási terület (47°90'N, 20°46'E, tszf. 320–340 m) cseres-tölgyes erdőállományban folyó növény-ökofiziológiai kutatási programnak. Vizsgálataink során folyamatos dendrometriás és nedváramlás méréseket végeztünk a 2008 és 2009 évek vegetációs időszakaiban annak megállapítására, hogy a kocsánytalan tölgy (*Quercus petraea (Matt.) Liebl.)* és a csertölgy (*Quercus cerris L.)* radiális

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törzsnövekedésében és vízforgalmában az időjárási extrémitások milyen mértékű változásokat okoznak. A dendrometriás mérési eredmények azt jelzik, hogy a csapadék mennyisége és eloszlása döntően meghatározza a törzsek radiális növekedését mindkét fajnál. Minkét faj esetében kimutattuk, hogy a 2009 évi tavaszi aszály hatására a törzsek radiális növekedése három héttel korábban befejeződött és alacsonyabb értéket ért el a 2008 évi növekedéshez képest. A törzs radiális változásának a finom időfelbontású mérése a növekedési ütemen kívül lehetőséget nyújtott arra is, hogy az adatok alapján a törzsek (fák) vízdeficit értékeit (ΔW) is megbecsüljük, amelyhez Zweifel et al. (2005) módszerét használtuk fel. A két fafaj közül a vízdeficit a *Q. petraea* törzsében mindig szignifikánsan nagyobb amplitúdójú változásokat mutatott, mint a *Q. cerris* esetében, ami alapján az utóbbi fajnál nagyobb törzsbeli vízkészletre következtettünk. Ugyanakkor a nedváramlás nappali középértéke és maximuma mindig a *Quercus cerris* esetében volt magasabb. 2009 augusztusában, erősen aszályos időszakban mindkét fajnál jóval nagyobb mértékben (50–55%-kal) emelkedett a fatörzsbeli vízdeficit a júliusi mérési eredményekhez képest, mint amit az ugyanezen időszakban mért nedváramlás csökkenés mértéke alapján várnánk (24–28%). Ez azt sugallja, hogy a fák a tartósan aszályos periódusokban a belső, törzsbeli vízraktárakat hasznosítják a vízszállító pályák feltöltésére és a transzpiráció fenntartására.

aszály / nedváramlás / *Quercus petraea* / *Quercus cerris* / radiális törzsnövekedés / vízdeficit

1 INTRODUCTION

Owing to climate change (IPCC, 2007) the future survival and sustainability of forest ecosystems has become of great concern (Jump et al. 2009, Mátyás 2010). For Carpathian basin climate projections predict a reduction in the total area of climate-zonal forests and the gradual shift „forward” of transition between forest and forest-steppe zones (Mátyás – Czimber 2004). Severe and recurring drought has been identified as major contributing factor to the recently accelerated tree decline and mortality in Europe (e.g. Jakucs et al. 1986, Gibbs – Greig 1997, Siwecki – Ufnalski 1998, Thomas et al. 2002).

In Hungary serious tree decline has been reported for the mixed stands of sessile oak (*Quercus petraea* (Matt.) Liebl) and Turkey oak (*Quercus cerris* L.) from the 80’s (Jakucs et al. 1986). These forests represent one of the most important vegetation type in the Carpathian basin therefore tree decline has large economic and nature conservation consequences. Sessile oak suffered more drastic decline than Turkey oak in Hungarian forests as well as in whole Europe. Mortality of sessile oak varied with site conditions and became very serious in xeric margins of this forest type suggesting that climate change will threaten sessile oak very strongly. Simulation of future distribution of sessile oak by BIOMOD model (Thuiller 2003) projects that there will be a shift of its bioclimatic envelope as a result of climate change. On regional scale, analyses provided also a very pessimistic scenario for Hungary since the species may loose the majority of the distribution area by 2080 (Czúcz et al. 2011).

The objective of this work was to analyse the effects of climatic fluctuations on growth and water status of two co-existing tree species *(Quercus petraea (Matt.) Liebl. and Quercus cerris L.)* in two subsequent growing seasons, 2008 and 2009. More specifically we intended 1) to estimate the influence of environmental conditions on stem radius increment with high time resolution; 2) to assess drought related responses of tree water deficit for the two species; 3) to describe seasonal and diurnal course of sap flow density and its correlation with environmental factors.

2 MATERIAL AND METHODS

2.1 Study site and experimental trees

The study was carried out at Síkfőkút Project LTER forest site (47°90’N, 20°46’E, elevation 320–340 m a.s.l.), Bükk Mountains, north-eastern Hungary in summer of 2008 and 2009.

The site is covered by a mixed forest stand (95–100 yr) dominated by sessile oak (*Quercus petraea*) and Turkey oak (*Quercus cerris*) in the canopy layer. The soil of the site is a deep brown forest soil formed on miocenic pebble (Jakucs 1985). According to the current climatic conditions the site is close to the forest-steppe limit. The average annual rainfall of the past 30 years is 555 mm and the mean annual temperature is 10.3 °C at the site (*Table 1*). The growing season usually lasts from mid-April to mid-October. In the northern mountain region of Hungary the annual total of global radiation falls between 4300–4400 MJ m^{-2} (Jakucs 1985). During the past decade extreme drought and heat-waves have appeared at the site in summer of 2003, 2007 and 2009.

The tree species composition of the stand was: *Quercus petraea* 46.9%, *Quercus cerris* 22.8%, *Carpinus betulus 0.4%, Acer campestre 28.2%, Acer tataricum* 0.9%, *Cerasus avium 0.8%*. Trees of oak species belong to the dominant and co-dominant crown classes, while other tree species represent intermediate and co-dominant crown classes of forest canopy.

For our study we selected one mature sessile oak and one Turkey oak (95–100 years old). Both trees represented the dominant crown class growing to uppermost position of the forest canopy (height of experimental trees was 20–22 m, DBH of the sessile oak tree was 29 cm, for Turkey oak 46 cm).

2.2 Measurements of environmental parameters

Weather conditions were monitored automatically by Hobo ProSeries RH&Temp sensor (Onset Computer Corporation, Pocasset, USA), and Hobo Micro Station (Onset Computer Corporation, Pocasset, USA) with external sensors (Rain gauge, PAR, atmospheric pressure, wind speed) during the study period. Weather data were recorded at every 30 min. at the top of a meteorological tower (25m above ground). Volumetric soil moisture content (SWC) was measured using ECH_2O sensors (Decagon Devices, Pullmann WA, USA) within the upper 30 cm with 15 min sampling interval.

To assess the differences in the microclimatic conditions between vegetation seasons of 2008 and 2009 we calculated the cumulative daily mean temperature and cumulative rainfall. Cumulative daily mean temperature and rainfall data and course of soil moisture in 2008 and 2009 are presented in *Figure 1*. Due to the lack of measurements of global radiation, the Hargreaves-Samani temperature based method was used to estimate the the mean daily potential evapotranspiration (PET mm day^{-1}) (Hargreaves – Samani 1982).

2.3 Sap flow measurements

Continuous sap flow measurements began at our site in growing season of 2009. Sap flow density (ml cm^{-2} min^{-1}) was measured with heat dissipation method developed by Granier (1985). An SF-G sensor (Ecomatik, GmbH, Dachau, Germany) was mounted on the northern side of tree stems to avoid direct solar heating and shielded with aluminum foil to minimize temperature fluctuations in the sapwood. The SF-G sensor consists of two identical needles with copper-constantan thermocouples and a special heating wire. The two needles were inserted 2 cm into the sapwood, one above the other, 15 cm apart. The upper needle was installed at a height of 1.5 m. The top needle was heated with constant energy supply (at 12V with 83 mA). The temperature difference between the two needles (ΔT) was the output signal of the sensor and used for calculation of sap flow density according to the formula by Granier (1985):

$$u = 0.714*[(\Delta T_{max}–\Delta T)/\Delta T]^{1.231},$$

where

ΔT is temperature difference between two needles;

ΔT_{max} is the maximum value of ΔT when sap flow can be considered as 0 during night.

SF-G Sensors were installed on March 26 2009 and monitoring of ΔT was planned in 5 min interval till the end of October but there were some short periods during the growing season when unexpected errors (due to heavy rain events, animal damages etc.) disrupted the continuous measurement.

2.4 Measurements of tree stem radius changes and estimation of tree water deficit

Tree stem radius changes (Δr) were monitored with automated DR dendrometers (Ecomatik Gmbh, Dachau, Germany) with resolution up to 0.2 microns. The dendrometers were mounted at 1m above ground on north side of stem of one sessile oak and one Turkey oak tree. Continuous recording of stem radius changes began on June 6 2008. Δr was recorded in 10 min intervals.

A sensor fixed in a frame was installed to the measuring section of the stem after removal of the dead bark. Sensors were installed carefully to avoid damages to the living tissues below the dead bark. The course of Δr depends mainly on stem radial growth and fluctuation of water-storage. Other factors e.g. temperature and xylem-tension-related fluctuations may contribute only slightly (<10%) to Δr (Zweifel et al. 2005). From the course of Δr we estimated the changes in stem water-storage by using the algorithm suggested by Zweifel et al. (2005). We hypothesized that a rainfall event above 10 mm can induce stem hydration and increase of r to maximum. The difference between the trunk radius of maximum hydrated (normally after a rainfall event) state and actual hydration status was used for quantifying the degree of stem water deficit (ΔW) during a given period. This is also considered as a measure of water deficit in the whole tree and defined as tree water deficit (Hinckley – Lassoie 1981).

3 RESULTS

3.1 Weather and soil moisture conditions

Compared to the average weather conditions of the last 30 years (1978–2007), annual mean temperature was higher by 0.9–1 °C in 2008 and 2009 (*Table 1*).

The vegetation period of both study years was warmer and drier than the average. Summer of 2009 was extraordinarily hot and had one of the lowest total amounts of rain during the last decade (*Figure 1*). However, in 2009 the total annual rainfall did not differ from the 30 year average while in 2008 it was 56 mm lower (*Table 1*).

In 2009 there was a four-week period without rainfall during budburst in April which led to rapid decline of soil moisture content (*Figure 1*). The whole vegetation period of 2009 was drier and warmer than in 2008 with low volumetric water content. In 2009 the end of vegetation period was without rain events that caused large water deficits in the soil in September. During the vegetation period of 2008 the soil was wet in spring. Volumetric soil water content transiently decreased in May, but it increased in June and July due to frequent rains.

Table 1. Annual mean of air temperature (T), mean daily air temperature of vegetation period ($T_{04–10}$), annual total rainfall (P) and total rainfall of vegetation period ($P_{04–10}$) in 2008 and 2009. Long-term mean values of air temperature and rainfall were calculated for 1978–2007

	T °C	$T_{04–10}$ °C	P mm	$P_{04–10}$ mm
2008	11,3	17,0	499	354
2009	11,3	17,9	554	299
30-year mean (1978–2007)	10,4	16,5	555	393

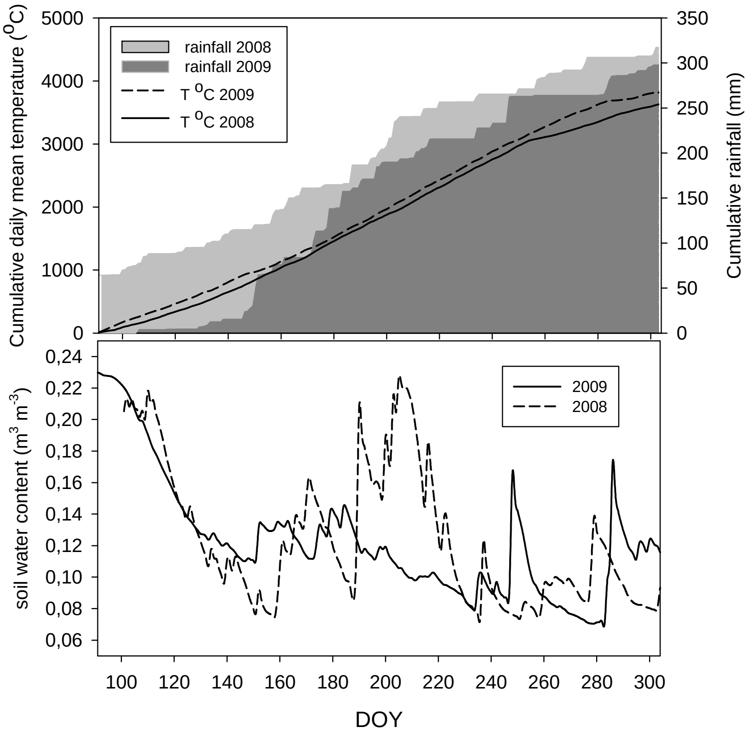

Figure 1. Cumulative values of daily mean air temperature, cumulative daily precipitation (upper figure) and volumetric soil water content (lower figure) during the growing seasons of 2008 and 2009 in the Síkfőkút study area

3.2 Stem radius changes and variation in tree water deficit

Dendrometers were installed on tree stems on June 6 2008. We selected a three-month period between DOY158 and 248 in 2008 and 2009 for comparison of stem radius changes (Δr). Although the course of Δr was different in 2008 and 2009, the stem radial increment did not change after DOY 248 in both years (*Figure 2*). DOY 158 is considered as reference day and Δr values show deviations from it.

The dendrometer data was set as 0 on the first day of this selected period. During the three-month period in 2009 there was only 750–850 µm maximum increment for *Quercus petraea* 500–600 µm for *Quercus cerris*. Stem radius stopped to increase by the first week of July 2009 and then only short-term fluctutations occurred due to the daily transpiration and rainfall events.

In 2008, however, both species showed three or four times larger stem radius increase in the corresponding period than in 2009 (*Figure 2*). In the corresponding period of 2008 the stem radius change was 2100–2300 μm for *Quercus petraea* and 1800–2100 μm for *Quercus cerris* in the three month period. In 2008 the stem radius showed increases till the end of July.

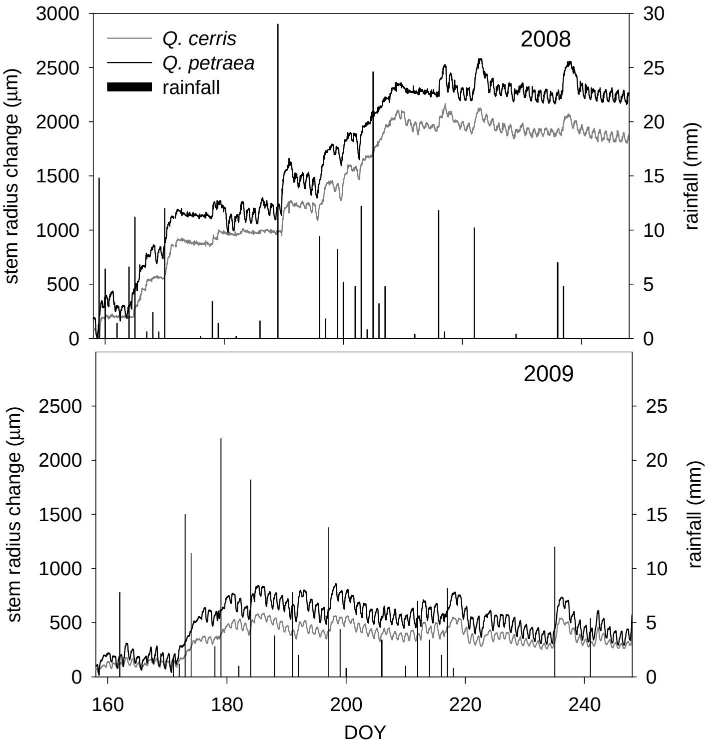

Figure 2. Temporal course of cumulative stem radius change (Δr) for Quercus petraea (black line) and for Quercus cerris (gray line) and daily sums of rainfall in summer of 2008 and 2009. DOY 158 is considered as reference day and Δr values show deviation from it

The three-month long dendrometer data series were also used to estimate fluctuations in water status of tree stems. Seasonal variations in stem water deficit calculated by means of method suggested by Zweifel (2005) are presented in *Figure 3*.

The general seasonal course of ΔW was similar for the two species in both years. Seasonal amplitude of stem water deficit differed in the two species, it was smaller for *Quercus cerris* than for *Quercus petraea*.

Variation of stem water deficit was, however, usually the most significant during dry periods and approached zero after heavy rain events. Even one-two week dry periods could induce rapid increases of tree water deficit depending on the soil water availability and VPD. In 2008 large stem water deficit developed within the period from DOY 175 to DOY 190 (4th week of June and 1st week of July) up to 250 μm for *Quercus cerris*, and 500 μm for *Quercus petraea* and between DOY 223 and DOY 236 up to 230 μm and 420 μm for *Quercus cerris* and *Quercus petraea*, respectively. In 2009 a long-lasting stem water deficit period appeared from DOY 200 to DOY 234 with 300 and 450 μm maximum values of ΔW for for *Quercus cerris* and *Quercus petraea*, respectively. There was only a short (3 days) interruption of this period when ΔW of stem approached 0 in both species. The diurnal fluctuation of ΔW were also different in the two species *(Figure 3).*

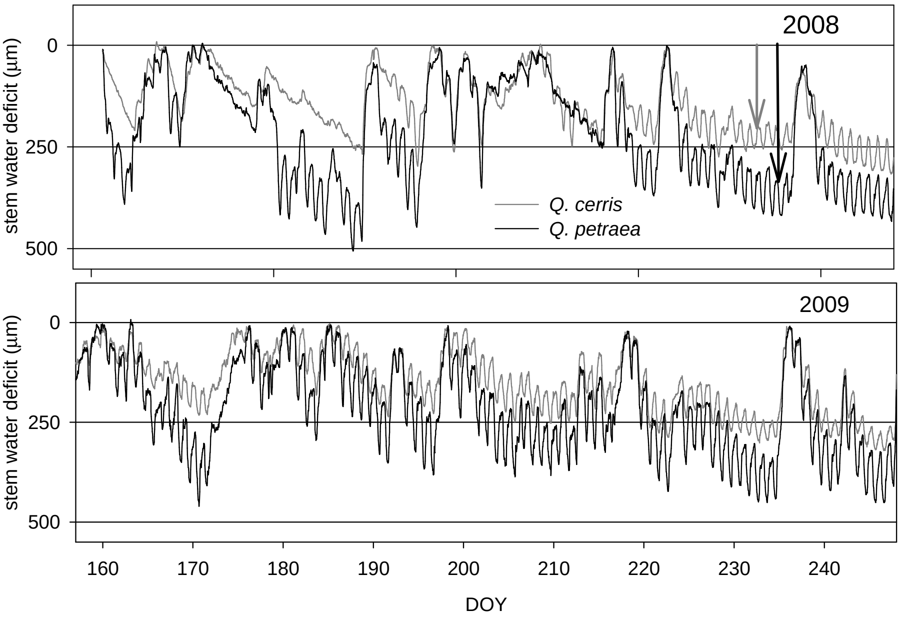

Figure 3. Variation in stem (tree) water deficit (ΔW, µm) with time for Quercus petraea (black line) and Quercus cerris (gray line)

On most sampling days in 2008 both species showed lower diurnal amplitudes of ΔW than in 2009. In 2008 diurnal amplitude of ΔW reached 80–120 µm in *Quercus petraea* and 40–80 µm in *Quercus cerris*. In 2009 the diurnal variation of stem radius extended to 130–200 µm in *Quercus petraea* and to 40–100 µm in *Quercus cerri*s.

3.3 Variation of main daytime sap flow density and correlation with PET in summer of 2009

In the second half of the vegetation period of 2009 we experienced severe drought at the site. During the experimental period from DOY 209 to DOY 283 mean daytime sap flow density ranged between 0.11 and 0.04 ml cm^{-2} min^{-1} in *Quercus cerris*, and 0.07 and 0.02 ml cm^{-2} min^{-1} in *Quercus petraea*. During the same period the daily PET changed between 12 and 4 mm day^{-1}.

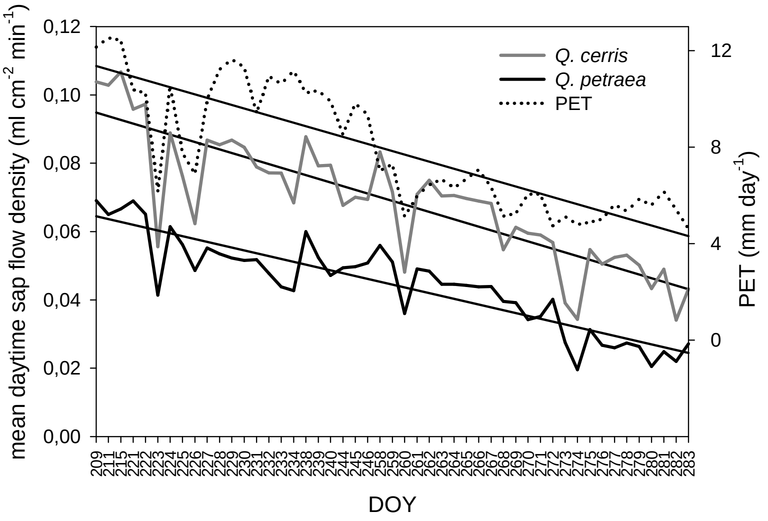

Figure 4. Daytime mean sap flow density of Quercus petraea (black line) and Quercus cerris (gray line) and potential evapotranspiration estimated by Hargreaves-Samani temperature based method (Hargreaves-Samani 1982) during the experimental period from DOY 209 to DOY 283. Rainy days are excluded from the data set

A general decreasing trend of mean daytime sap flow density was observed for both species as the drought proceeded in August and September (*Figure 4*). Analysis of a dataset from this period (50 days after exclusion of rainy days) showed that the daytime sap flow density of both species changed in close positive correlation ($P<0.01$) with PET which also showed declining trend in the second part of growing season. The correlation was closer for *Q. petraea* ($R^2=0.6248$) than *for Q. cerris* ($R^2=0.7410$).

3.4 Diurnal course of sap flow density

From the continuous sap flow measurements of 2009 we have selected days from two characteristic periods to assess the relationship between sap flow density and environmental conditions at daily scale.

i) DOY 209, DOY 211 and DOY 215 represent sunny days in a moderately rainy period with small rains on DOY 210 (1 mm), DOY 212 (7mm) and DOY 214 (3.4mm), decreasing SWC (from 0.110 to 0.099 cm^3 cm^{-3}), high daytime VPD values (VPD_{max} 3–4 KPa) and light intensity ($PPFD_{max}$ 1800–1900 µmol m^{-2} s^{-1}). There were only two small rains (<4 mm) rain during the previous 10 days (*Figure 5*).

ii) DOY 231, DOY 232 and DOY 233 in the driest period of summer with SWC 0,080–0,083 cm^3 cm^{-3}, high daily VPD (VPD_{max} 2.9–3.6 kPa) and PAR (PPFD 1700–1800 µmol m^{-2} s^{-1}). There was no rainfall event in the previous 10 days (*Figure 6*). This period represented typical stage of the drought stress.

The magnitude of diurnal sap flow amplitude depended significantly on the environmental conditions on selected days and decreased as the drought stress proceeded on sunny and hot days (DOY 209, 211 and 215) of a moderately rainy period in July, the mean SWC value on the selected three days reached 0.10 cm^3 cm^{-3}. The low SWC suggests that in July a significant depletion of soil water reserves occurred and small rains were not enough for soil refilling. Comparing with other periods of growing season both tree species exhibited relatively high stem water deficit on these days (*Figure 3*).

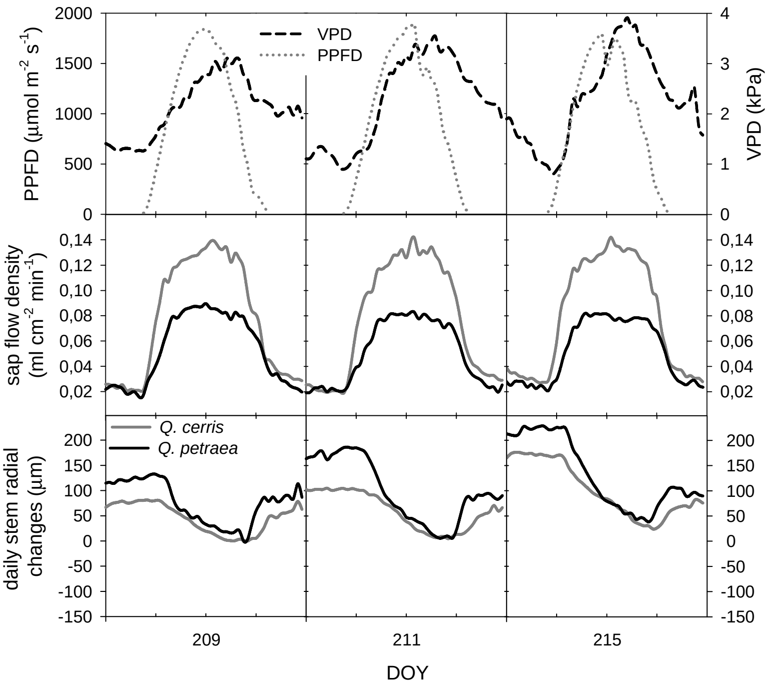

Figure 5. Diurnal course of VPD, light intensity (PPFD) and sap flow density and daily stem radial changes of Quercus petraea and Quercus cerris on sunny days of a moderately rainy period in July 2009

On DOY 209–Doy 215 the mean daily stem water deficit (ΔW) was 169 μm for *Q. cerris* and 251 μm for *Q. petraea* (*Figure 3*). Between the two selected periods sap flow density of both tree species was the highest on these days. The daytime mean sap flow was 0.10 ml cm^2 min^{-1} in *Q. cerris* and 0.066 ml cm^2 min^{-1} in *Q. petraea*. The daily maximum of sap flow was relatively high and approached 0.14 ml cm^2 min^{-1} for *Q.cerris* and 0,09 ml cm^2 min^{-1} for *Q. petraea* (*Figure 5*). VPD was very high on these days and showed daily maximum between 3.1 and 3.9 kPa. Sap flow density was in close correlation with VPD but showed a maximum earlier during the day. The stem radius reached maximum in the morning (between 6 and 8 a.m.) and minimum values in the afternoon (between 4 and 6 p.m.). Temporal appearance of minimum was closely related to the maximum of VPD.

In 2009 a progressive drought appeared from the first week of August which lasted almost for the whole month and was interrupted only by short rain events (*Figure 1*). SWC reached its minimal value (0.0819 cm^3 cm^{-3}) in this month considering the whole summer (*Figure 1*). On the three selected representative days of drought period (DOY 231–233) the daily maximum of sap flow was low in both tree species (0.101 ml cm^2 min^{-1} and 0.064 ml cm^2 min^{-1} (*Figure 6*). These sap flow density values were 28 % (*Q. cerris)* and 24 % (*Q. petraea*) lower than in July (*Figure 5*).

Q. cerris exhibited very similar diurnal course of sap flow density as in July in correlation with PPFD and partly with VPD too. While *Q. cerris* showed maximum sap flow density at midday, *Q. petraea* had a short maximum of sap flow density in the morning (at VPD 2–2.5 kPa) followed with a gradual reduction later on the day. The amplitude of diurnal variation in the stem radius was higher in *Q. petraea* than in *Q. cerris*.

Stem water deficit (ΔW) was 55 % (*Q. cerris*) and 49 % (*Q. petraea*) larger were deduced than in July. Mean daily value of ΔW was 263 μm for *Q. cerris* and 374 μm for *Q. petraea* (*Figure 3*) suggesting the reduction of stem water storage due to the drought.

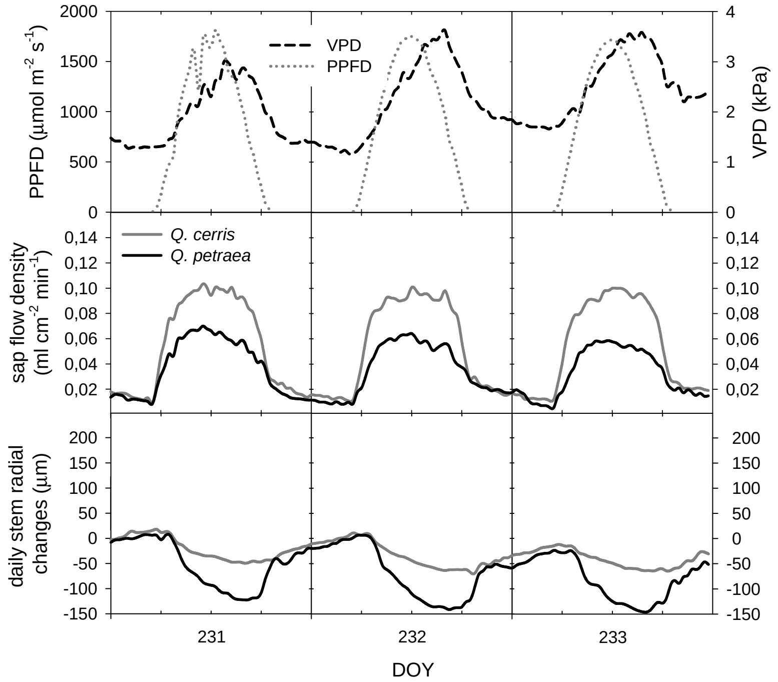

Figure 6. Diurnal course of VPD, light intensity (PPFD) and sap flow density and daily stem radial changes of Quercus petraea and Quercus cerris on sunny days during the drought in August 2009

4 DISCUSSION

At the study site the temporal course of stem radial changes (Δr) were analized during the period from 6 June till 15 September presuming different temporal growth dynamics of both species in 2008 and 2009. Rainfall strongly determined the course of radial growth increment in both species.

Due to the extreme environmental conditions in spring of 2009, the radial growth of trees was strongly limited by drought and the maximum radial increment of both species was reached three weeks earlier (by end of June) than in 2008 (by end of July). We suggest that the extreme drought in spring of 2009 combined with high temperature forced the trees to allocate carbohydrates to belowground carbon sinks to provide water and nutrients for shoot growth. Allocation of carbohydrates for producing fine roots when rainfall was low and SWC reduced rapidly could be a main cause for reduced growth rate of stem in the investigated period in 2009. Former studies suggest that carbohydrate supply to mycorrhiza might also contribute significantly to the switch of allocation pattern in trees under drought stress (Nehls et al. 2007).

At our site *Quercus petraea* exhibited larger stem increment during the experimental period of both years compared to *Quercus cerris*. The short-term fluctuations of Δr, however, were smaller in *Q. cerris* than in *Q. petraea*. This suggested that *Q. cerris* might have larger water storage in the trunk available for transpiration, as proposed by former studies on sap flow measurements (Tognetti 1996). Temporal course of stem (tree) water deficit also reflected that the two species might differ in water storage in the trunk. The magnitude of tree water deficit variation (ΔW) estimated from dendrometer monitoring data by measuring water-related changes in stem radius was always smaller in *Q. cerris* than in *Q. petraea.* In August of 2009 when drought became severe, increases (50–55 %) in tree water deficit (ΔW) of both species compared to July were larger as expected from the extent of decreases in sap flow density (24–28%). Water status including transpiration rate of trees is strongly determined by stomatal regulation (Zweifel et al. 2001, Gao et al. 2002). Therefore a strong stomatal influence on tree water deficit can also be postulated. Our data suggested that due to the low SWC the transpiration was supported mainly from the inner water storage of trees during prolonged drought which resulted in high stem water deficit (*Figure 3*).

Similar seasonal course of sap flow density was found for the two tree species, but *Quercus cerris* always showed higher sap flow density than *Quercus petraea.* In the regulation of sap flow, stomata play pivotal role. With their help water demand of trees can continuously be adjusted to the actual water availability (McDowell et al. 2008). Under decreasing SWC conditions by August, stomatal regulation became important in controlling the transpiration of both species. There was a decline in maximum daytime sap flow density during the drought period in August compared to that of July that can be interpreted as the consequence of stoma closure in the whole crown of both species. When trees experience very low SWC and high evaporation demand, the sap flow tends to be more and more controlled by stomata.

Stoma closure is the most efficient reaction to daily and seasonal water shortage. By closing their stomata, plants avoid harmful dehydration, although this goes at the expense of photosynthesis assimilation due to the limited uptake of CO_2 (Mészáros et al. 2007). However, closing of stomata during daytime for long periods may induce carbon starvation of trees and affect their growth and competitive ability (Bréda et al. 2006, McDowell et al. 2008).

Concerning sap flow density the two tree species responded differently to the drought. In this period only *Quercus cerris* could maintain a regular diurnal pattern of sap flow density (and transpiration) (DOY 231–233, *Figure 6*) although at reduced maximum values.

Maximum sap flow density of *Q. petraea* gradually shifted back from midday by 2–4 hours to the morning on dry and hot days. This suggests the strengthening of dehydration-induced stomatal control over the light dependent stomatal regulation is in good agreement with reports on mature trees of other forest tree species (Aranda et al. 2000, Gartner et al. 2009).

Despite low SWC and high VPD, *Q. cerris* exhibited 38 % higher mean daytime sap flow density than *Q. petraea*. During the same period 42 % lower stem water deficit was estimated for *Q. cerris* than for *Q. petraea*. Such differences in water relations between the two co-existing species have significance in relation to competition under changing climate. This is clearly demonstrated by the shift of dominance conditions at the investigated site (Kotroczó et al. 2007).

5 CONCLUSIONS

Using continuous monitoring of stem radius changes combined with sap flow measurements at high time resolution we concluded that the two co-existing species respond differently to drought. Stem (tree) water deficit deduced from dendrometer measurements and temporal course of sap flow density can be used for assessing drought stress and describing inter-specific differences in tolerance and stress coping mechanisms.

Acknowledgements: The work was financially supported by National Research Foundation (OTKA Contract No. 68397), LIFE08 ENV/IT/000399 and TÁMOP-4.2.2/B-10/1-2010-0024.

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10.37045/aslh-2011-0009 *Acta Silv. Lign. Hung., Vol. 7 (2011) 109–123*

The Riparian Alder Forests of the Sopron Hills

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Abstract – The present study demonstrates the classification of the riparian alder forests of the Alpokalja region through the analysis of their stands in the Sopron Hills. Besides the historical, ecological and floristic data collection, the differentiation of these forests was examined using 36 coenological relevés recorded according to the Braun-Blanquet method. Cluster analysis, principal component analysis and TWINSPAN analysis were applied in the process; the definition of diagnostic species for the resulting units was carried out by fidelity analysis using the Φ coefficient. The presence of three alder forest associations was verified by the research in the study area. In the vicinity of the lower and middle sections of the streams, characterized by stagnant water, small patches of swampy alder forests (*Angelico sylvestris – Alnetum glutinosae*) occur. In the fast-flowing stream sections alder woods rich in species of mesophilic deciduous forests (*Aegopodio – Alnetum glutinosae*) can be found, while along the middle and upper sections of the streams, at sites with seepage water, mixed ash-alder forests with montane herb species (*Carici remotae – Fraxinetum*) are typical. The investigations revealed that the *Carex brizoides* dominance-type alder groves were secondary forests that formed in former meadows and they belong to the 3 mentioned riparian alder forest types.

riparian alder forests / phytosociology / Sopron Hills

Kivonat – **A Soproni-hegység égerligetei.** Jelen tanulmány az Alpokalja égerligeteinek osztályozási problémáit a Soproni-hegység állományainak elemzésén keresztül mutatja be. A történeti, ökológiai és florisztikai adatgyűjtés mellett a szerző a ligeterdők differenciálódását Braun-Blanquet módszere szerinti 36 cönológiai felvétel felhasználásával vizsgálta. A feldolgozás során cluster-analízis, főkomponens-analízis és TWINSPAN-elemzés készült, az elkülönített egységekre a diagnosztikai fajok kimutatása a hűség-értékek Φ koefficiens szerinti számításával történt. Az elemzések alapján a hegység területén három égerliget-asszociáció jelenléte volt igazolható. Az alsó és középső patakszakaszok kiszélesedő, pangóvizes részein kis foltokban láposodó égerligetek (*Angelico sylvestris – Alnetum glutinosae*) fordulnak elő. Ugyanebben a fekvésben a patakok gyors folyású szakaszain üde lomberdei fajokban gazdag égerligetek (*Aegopodio – Alnetum glutinosae*), míg a középső-felső patakszakaszok szivárgó vizes termőhelyein montán elemekkel színezett, kőriselegyes égerligetek (*Carici remotae – Fraxinetum*) jellemzőek. A vizsgálatok feltárták, hogy a *Carex brizoides* dominancia-típusú égerligetek egykori rétek helyén kialakult, másodlagos jellegű erdők, s a fenti három égerliget-típushoz tartozó állományokat foglalnak magukba.

égerligetek / növénycönológia / Soproni-hegység

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1 INTRODUCTION

The near-natural vegetation of the border region between the Alps and the Pannonian Basin has a strong transitional character due to the combined effects of the sub-Atlantic and sub-continental (and to a smaller extent sub-Mediterranean) climates. The montane influence and the occurrence of montane plant species is most remarkable in the regions of the Kőszeg and the Sopron Hills, which can primarily be explained with the direct biogeographical connections, and the orographical characteristics of the two regions (ridges exceeding the height of 800 and 600 m a.s.l., respectively).

The montane characteristics can be best detected in the riparian alder forests along the streams in both regions (see Szmorad 1994, Király – Szmorad 2004a) where the microclimatic conditions of the stands situated between beech forests allow the occurrence of numerous montane plant species. On the other hand, the alder forest sections of the foothills resemble more of the stands described in the inner basin, while secondary stands formed as a result of earlier anthropogenic impact are also possible to be found. This complexity of the situation makes it difficult to create a coenological classification of these alder forests; the different syntaxonomical systems of the two neighboring countries, Austria and Hungary (see Wallnöfer et al. 1993, Kevey – Borhidi 1996, Borhidi 2003, Willner 2007, Kevey 2008), and the different interpretations of the associations in the Austrian and Hungarian literatures further complicate this issue.

The classification issues are presented in this paper as a case study on the alder forests in the Sopron Hills region, divided by the Hungarian-Austrian border (see Szmorad 2010). There are only a few short descriptions of the alder woods of this area from the Hungarian side (Soó 1941, Csapody 1964), whereas no research has been carried out on the Austrian part. There are very few coenological relevés published that could be analyzed, and most of the riparian stands have never been subject to vegetation research. The coenological, ecological and phytogeographical characterization of the stands also considering historical aspects have not yet been carried out and the question of the montane riparian ash-alder forests has not yet been resolved (see Kevey 2008).

2 STUDY AREA

The Sopron Hills are the north-eastern subrange of the Alps reaching furthest into the Pannonian Basin together with the Kőszeg Hills. They are of medium height. To the west they are separated from the adjacent, nearly north-south running Rosalia Hills by a saddle above the village of Sieggraben. The area of the Sopron Hills is approx. 150 km^2 (Király 2004).

Concerning the area’s geology, the formations of two geological epochs play a major role: in the eastern part of the hills an island-like extrusion of a palaeozoic schist block (consisting of muscovite-gneiss, mica slate, quartzite and leucophyllite) can be observed (Vendl 1929) while the western part between that and the Rosalia Hills is covered with Miocene sandy, gravel–clay sediments (Vendl 1930, Küpper 1957). On the southern face of the hills (between Ritzing and Neckenmarkt, also south of Kalkgruben) there are intrusions of Leitha limestone, while acidic sandstones (between Neckenmarkt and Harka) add to the geological structure, as well (Draganits 1996). In the north-western part of the region, significant areas are covered with a Badenian clay sequence (Fuchs – Grill 1984).

The main ridge runs in West-East direction, its highest point is the Brenntenriegel (606 m a.s.l.) situated within Austrian territory. The surface structure is defined by wide and flat ridges and slopes of varying steepness. The valleys are usually deeply cut in the schists, thus they are narrow with an upper-course character, without alluvial valley floors (Kárpáti 1955).

On the other hand, the valleys that formed on the Miocene sediments show mostly middle-course characteristics, their streams often meander on the 30–50 m wide alluvial valley floors.

The hydrographic network of the area consists of small streams. Along their upper sections and in the vicinity of valley heads seeping springs are frequent, whereas smaller hallows with stagnant water appear along the middle and lower sections. The typical soil types of the valley floors are wet (in some cases affected by seeping or stagnant waters) alluvial and colluvial forest soils (Csapody – Neuwirth 1963). On wider valley floors the site conditions are more defined by the groundwater.

The climate of the region is basically cool with high precipitation. However, a definite macroclimatic gradient can be observed west-easterly; while the eastern hill front is warmer and dryer, the western, inner area is much cooler and has higher precipitation. The mean annual temperature varies between 8–9 ºC, and the annual precipitation usually between 650–900 mm (Király 2004).

From the phytogeographical point of view the Sopron Hills are situated in the border region of the Alpine (*Alpicum*) and the Pannonian (*Pannonicum*) floristic provinces. The phytogeographical classification of the area is difficult, since the detectable floristic gradients (Király – Szmorad 2004b) indicate a transitional nature and a dualistic character, which often appears in the forest vegetation as well.

3 FORMER RESEARCHES

The first references to the riparian alder forests of the Sopron Hills can be found at Gombocz (1906); later Soó (1941) studied the area. The latter mentions alder forests (*Alnetum glutinosae*) and ash-alder woods (*Fraxineto – Alnetum*) based on some coenological relevés recorded on a single site at the upper section of the Rák Stream. He distinguished several different types (for the former *Phragmites communis – Caltha palustris*, *Carex remota*, *Impatiens noli-tangere*, for the latter *Veratrum album*, *Carex brizoides*, *Chrysosplenium alternifolium*, *Petasites hybridus* types) and summarized his data in a synoptic table.

After World War 2 the reviving Hungarian botanical research was mostly confined to the eastern part of the hills due to the state border zone. The essay of Orlóci – Tuskó (1955), from this period mentions riparian forests dominated by black alder (*Alnetum incanae Alnus glutinosa* consociation) and mixed ash woods (*Cariceto remotae – Fraxinetum*). In his phytogeographical study using mainly earlier data Kárpáti (1956) describes alder woods under the name *Alnetum glutinosae-incanae* in the Sopron Hills region and ash woods (*Cariceto remotae – Fraxinetum*) in the Vadkan and Tacsi Valleys, the Fáber Meadow and the Nagyfüzes areas.

The riparian forests along the streams of the eastern half of the Sopron Hills were examined in detail by Csapody (1964). The montane alder forests that he named *Alnetum glutinosae-incanae* Br.-Bl. 1915 were characterized on the basis of 9 relevés and he also described the ash woods under the name *Carici remotae – Fraxinetum* Koch 1926 *orienti-alpinum* Knapp 1942, publishing a single relevé. The potential vegetation map of Csapody et al. (1964) can be considered an addition to this study; the authors indicated montane alder forests in some sections of the Zsilip Valley, Hidegvíz Valley and the valleys of the eastern rim of the hills, as well as small ash wood stands in the head part of the Kovács Valley and two spots in Nagyfüzes.

There was no significant research concerning the riparian alder forests of the Hungarian part of Sopron Hills following the previously mentioned ones; the botanical studies published until the early 2000's only refer to earlier works and try to interpret these. Based on the floristic research of the region Király – Szmorad (2004a) provide a very short description of the riparian stands (*Aegopodio – Alnetum, Carici brizoidis – Alnetum*) whereas the historical aspects of the research on alder forests in the Alpokalja region are shortly summarized by Baranyai-Nagy – Baranyai (2008).

Publications about the Austrian side of the research area could not be found, and besides the general descriptions neither the work of Wallnöfer et al. (1993) nor that of Willner (2007) provides help concerning the coenological classification of the local riparian forests.

4 METHODS

I studied all the stream valleys of the Sopron Hills (ca 130 km) in the course of my research and tried to gather all relevant data and information concerning the site characteristics, structure, species composition, earlier management, naturalness and dynamics of the riparian alder forests. For the documentation and detailed examination of these stands I have recorded 30 relevés with the classical coenological method (Braun-Blanquet 1951). The size of the sample areas was either 20 × 20 or 10 × 40 meters (= 400 m^2). The plots were not permanent; data acquisition was carried out once in May or June.

When choosing the sampling plots I avoided disturbed and weedy stands (preferential sampling). Thus they were designated in middle-aged or old-growth stands with high naturalness and without conifers (in order to avoid the influence of such plantations, which had affected riparian sites, as well).

Besides my own ones I have included some (6) relevés by Csapody (1959–1966), surviving as manuscripts. These were also taken in the early summer and represented riparian forests with high naturalness. However, I have omitted some of Csapody's data (1964) since they were recorded in strongly disturbed stands as the high number and cover values of the species indicating disturbance would have strongly distorted the results of the comparative coenological analysis.

In the course of analysing the coenological data with multivariate methods I first used the SYN-TAX 2000 software package (Podani 2001). Before the analysis the cover values of the tree species in the canopy, shrub and herb layers were assembled by species and the A-D values were converted into percentages equal to the central values of the intervals. In case of binary data the Jaccard index was applied for the cluster analysis, while the data transformed using logarithmic standardization (base 2 and 10) were analyzed using the Beta-flexible method (value: –0.25) and the Bray-Curtis index. Principal component analysis (PCA) was applied for ordination.

I have also analysed the coenological data with the TWINSPAN method. This method of Hill (1979) is based on reciprocal averaging (correspondence analysis).The data have been processed with the 7.0 version of the JUICE software package (Tichý 2002, Tichý – Holt 2006). Before the analysis the cover values of the tree species in the shrub and herb layers were assembled by species and the A-D values converted to percentages equal to the central values of the intervals. I chose the level of pseudospecies as 3; their values are 0, 5 and 25%. The TWINSPAN analysis was run with the maximum number of divisions (6) and I interpreted the resulting classification according to the level of the divisions.

I have assigned the diagnostic species for the riparian alder forests for the finalized groups of relevés. Following the method of Chytrý et al. (2002) I defined these by calculating the fidelity values according to the Φ-coefficient. The table of synthetic data (fidelity, constancy) is published with $\Phi = 0.30$, using Fischer's exact test ($P < 0.05$) in order to emphasize species with high fidelity and to avoid bias due to small sample size.

The results from the analysis of the coenological relevés were evaluated (including the experiences of the field trips) and the vegetation types derived from classification were matched with the coenological units. Finally, I prepared the concise description of the region's alder associations, including a literature review. The letters in brackets signify the layers (A = canopy layer, BC = shrub and herb layer, C = herb layer, D= moss layer) in the descriptions. Constant and sub-constant species are represented above 60% constancy, dominant species above 60% cover (in the latter case the percentage values signify the frequency of the dominant occurrences).

I used the vascular plant names of the identification book edited by Király (2009) while moss names are based on the checklist of Erzberger – Papp (2004).

5 RESULTS

5.1 General results of the field research

As stand types associated with streams, alder woods can be found in any valley of the Sopron Hills. Besides the continuous, ribbon-like stands there are some occurrences limited to short valley sections in the north-western and south-eastern part of area on sand-gravel sediments with lower clay content. The latter phenomenon is most apparent south of Marz (in the valley between Gruskogel and Hochkogel), and above Neckenmarkt (in the valley of the Goldbach) mainly due to intermittent streams absorbed by the loose ground. Besides the riparian stands in some parts of the hills (e.g. around Asztalfő) alder woods of similar character appear on wet patches close to springs.

In the narrow valleys of the eastern part formed on schist, the alder stands are narrow, often only a single line wide. More extensive (with an extent of 20–50 m) alder woods which are more suitable for coenological analysis only occur in the valleys of the area covered with sedimentary rocks.

The original site conditions of these forests have been modified in many places by road and leat constructions, stream regulation works, drainage structures, buildings and artificial lakes (in the Austrian part nearly 30 ponds) during past centuries. Although such anthropogenic effects have influenced the sites of the alder stands (mainly the hydrological balance), most of them can still be considered quasi natural.

On the other hand, former land use practices have significantly reduced the extent of the alder stands. The forests on the floodplains of the lower and middle stream sections were cut down centuries ago and replaced by extensive meadows. Many of the meadows are still managed (especially on the Austrian side), however, a large-scale reforestation process started in the 1950's (see Baranyai-Nagy – Baranyai 2008). Non-native tree species were also introduced therefore many stands of *Picea abies*, *Pinus sylvestris* and *Populus × euramericana* can be seen on the valley floors. In the lower valley sections (near settlements and orchards) *Juglans regia* often occurs subspontaneously.

In the riparian alder woods *Alnus glutinosa* is the dominant tree species, but the stands are usually mixed. Of the accompanying species *Fraxinus excelsior* can play a major (even codominant) role (especially along the upper stream sections, in wet or seepage sites). *Alnus incana* is generally missing; there are only two records of this species in the area. The "Loipersbach – Herrentisch" occurrence is probably located in the Aubach valley, while the "NNW Deutschkreutz" in one of the alder woods at the south-eastern foot of Sopron Hills (see Király et al. 2004).

The quasi natural stands of the Sopron Hills alder woods are very diverse and also show significant variability in terms of structure and species composition. The differentiation of the wood types is mostly determined by their vertical location, the morphological characteristics of the valley floor, the depth of the stream bed and water availability but earlier land use practices (meadow management, forest usage, etc.) also seems to have a major influence.

Depending on the background variables the different types of riparian forests are often alternately positioned along the longitudinal axis of a valley.

The coenological characteristics of the riparian forests are defined by the species of mesophilic deciduous forests (*Fagetalia*) and riparian forests (*Alnion incanae*) but in sites with stagnant water some species of swamp forests (*Alnetea glutinosae*) and wet meadows (*Molinetalia*) also appear. According to the prior field studies the proportion of the coenological species groups within the stands (both with regard to species composition and cover) changes mainly depending on the water supply.

Alder woods have a considerable spring aspect, except for the stands nearing swamp state. The most frequent species include *Adoxa moschatellina, Anemone ranunculoides, Anemone nemorosa, Chrysosplenium alternifolium, Ranunculus ficaria, Lathraea squamaria* while *Allium ursinum, Corydalis cava, Dentaria enneaphyllos, Isopyrum thalictroides* occur less often.

The alder woods with an upper-course character are important sites of the montane plant species of Sopron Hills. *Pleurospermum austriacum* used to grow on the edge of a riparian alder wood and *Antriscus nitida, Doronicum austriacum, Equisetum sylvaticum, Gentiana asclepiadea, Lysimachia nemorum, Petasites albus* also partly or entirely occur in such woods (Király et al. 2004, Szmorad 2008). The occurrence of numerous montane moss species can also be linked to upper-course riparian alder forests; the mosses of the spruce zone (typical of the *Vaccinio-Piceetalia* order) occur in almost every case in these stands (see Szövényi et al. 2001).

The sites of these riparian alder stands provide favourable conditions for the spreading of several invasive species. The most notable ones are *Fallopia japonica* (mainly in Austrian valleys), *Telekia speciosa* (Hidegvíz-völgy), and *Impatiens glandulifera* (mainly at foothill stream sections) (see Király et al. 2004). The presence of invasive plants in the inner hill regions is mainly related to settlements and wildlife management facilities (feeding sites).

5.2 Results of the numerical analysis

The cluster analyses of the coenological data show 3 markedly different groups of samples. Here only the dendrogram made with log2 standardization is presented *(Figure 1.)* but the results were very similar when using binary data or log10 standardization.

The first group of the dendrogram (A) contains the relevés of the moderately swampy alder forests with the dominance of *Carex acutiformis* and *Caltha palustris* and the presence of *Cardamine amara, Crepis paludosa, Lycopus europaeus* and further species typical to sites with stagnant water.

The second group (B) includes relevés of the mixed ash-alder woods occurring in sites with seepage water and springs along upper and middle stream sections. In these samples (similarly to the previous group) *Fraxinus excelsior* sometimes plays a codominant role while *Caltha palustris, Carex brizoides, Carex pendula, Equisetum telmateia, Impatiens noli-tangere* and *Petasites albus* can reach significant cover in the herb layer.

The third group (C) is more distinct from the others, it is partly moderately disturbed, partly shows characteristics of mesophilic deciduous forests and is mixed with hornbeam. In the relevés assigned to this category (mainly at middle and lower stream sections) *Carpinus betulus, Salix fragilis* and *Tilia cordata* play a major role in the canopy layer, while *Sambucus nigra* and *Corylus avellana* do so in the shrub layer. The dominant species of the herb layer are *Aegopodium podagraria, Carex brizoides* and *Galeobdolon montanum.*

The scattergram of the PCA does not show spectacular groupings among the records due to the compositional variability of the alder forests. However if the 3 groups of the cluster analysis are projected unto the scattergram, the arrangement of the groups becomes apparent *(Figure 2).*

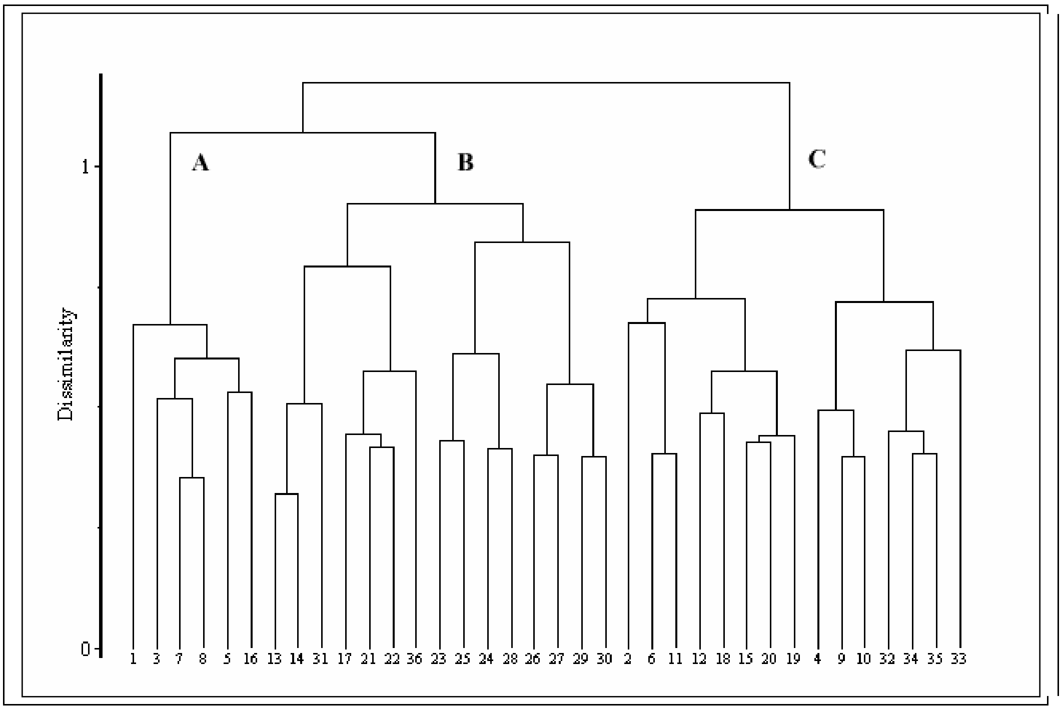

Figure 1. Dendrogram of the relevés (base data: logarithmic standardization, base 2, method: Beta-flexible, coefficient: Bray – Curtis index). (A) swampy alder forests, (B) riparian ash-alder forests, (C) riparian hornbeam-alder forests. Own relevés: 1–30, Csapody's (1959–1966) relevés: 31–36.

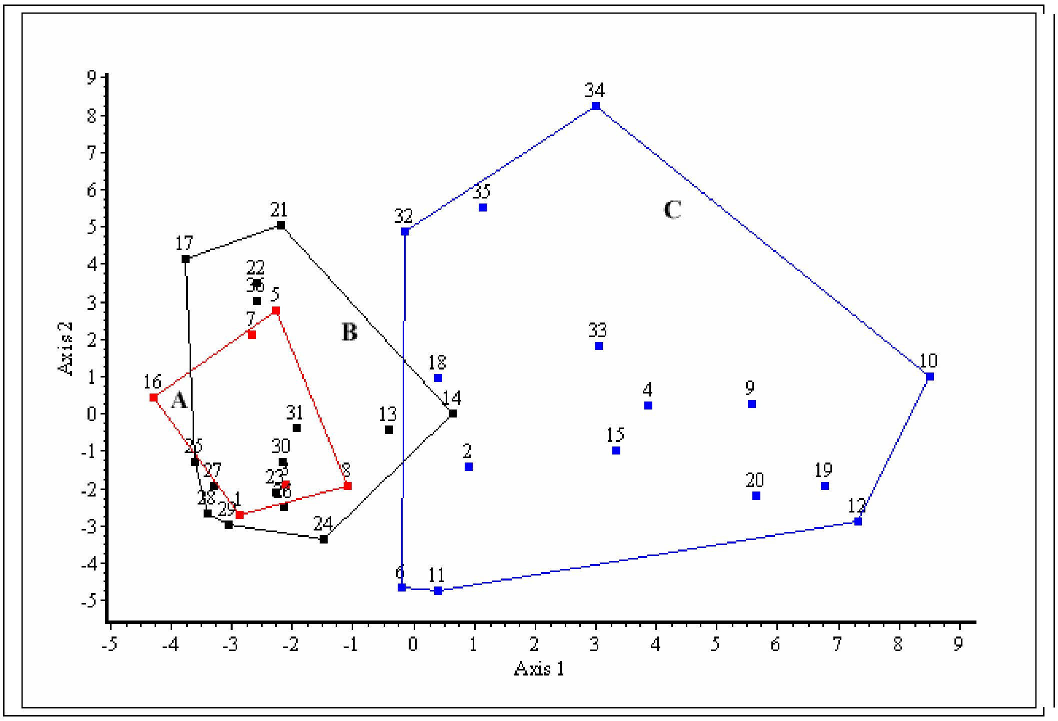

Figure 2. Scattergram of the relevés (centered principal components analysis, partitions according to Fig. 1). (A) swampy alder forests, (B) riparian ash-alder forests, (C) riparian hornbeam-alder forests. Own relevés: 1–30, Csapody's (1959–1966) relevés: 31–36

Group (C) (mixed with hornbeam) on the right side of the point cloud is relatively well separated from the other two groups, which are defined by stagnant or seeping waters, whereas the ordination diagram shows higher floristic similarity between groups (A) and (B).

In the TWINSPAN analysis the first division of the 36 relevés brought a differentiation of the types showing mesophilic characteristics (1) and those more defined by water (0). At the second division the difference between the two groups of hornbeam-mixed alder stands (1) was hardly detectable; in both units (11, 10) mainly the *Aegopodium podagraria, Carex brizoides, Galeobdolon montanum* és *Impatiens noli-tangere* dominance-type relevés were included (therefore the two groups should form a single coenological unit). The second division of the stands more defined by hydrological conditions (0) resulted in a further differentiation of slightly swampy alder stands characterized with stagnant water and the dominance of *Caltha palustris, Carex acutiformis, Carex brizoides* (01) and mixed ash-alder stands with seepage water occurring along upper-course streams, dominated by *Caltha palustris, Carex pendula, Impatiens noli-tangere* or *Petasites albus (00).*

As a conclusion of the analysis of the 36 coenological relevés, accepting the arrangement resulting from the TWINSPAN analysis, the final classification contains 3 categories: swampy alder forests (a), riparian ash-alder forests (b), riparian hornbeam-alder forests (c). The 3 groups can be identified as association-rank coenological units and related to forest associations described earlier. Their differentiation is presented with the list of diagnostic species, including fidelity and constancy values *(Table 1.).*

5.3 Description of the riparian alder forests

5.3.1 Swampy alder forests

(*Angelico sylvestris – Alnetum glutinosae* Borhidi in Borhidi & Kevey 1996)

Occurrence, site. This is a rare riparian alder forest type of the lower and middle stream sections. Its stands are small compared to the other two types and only appear in short sections between the mixed ash-alder woods and the mesophilic alder stands. It usually occurs where the valley floor widens, the stream bed is shallow and flow velocity is low. Water from temporary flooding usually remains longer, the site is characterized with shallow stagnant water patches (from ecological point of view the site is somewhere between riparian forests and swamp forests). The soils are colluvial forest soils showing swamp characteristics. Besides the primary forests some secondary stands also occur, mainly due to road constructions or blocked culverts.

Structure and species composition. Canopy is loose, and its dominant species is *Alnus glutinosa*. Other tree species are rare, only *Fraxinus excelsior* may reach a higher cover. The shrub layer is sparse; its only characteristic species is *Viburnum opulus*. The dominance of *Carex acutiformis* and *Carex brizoides* prevails in the herb layer but certain other taxa, typical of sites with stagnant water (*Caltha palustris, Cardamine amara, Carex paniculata, Crepis paludosa, Lycopus europaeus, Solanum dulcamara, Veronica beccabunga*), also influence the attributes of the stands. *Fagetalia* species only play a minor role but their presence emphasizes the transitional riparian-swamp forest coenological character typical of the region.

Constant-subconstant species: *Alnus glutinosa* [A] 100; *Acer pseudo-platanus* [BC] 86, *Euonymus europaeus* [BC] 86, *Fraxinus excelsior* [BC] 86, *Alnus glutinosa* [BC] 71, *Rubus fruticosus* agg. [BC] 71, *Viburnum opulus* [BC] 71; *Aegopodium podagraria* [C] 100, *Stachys sylvatica* [C] 100, *Dryopteris carthusiana* [C] 86, *Equisetum arvense* [C] 86, *Impatiens noli-tangere* [C] 86, *Urtica dioica* [C] 86, *Athyrium filix-femina* [C] 71, *Cardamine amara* [C] 71, *Carex remota* [C] 71, *Circaea lutetiana* [C] 71, *Ranunculus ficaria* [C] 71, *Galeobdolon montanum* [C] 71, *Ranunculus repens* [C] 71; *Hypnum cupressiforme* [D] 100, *Eurhynchium hians* [D] 71, *Plagiomnium undulatum* [D] 71

Table 1. Synoptic table of fidelity and contancy based on 36 relevés from riparian alder forests. Determination of diagnostic species: with the use of Phi koefficient (Φ = 0.30) and Fischer's exact test (P < 0.05). Vegetation types: (a) swampy alder forests (Angelico sylvestris – Alnetum glutinosae Borhidi in Borhidi & Kevey 1996), (b) riparian ash-alder forests (Carici remotae – Fraxinetum Koch ex Faber 1936), (c) riparian hornbeam-alder forests (Aegopodio – Alnetum glutinosae V. Kárpáti & I. Kárpáti & Jurko ex Šomšák 1961). Layers: A = canopy layer, BC = shrub and herb layer, C = herb layer, D = moss layer. Asterisks (*) before species names indicate taxa with uncertain diagnostic value.

Vegetation types		(a)	(b)	(c)	(a)	(b)	(c)
Number of relevés		7	11	18	7	11	18
Species	Layer	Phi coefficient (× 100)			Constancy (%)		
Filipendula ulmaria	C	92.2	---	---	100	0	11
Lycopus europaeus	C	89.9	---	---	100	9	6
Carex paniculata	C	79.1	---	---	71	0	0
Crepis paludosa	C	68.9	---	---	86	18	11
Lysimachia vulgaris	C	58.8	---	---	86	36	11
Dryopteris expansa	C	58.0	---	---	71	27	0
Cirsium rivulare	C	57.7	---	---	43	0	0
Plagiomnium ellipticum	D	57.7	---	---	43	0	0
Carex acutiformis	C	53.2	---	---	71	18	17
Veronica beccabunga	C	52.3	---	---	71	36	0
Brachythecium mildeanum	D	51.4	---	---	43	0	6
Equisetum sylvaticum	C	45.9	---	---	29	0	0
** Glechoma hederacea*	C	45.8	---	---	43	0	11
Solanum dulcamara	C	44.0	---	---	71	45	6
Dryopteris dilatata	C	43.8	---	---	71	18	33
Caltha palustris	C	43.7	---	---	100	73	44
** Fagus sylvatica*	BC	42.9	---	---	57	9	22
Juncus effusus	C	42.6	---	---	43	9	6
Valeriana dioica	C	42.6	---	---	43	9	6
Plagiothecium denticulatum	D	40.1	---	---	71	36	22
Rumex sanguineus	C	---	52.5	---	0	36	0
Senecio ovatus	C	---	52.5	---	0	36	0
Paris quadrifolia	C	---	48.0	---	29	82	33
Carex pendula	C	---	46.5	---	43	82	22
** Carex pilosa*	C	---	45.7	---	0	36	6
** Atrichum undulatum*	D	---	45.3	---	57	100	56
Petasites albus	C	---	44.6	---	14	55	11
** Herzogiella seligeri*	D	---	42.4	---	57	82	17
** Rubus fruticosus agg.*	BC	---	40.1	---	71	100	56
Tetraphis pellucida	D	---	38.7	---	29	55	6
** Cardamine amara*	C	---	38.1	---	71	91	33
** Carex sylvatica*	C	---	37.2	---	57	91	50
Circaea lutetiana	C	---	31.3	---	71	91	50
Stellaria holostea	C	---	---	67.1	29	18	94
Salix fragilis	A	---	---	63.2	0	0	50
Galium aparine	C	---	---	53.2	29	36	89
Amblystegium serpens	D	---	---	50.0	0	0	33
Knautia drymeia	C	---	---	49.1	0	9	44
Malus sylvestris	BC	---	---	45.2	0	0	28
Cardamine enneaphyllos	C	---	---	45.2	0	0	28
Corylus avellana	BC	---	---	43.4	29	73	94
Symphytum tuberosum	C	---	---	43.2	0	36	61
Mercurialis perennis	C	---	---	42.0	14	9	50
Sambucus nigra	BC	---	---	41.4	43	36	83
Carpinus betulus	BC	---	---	38.4	29	45	78
Geum urbanum	C	---	---	37.3	43	45	83
Moehringia trinervia	C	---	---	37.1	29	18	61
Brachythecium velutinum	D	---	---	35.0	14	27	56
Rubus caesius	BC	---	---	31.8	57	9	67

Dominant species: *Alnus glutinosa* [A] 86, *Fraxinus excelsior* [A] 14; *Carex acutiformis* [C] 29, *Carex brizoides* [C] 29

Syntaxonomy, nomenclature. Swampy alder forests appear in the Hungarian coenological literature as 'alder marsh forests', formerly under the name *Carici acutiformis – Alnetum* Soó 1963 then recently as *Angelico sylvestris – Alnetum glutinosae* Borhidi in Borhidi & Kevey 1996. Due to its transitional nature, the coenotaxonomical position of the association has changed; earlier Soó (1963) assigned them to the riparian forests, whereas recently Borhidi (1984), Borhidi – Kevey (1996) and Kevey (2008) to the swamp forests (*Alnetea glutinosae*). Austrian literature mentions similar stands also among alder swamp forests, however, the forests earlier described as *Carici acutiformis – Alnetum* Scamoni 1935 are more recently considered part of the disputably broad association *Carici elongatae – Alnetum glutinosae* Koch et Tx. 1931 s.l. (Willner 2007).

Phytogeographical relationships. The transitional swampy alder forests have been mainly reported from the widening stream valleys of the Transdanubian part of the Pannonian region so far, but similar stands also occur in the Szigetköz area (Kevey 2008). The association has been only known from a few uncertain hints (Soó 1963) in the Sopron area. This association becomes rare the closer we get to the Alps, further occurrences may be expected towards the Vienna and Graz Basins. Wallnöfer et al. (1993) mention similar riparian stands from Karinthia.

5.3.2 Riparian ash-alder forests

(*Carici remotae – Fraxinetum* Koch ex Faber 1936)

Occurrence, site. It is a forest type prevalent mainly in the inner Sopron Hills area, along the upper and middle sections of streams in the vicinity of springs and seepage water. The valley floor is usually narrow therefore the stands are usually only 15–20 m wide. The stream bed is shallow, the site is basically defined by the water seeping from the alluvial sediments, but smaller swamp-like patches can also be found (especially near adjacent spring vegetation). The valley floors are flooded for a short time several times a year (after spring thaw or heavy rainfalls). Poor, thoroughly wet alluvial (sometimes even gleyish) soils predominate consisting of rough debris and stilt.

Structure and species composition. In the canopy layer of the relatively closed stands *Alnus glutinosa* is the dominant species, but *Acer pseudoplatanus* and *Fraxinus excelsior* are also common (sometimes even codominant). The shrub layer cover is insignificant (no typical shrub species) whereas the diverse herb layer can be characterized mainly with meso- and hygrophilic species (*Caltha palustris, Carex pendula, Equisetum telmateia, Impatiens noli-tangere, Petasites albus*). The montane character of the stands is emphasized by the sporadic emergence of some montane species (*Doronicum austriacum, Gentiana asclepiadea, Lysimachia nemorum, Veronica montana, Stellaria alsine*) and the presence of the spruce-zone mosses.

Constant-subconstant species: *Alnus glutinosa* [A] 100; *Acer pseudo-platanus* [BC] 73, *Corylus avellana* [BC] 73, *Fraxinus excelsior* [BC] 73, *Alnus glutinosa* [BC] 64, *Euonymus europaeus* [BC] 64; *Stachys sylvatica* [C] 100, *Galeobdolon montanum* [C] 91, *Carex remota* [C] 82, *Dryopteris carthusiana* [C] 82, *Pulmonaria officinalis* agg. [C] 82, *Aegopodium podagraria* [C] 73, *Athyrium filix-femina* [C] 73, *Caltha palustris* [C] 73, *Dryopteris filix-mas* [C] 73, *Ranunculus repens* [C] 73, *Impatiens noli-tangere* [C] 64, *Milium effusum* [C] 64, *Oxalis acetosella* [C] 64, *Ranunculus lanuginosus* [C] 64; *Hypnum cupressiforme* [D] 100, *Rhizomnium punctatum* [D] 73, *Plagiomnium undulatum* [D] 64, *Brachythecium rivulare* [D] 64

Dominant species: *Alnus glutinosa* [A] 82; *Caltha palustris* [C] 9, *Impatiens noli-tangere* [C] 9, *Petasites albus* [C] 9

Syntaxonomy, nomenclature. The alder forests of the Sopron Hills that show montane characteristics were previously described under the name *Alnetum glutinosae – incanae* Br.-Bl. 1915 (Soó 1963, Soó et al. 1969) in Hungarian literature, later as *Carici brizoidis – Alnetum* I. Horvat 1938 em. Oberd. 1953 (Borhidi – Kevey 1996, Kevey 2008). The occurrences of the riparian ash-alder woods also showing montane characteristics (*Carici remotae – Fraxinetum* Koch ex Faber 1936) presented an unresolved issue (Kevey 2008). The similarly situated forests with alike floristic composition are uniformly classified as *Carici remotae – Fraxinetum* Koch ex Faber 1936 (see Wallnöfer et al. 1993, Willner et al. 2002, Willner 2007) in Austria. With regard to the Central European literature the latter name should be used in the case of the Sopron Hills stands.

Phytogeographical relationships. Similar riparian alder woods have been described in several places in the Alp-Pannonian border region. The coenological relevés representing the nearest similar stands were published from the Vienna Forest (see Wallnöfer et al. 1993) and the Leitha Hills (Hübl 1959, Karrer – Kilian 1990) but the riparian alder woods of the higher areas of the Kőszeg Hills (Szmorad 1994) and the neighbouring Rosalia Hills (Szmorad ined.) can also partly be assigned to this group. Besides the stands in the Sopron Hills, in Hungary this association type was only described in the Bakony area (Soó – Zólyomi 1951).

5.3.3 Riparian hornbeam-alder forests

(*Aegopodio – Alnetum glutinosae* V. Kárpáti & I. Kárpáti & Jurko ex Šomšák 1961)

Occurence, site. This riparian alder forest type is prevalent along the middle sections of the stream valleys and the lower sections reaching the outer rim of the hills, adjacent to the former pedunculate oak-hornbeam stands of the surrounding basins. The valley floor in these places is usually wider (up to 30–50 m), so more extensive stands can form (e.g. the lower section of the Aubach). The streams are fast and their bed deeply cut into the alluvium. Site conditions are less defined by the surface or sub-surface waters (either stagnant or flowing) rather by the groundwater in the alluvial sediments. Conditions can change only temporarily and to a small scale after thaw or rainfall. The soils are better developed and structured colluvial forest soils.

Structure and species composition. The stands are strongly structured vertically including both the canopy and the shrub layers. In the relatively closed canopy layer *Alnus glutinosa* predominates but there are several other species (*Acer psudoplatanus, Acer campestre, Carpinus betulus, Fraxinus excelsior, Tilia cordata, Salix fragilis, Ulmus glabra*) present, as well. In addition *Padus avium* sporadically appears in the lower canopy layer. The most important components of the shrub layer are *Cornus sanguinea, Corylus avellana, Euonymus europaeus, Sambucus nigra* but in some stands the role of *Rubus caesius* and *Rubus fruticosus* agg. can become more substantial. *Ribes rubrum* and *Viburnum opulus* also frequently appear in the lower shrub layer. Due to the moderate hydrological influence the species of the mesophilic deciduous forests (*Aegopodium podagraria, Galeobdolon montanum, Mercurialis perennis, Oxalis acetosella,* etc.) play a major role in the herb layer, while the importance of hygrophilic and meso-hygrophilic species decreases.

Constant-subconstant species: *Alnus glutinosa* [A] 100; *Euonymus europaeus* [BC] 83, *Acer pseudo-platanus* [BC] 78, *Alnus glutinosa* [BC] 67; *Aegopodium podagraria* [C] 89, *Galeobdolon montanum* [C] 83, *Urtica dioica* [C] 83, *Oxalis acetosella* [C] 78, *Pulmonaria officinalis* agg. [C] 72, *Athyrium filix-femina* [C] 67, *Ranunculus ficaria* [C] 67, *Impatiens noli-tangere* [C] 67, *Milium effusum* [C] 67, *Polygonatum multiflorum* [C] 67, *Dryopteris carthusiana* [C] 61; *Hypnum cupressiforme* [D] 78

Dominant species: *Alnus glutinosa* [A] 72; *Corylus avellana* [BC] 6; *Carex brizoides* [C] 22, *Aegopodium podagraria* [C] 17, *Allium ursinum* [C] 6, *Impatiens noli-tangere* [C] 6

Syntaxonomy, nomenclature. In the Hungarian syntaxonomical system (see Soó 1963, Borhidi – Kevey 1996) the riparian alder forests rich in mesophilic deciduous species ('mixed hornbeam-alder woods') can be identified with the association described under the name *Aegopodio – Alnetum glutinosae* V. Kárpáti & I. Kárpáti & Jurko ex Šomšák 1961. Of the forest associations described in Austria the *Pruno-Fraxinetum* Oberd. 1953, found in hilly or lowland regions, can be considered closest to these stands (Wallnöfer et al. 1993, Willner 2007) although these are doubtless a type showing a transition towards lowland riparian forests (*Ulmenion*) and as such are surely missing from the Sopron Hills. In order to specify the relationship between these types (*Aegopodio – Alnetum glutinosae* and *Pruno – Fraxinetum*) further investigations based on more extensive data (from larger areas) are needed.

Phytogeographical relationships. Similar stands can be found in the southern areas of Slovakia (Michalko 1987), and many regions of the Hungarian Mountains and Western Transdanubia. The similar stands with *Aremonio – Fagion* elements in Southern Transdanubia, are described under the name *Carici pendulae - Alnetum glutinosae* (Kevey 2008). In the vicinity of the study area such stands can be found in the Fertő hill regions (Kevey 2008) and the Kabold-Füles hill regions (Szmorad ined.) but the alder woods in the foothills of the Kőszeg Hills (see Szmorad 1994) can also be assigned to this type.

6 CONCLUSIONS

One of the most important results of the analysis is the presence of montane mixed ash-alder forests (*Carici remotae-Fraxinetum* Koch ex Faber 1936) showing the influence of the Alps is verified. These riparian forests related to springs and seepage water sites are described in the botanical literature from Western and Central Europe (Neuhäuslová-Novotná 1977, Douda 2008), and the edge of Northern Europe from Ireland (Kelly – Iremonger 1997) to Lithuania (Prieditis 1997). They always appear under Atlantic and sub-Atlantic climate influences and despite the similarities of the sites and the coenological characteristics they form differentiating and distinguishable associations within a large distribution area (Oberdorfer 1992).

Carici remotae – Fraxinetum forests (strictly speaking) were most intensively studied in Austria (Willner et al. 2002, Willner 2007), the Czech Republic (Neuhäuslová-Novotná 1977, Douda 2008) and Slovakia (Michalko 1987). The differential species (*Carex remota, Carex pendula, Chrysosplenium alternifolium, Equisetum telmateia, Lysimachia nemorum, Valeriana dioica*, *Veronica montana*) defined for the Austrian stands (see Willner 2007) are also characteristic of the mixed ash-alder stands of the Sopron Hills and the occurrences of some montane species in the region are also related to this type of riparian alder woods.

Most of the stands classified as mixed ash-alder forests have been described under the name *Carici brizoidis – Alnetum* I. Horvat 1938 em. Oberd. 1953 in the Hungarian literature. However, this name is not used for any alder wood associations in any coenological monographs published in Austria, the Czech Republic and Slovakia; therefore due to the great similarities (see Borhidi 2003) these two units mostly correspond in the Alpokalja region (the case of the higher-altitude alder woods of the Hungarian Mountains needs to be further investigated).

Concerning the riparian alder woods dominated by *Carex brizoides* it has to be noted that their stands are mostly secondary, formed by the reforestation of former meadows. All examined relevés from the Sopron Hills that could be assigned to this type came from sites of former meadows and similar cases were recorded in other Central European areas (Neuhäuslová-Novotná 1977). On the other hand, stands with *Carex brizoides* dominance cannot be uniformly assigned to any single alder wood type. Their floristic composition differs corresponding to their site; in most cases they can be classified as either swampy alder forests or mixed hornbeam-alder forests.

The two other associations are mainly typical to the Pannonian Basin; their role and extent diminishes towards the west. Narrow mountain valleys are not favourable for swampy alder forests while the mixed hornbeam-alder stands common in hills and lower mountains (described from Austria for the first time in this paper) are replaced by alder forests with *Alnus incana* dominance in higher grounds of the inner Alps (*Equiseto – Alnetum incanae* Moor 1958) (Willner 2007). This spatial pattern of the associations can also be observed in other regions of the Alpokalja area e.g. in the Kőszeg Hills.

The coenotaxonomical position of the studied riparian alder forest associations is similarly viewed in recent Austrian and Hungarian works (Willner 2007, Kevey 2008). The transitional swampy alder forests (*Angelico sylvestris – Alnetum glutinosae)* are assigned to the alder swamp woods (class: *Alnetea glutinosae*, order: *Alnetalia glutinosae,* alliance: *Alnion glutinosae*), while the mixed riparian ash-alder and hornbeam-alder forests to the riparian alder woods (class: *Querco-Fagetea*, order: *Fagetalia sylvaticae*, alliance: *Alnion incanae*). Although the interpretation of these syntaxa is slightly different in the two countries there are no open issues concerning the classification of the alder woods of the Alpokalja region.

Acknowledgements: The author thanks Dr. Dénes Bartha, Dr. Balázs Kevey and Dr. Gergely Király for their help in the research, in reviewing the literature and also for their valuable comments on the draft. Special thanks to Eszter Tanács and Zsuzsa Tolnay for the translation.

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10.37045/aslh-2011-0010 *Acta Silv. Lign. Hung., Vol. 7 (2011) 125–131*

Black locust (*Robinia pseudoacacia* L.) Short-Rotation Crops under Marginal Site Conditions

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Abstract – The improvement of the reliability of renewable resources and the decline in reserves of fossile raw material in the coming decades will lead to increasing demands for wood material and consequently to a greater role of short rotation forestry (SRF). Particular efforts have been made in Europe to substitute fossils with renewables, in this context the proportion of renewable energy should be increased to 20% by 2020. SRF can be provide relatively high dendromass (biomass) increment rates if the short rotation tree plantations are grown under favourable site conditions and for an optimum rotation length. However, in many countries only so-called marginal sites are available for setting up tree plantations for energy purpose. For SRF under marginal site conditions black locust (*Robinia pseudoacacia* L.) can be considered as one of the most promising tree species thanks to its favourable growing characteristics. According to a case study presented in the paper black locust can produce a Mean Annual Increment (MAI) of 2.9 to 9.7 oven-dry tons ha^{-1} yr^{-1} at ages between 3 and 7 years using a stocking density of 6667 stems ha^{-1}. On the base of the presented results and according to international literature the expected dendromass volume shows great variation, depending upon site, species, their cultivars, initial spacing and length of rotation cycle.

***Robinia pseudoacacia* L. / short-rotation crops / oven-dry stem dendromass**

Kivonat – Rövid vágásfordulójú akácgazdálkodás marginális termőhelyeken. A megújuló energiaforrások megbízhatósági fejlesztése és a fosszilis nyersanyag-tartalékok kimerülése a következő évtizedekben a faanyag iránti igény növekedését és ebből kifolyólag a rövid vágásfordulójú fatermesztés nagyobb arányú térnyerését fogja eredményezni. Európában már történtek bizonyos erőfeszítések a fosszilis energiahordozóknak megújulókkal történő helyettesítésére, ezzel összefüggésben a megújuló energiaforrások részarányának 2020-ra el kell érni a 20%-os arányt. A rövid termesztési ciklusú fatermesztés viszonylag magas biomassza (dendromassza) hozamot nyújt, ha a rövid vágásfordulójú faültetvényeket kedvező termőhelyi körülmények között és optimális vágásfordulóval termesztik. Azonban sok országban csak az ún. határ-termőhelyeken tudnak energetikai célú faültetvényeket létesíteni. Marginális termőhelyi körülmények között rövid vágásfordulójú faültetvény létesítésére az akác (*Robinia pseudoacacia* L.) az egyik legígéretesebb fafaj, néhány igen kedvező termesztési tulajdonságának köszönhetően. A dolgozatban bemutatott esettanulmány alapján az akác 6667 törzs/ha állománysűrűség mellett 3 és 7 éves kor között 2,9–9,7 t/ha/év abszolút száraz faanyagban mért évi átlagnövedék elérésére képes. Az ismertetett eredmények és a vonatkozó nemzetközi szakirodalom alapján a várható dendromassza mennyisége – a termőhelytől, a fafajtól, a fajtától, a telepítési hálózattól és a vágásforduló időtartamától függően – nagy ingadozást mutat.

Fehér akác / rövid vágásfordulójú ültetvények / abszolút száraz dendromassza

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1 INTRODUCTION

Using renewable natural resources to generate power has been investigated worldwide in the last 2–3 decades as a consequence of oil crisis commencing early in the 1970's. Particular efforts have been made in many countries to substitute fossils with renewables in order to reduce the dependence on fossil oils and also to apply what had been agreed to in the Kyoto protocol.

Short rotation forestry (SFR) is the intensive cultivation of fast growing tree species on agricultural lands for short rotation periods. Forest crops (tree plantations and forest stands), of course, are not the only sources of biomass for energy, though they are among the most efficient in terms of the ratios of energy contained in the harvested crop to total energy input.

According to the EU regulations, the use of renewable energy sources in Europe should be increased by 20% till 2020. Plantations established for biomass (dendromass) production and managed on short rotation in general may contribute to meet the demand of wood for energy purpose as a renewable source.

The major advantages of establishing short-rotation (energy) plantations are:

- they are renewable (continuous) and reproduce repeatedly;
- they provide an alternative for utilizing lands on which agricultural production is temporarily abandoned;
- they are environmentally compatible (protect against erosion) if the right silvicultural techniques are applied;
- they reduce the use of fossil energy sources, which pollute the environment with sulphur and ash;
- the ash of burnt wood can be used as fertilizer for plant crops;
- by establishing large scale energy plantations, the cost of geological research, mine openings and mining can be reduced;
- the plantations can be distributed in the country more uniformly than the fossil energy sources;
- capital for establishment is considerably less and the return on investment shorter than that of the fossil energy sources, especially compared to deep underground coal-mining;
- their wood material can be used at most any time, and plantations can be established near the area of consumption, thus reducing the transportation cost;
- they could contribute to the employment of people in the given area.

2 CHARACTERISTICS OF BLACK LOCUST SUITABLE FOR SHORT ROTATION FORESTRY

In Hungary the black locust covered 37,000 ha in 1885, 109,000 ha in 1911, 186,000 ha in 1938 and 415,000 ha in 2010. One-third of black locust stands are high forests, while two-thirds of them are a coppice. In the 1960’s, Hungary had more black locust forests than all the other European countries.

Black locust timber can be used by industry (mining, construction, furniture), agriculture (posts and poles), and black locust stands are the main basis for Hungarian apiculture and honey production. It is one of the most suitable tree species for establishing energy plantations and for transforming existing traditional forests into energy forests.

The frequently expressed misconception that rapid growth rate is associated with low wood density is clearly not proved by black locust. Not only has the species a very high density (690 kg×m^3), but its fast height growth rate, 2–6 cm×day^{-1} in its juvenile stage, places it among the most fast growing plants. With this combination of both high density and volume increment, black locust can achieve impressive dendromass yield when growing on good sites. Moreover, because of its ability to fix atmospheric nitrogen, it requires little or no nitrogen fertilization. Considering the yield criteria (volume and density) and the symbiotic associations of both bacteria and mycorrhizal fungi, black locust offers an excellent opportunity for energy plantations.

Black locust energy forests can also be established by coppicing. Advantages of energy forests of coppice origin are that the cost of establishment is low compared to that of soil preparation, plantation and cultivation. From the developed root system of the previous stand, a large biomass (above-ground dendromass) can be produced within a short time period. The disadvantage is that the distribution of trees in coppice stands is not as uniform as in plantations optimized for energy production. In coppice stands, the quantity of the produced above-ground dendromass is lower and the rotation is highly influenced by the uneven distribution of stems.

More and more agricultural land is set aside without field crops and can be used for energy production plantations. Black locust is one of the best tree species for this purpose, thanks to its excellent properties, such as vigorous growing potential in the juvenile phase, excellent coppicing ability, high wood density, dry matter production, favourable combustibility of its wood, relatively fast drying and easy harvesting and processing (Halupa – Rédei 1992, Halupa et al. 2000).

3 EXPECTED PRODUCTION IN A BLACK LOCUST SHORT ROTATION PLANTATION UNDER MARGINAL SITE CONDITIONS: A CASE STUDY

3.1 Location

Data used in this study came from a short-rotation plantation trial established in Hungary in the subcompartment Helvécia 80A (*N 46^{0}50’28”, E 19^0 37’34”*) in Central-Hungary between the Danube and Tisza rivers. The forest subcompartment has slightly humous sandy soil without ground-water influence. The annual precipitation amounts to only 500 mm in some years, of wich only less than 300 mm comes in the dry summer period. It means that the water supply is a limiting factor. The trial at Helvécia is not one of the best sites available in Hungary but can be considered as an average yield class site for black locust (Rédei – Veperdi 2005, Rédei – Veperdi 2007).

3.2 Material and methods

The trial was established at a spacing of 1.5 m × 1.0 m, with three repetitions and four treatments representing different plant materials: common black locust and four cultivars ‘*Üllői*’, ‘*Jászkiséri*’, ‘*Nyírségi*’, and ‘*Kiscsalai*’. Each treatment corresponds to a plot of 15 by 20 m. One-year-old rooted cuttings were used in the case of cultivars and one-year-old seedlings in the case of common black locust.

Measurements were made at the ages of 3, 5 and 7 years. At each of these ages, all stems on each plot were counted and 10 trees from each plot were randomly selected for destructive sampling, and their volume (v) was determined with Smalian’s formula (Vaan Laar – Akca 1997). The mean tree volume (v_{mean}) was computed as an arithmetic mean of the volume of felled trees. Stand volume (Vha^{-1}) was estimated through multiplication of v_{mean} by stand density (Nha^{-1}). The stem oven-dry dendromass was determined in laboratory by using a drying temperature of 70^{o}C for 72 hours.

Analysis of variance was done for the mean annual increment of oven-dry stem dendromass at age of 7 years.

3.3 Results

Results concerning the trial with cultivars and common black locust at the age of 3, 5 and 7 years are provided in *Table 1* and focused on the differences in the values of the mean annual increment of oven-dry stem dendromass in *Figure1*. At the age of 5, the highest increment value was produced by the cultivar '*Üllői'* (8.0 tons ha^{-1} yr^{-1}), followed by '*Jászkiséri'* (7.4 tons ha^{-1} yr^{-1}) and the common black locust (6.7 tons ha^{-1} yr^{1}). At the age of 7, the order was the following: '*Üllői'* cultivar (9.7 tons ha^{-1} yr^{-1}), common black locust (8.4 tons ha^{-1} yr^{-1}) and '*Jászkiséri'* cultivar (7.6 tons ha^{-1} yr^{-1}).

Table 1. Evaluation of a short-rotation plantation with black locust cultivars on the base of plot averages (Helvécia 80/A); Stem number = 6666 per ha, H=height, DBH= diameter at the breast height (1.3m).

Cultivars	Age	Mean		Oven-dry stem dendromass	Mean annual increment of oven-dry stem dendromass
		H	DBH		
	(yr)	(m)	(cm)	(tons ha^{-1})	(tons ha^{-1} yr^{-1})
'*Üllői'*	3	4.1	3.1	8.9	3.0
	5	6.2	4.9	40.1	8.0
	7	9.3	6.4	68.1	9.7
'*Jászkiséri'*	3	3.6	2.9	7.1	2.4
	5	6.1	4.7	37.1	7.4
	7	8.8	6.2	53.2	7.6
'*Nyírségi'*	3	3.1	2.7	7.2	2.4
	5	5.3	4.2	28.4	5.7
	7	7.6	5.1	46.2	6.7
'*Kiscsalai'*	3	3.9	3.2	12.5	4.2
	5	6.1	4.6	31.1	6.2
	7	8.4	5.9	49.7	7.1
Common black locust	3	3.7	3.1	10.9	3.6
	5	6.1	4.7	33.5	6.7
	7	8.2	5.5	59.1	8.4

The data from the *Table 1* and the *Figure 1* indicate that it is not reasonable to harvest the plantations in the first three years, as the mean annual increment of oven-dry sterm dendromass at the age of 5 and 7 is 1.5–3 times higher than it was at age of 3. This result is important as it is known that too early harvesting may also increase the population of biotic pests (Rédei – Veperdi 2005).

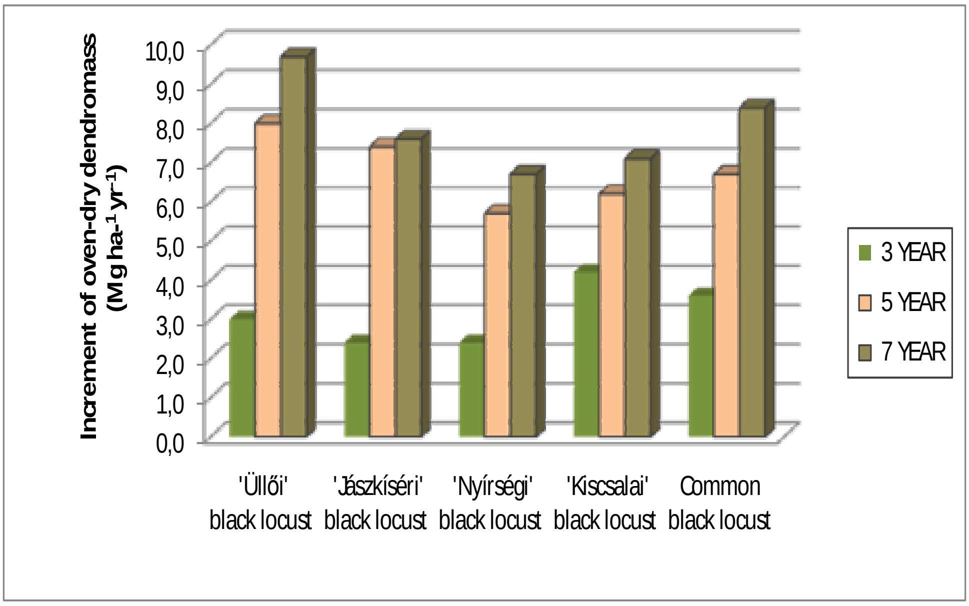

Figure 1. Mean annual increment of oven-dry stem dendromass of black locust cultivars and common black locust at different ages

According to the significance test at P = 5% level, significant differences were found in the mean annual increment of oven-dry stem dendromass ($F=40.991>F_{0.05}=3.422$, $SD_{5\%} = 0.69$ m^3 ha^{-1} yr^{-1}). When comparing the respective yields produced by the black locust clones and the common black locust, it becomes evident that using expensive black locust clonal material for setting up short rotation plantation has no added value.

4 DISCUSSION AND CONCLUSIONS

Dendromass yields of tree plantations and forest stands for energy purpose can be very promising but show great variation depending upon site, species, and climatic region. From the first experimental results in the 1970's, Canell and Smith (1980) and Pardé (1980) suggested that in most temperate regions it would not be realistic to give field predictions higher than 6 to 8 tons ha^{-1} yr^{-1} of wood dry weight in stems and branches. In some other papers, black locust increment in oven-dry weight of energy plantations from different temperate climate region ranged from 6 to 12 tons ha^{-1} yr^{-1} (Frederick 1989). The trial described in this paper gave also similar results.

Given the large share of marginal arable land in NE - Germany and the predicted climate change, *Robinia pseudoacacia* is expected to grow in importance. In order to evaluate the growth performance of this species under extreme conditions, four experiments were established in the post-mining landscape of the Lusatian lignite-mining district (NE - Germany). Biomass production was estimated for 3- to 14-year-old shoots on 4- to 14-year-old roots. Results for the annual production of oven-dried biomass of *Robinia pseudoacacia* ranged between 3 and 10 tons ha^{-1}, which was substantially grater than the biomass of poplar and willow clones established on the same site. The economic results showed that the cultivation of this tree species was an economically competitive land – use strategy for the post - mining landscapes (Grünewald et al. 2009).

Good results were obtained with black locust (12.5 tons ha^{-1} $year^{-1}$) in Italy. It proved to be resistant to most pests. In general it required fewer tending operations than poplar and willow (Facciotto et al. 2009).

Table 2 gives the most important structure and dendromass factors of the two black locust short-rotation crops of coppice origin based on stand surveys at the age of 4 in the same forest subcompartment mentioned above in Helvécia, Hungary. Considering that height (H) and mean diameter (DBH) values are almost the same, and thus the mortality resulting in different stand densities must have been responsible for the differences in the stem oven-dry dendromass. The difference of 57% in stand density resulted in a surplus of about 15% in mean annual increment of oven-dry stem dendromass.

Table 2. Evaluation of a short-rotation black locust stand of coppice origin in the trial Helvécia 80/A, N= stem number , H=height, DBH=diameter at breast height 1.3 m

Factors		Mean		Oven-dry stem dendromass	Mean annual increment of oven-dry stem dendromass
N	age	H	DBH		
(ha^{-1})	(yr)	(m)	(cm)	(t ha^{-1})	(t ha^{-1} yr^{-1})
8333	4	4.8	2.5	31.2	7.8
5306	4	4.7	2.8	27.1	6.8

In Hungary, as mentioned above, black locust is the most suitable tree species for establishing energy tree plantations. Technology improvements in converting wood to energy will increase wood use and help to meet the rising global demand for energy. Black locust is planted extensively world wide and has desirable fuel wood characteristics. It’s low moisture content enables reduced handling costs and enhances suitability for efficient energy conversion. Black locust is therefore considered the best fuel wood in Hungary, having good combustibility even when wet.

In short rotation tree plantations, where the average rotation period is 4–5 years, regarding game damage the most critical period is the first 1–2 years (following their establishment). In the case of black locust, main part of game damage is browsing which has a great negative effect of the annual increment, and subsequent dendromass production. It could cause 30–35% shortfall in the mean annual increment. The most effective but most expensive way of game control is game fencing, or if there is a possibility, electric fence.

The results obtained in the experimental plots described in this paper show that the quantity of dendromass strongly depends on the plant material (cultivars) as well as on the number of stems per hectare. These factors are important for the determination of optimum rotation period.

The presented results are the initial step of a more comprehensive evaluation of short-rotation crops established for energy purpose. The preliminary results should be confirmed by other experiments in similar site conditions and with different tree species and/or their cultivars.

Acknowledgements: Research on black locust short rotation forestry is partly supported by the project CNR (Italy)-MTA (Hungary): Multidisciplinary integrated approach for the improvement and sustainable use of *Robinia pseudoacacia* L. clones.

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10.37045/aslh-2011-0011 *Acta Silv. Lign. Hung., Vol. 7 (2011) 133–143*

Utilisation of Coloured Paper Refuse in Eco-products

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Abstract – In the course of our research we have found a solution for recycling coloured advertising paper in a cellulose fibre based composite. This paper quality is produced in huge quantities and can be recycled with difficulties even in paper industry. Our aim was to produce a kind of organic composite that does not contain any adhesives fixing the matrix part of the composite. An eco-product generated this way has similar physical and mechanical attributes to medium density fibreboard (MDF). Fibre made of coloured newspaper can easily be adapted to board production while, at the same time, this supports also the development of an environment oriented product policy. Board-based composites produced by utilizing recycled refuse paper can be used for designing and creating environmentally friendly products following the eco-design trend.

refuse paper / fibre composite / free from adhesive / eco-product / environment-oriented product policy / eco-design

Kivonat – Papírhulladék hasznosítása ökotermék előállítására. A kutatómunka során a nagy mennyiségben keletkező és papíripari célra is nehezen újrahasznosítható színes reklámújság hulladék cellulózrost alapú kompozitban történő hasznosítására sikerült megoldást találnunk. A cél egy olyan biokompozit termék előállítása volt, melynek gyártása során a kompozit mátrix részét biztosító külön kötőanyag nem került felhasználásra. Az így elkészített ökotermék a közepes sűrűségű farostlemezhez (MDF) hasonló fizikai-mechanikai tulajdonságokkal rendelkezik. A színes újságpapírból készült rost a lapgyártás folyamatába könnyen beilleszthetővé válhat, miközben jelentős környezeti terheléstől képes közvetlenül megszabadítani a természetet, lehetővé téve ezzel egy környezetorientált termékpolitika létrejöttét. Az újrahasznosított hulladékpapír felhasználásával készült lapalapú kompozitok így alkalmassá tehetők környezetbarát termékek tervezésére, kialakítására egy ún. ökodesign irányvonal bevezetése révén.

papírhulladék / rostkompozit / kötőanyagmentes / ökotermék / környezetorientált termékpolitika / ökodesign

1 INTRODUCTION

The aim of environment oriented product policy is to find the versions providing optimal protection of the environment by taking into account the whole life cycle of products. A comprehensive concept is needed that includes the planning, the manufacturing and

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eventually the disposal or recycling of a product. Eco-design in this sense is a preventive planning process with environmental protection in the centre.

The problem of refuse materials is one of the widest and most diversified problems of environmental protection. While the appearance of refuse materials is inevitable, the differentiation between refuse material disposal and refuse material recycling is about to disappear parallel with the advancement of ideas about the refuse problem (Takáts 1998).

Refuse paper provides not only recyclable material to produce paper again but represents also a huge potential raw material base to be used in the composite technologies *(Figure 1).*

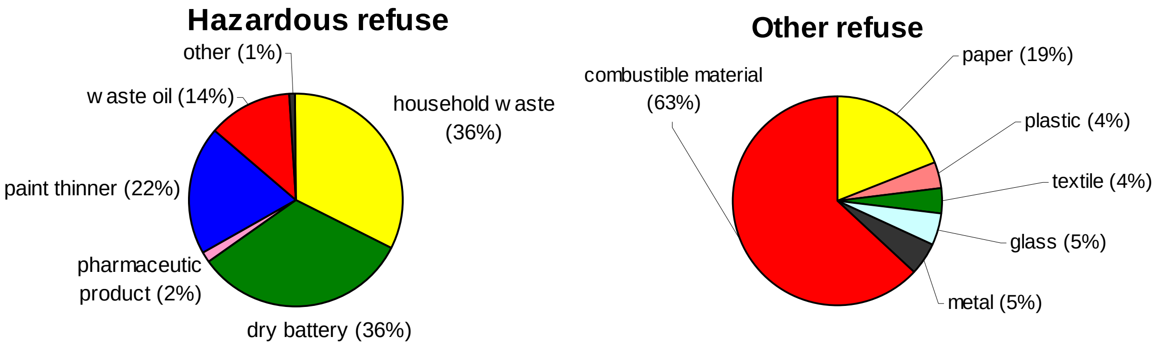


Figure 1. Average composition of communal solid refuse in Hungary (2000–2005) (KVVM 2006)

Paper industry was among the first to realise the importance of environmental protection and the reasonable management of natural resources in the last 30 years. As a result of this, cellulose companies have become net energy emitters and paper manufacturers have reduced their fibre needs to 50%, their specific energy consumption to one-third and their water consumption to one-tenth. For example, the recycling of paper reached a record of 32 million tons in Europe in 1996, one-third of which (more than 10 million tons) was collected in Germany. The ratio of recycling was 49.8%. According to the data of CEPI (Confederation of European Paper Industries) the ratio of recycled paper used in paper production has increased by 10% in Europe in the last 10 years. With this recycling rate, paper industry surpasses all other industrial branches.

Secondary fibre uses are even more favourable in the Hungarian paper industry than the EU average due to its product composition (high proportion of wrapping paper, card board, and hygienic paper). A significant part of refuse paper need is covered from import. However, collection ratios have considerably improved in the last ten years (Figure 2.). It has to be mentioned that the increase in the ratio of recycling has its limits. During manyfold recycling, fibres get shorter and the quality of paper product decreases. More emphasis has to be put on preserving sound fibres by moderate methods during fibrification (Winkler 1999).

Recycling of paper does not reach the level required by environmental protection or recycling interests in the world, although countries that consume great quantities of paper recycle a significant amount of it. The general difficulty in recycling refuse paper: paper manufacturing companies have high requirements for refuse paper to be returned into the production process. That is why we have to search for other opportunities in recycling refuse paper. One alternative could be the application in wood industry, especially in the furniture industry, by producing new eco-composite products.

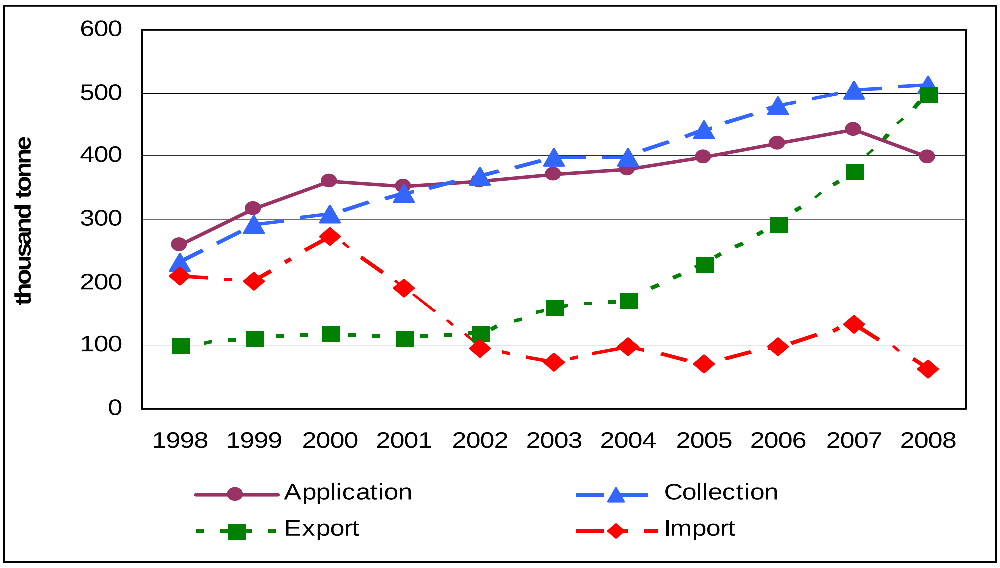


Figure 2. Refuse paper turnover in Hungary (1998–2008)
(Kopint-Datorg 2010)

The highest quality refuse paper can be produced by selective paper collection. Selective paper collection is considered to be a new phenomenon for the population in Hungary. People still have to be made aware of this process and they have to realise the fact that this activity will have visible results in the reduction of environmental burdens in the long-run. The deposition of refuse containing printer's ink extracted from refuse paper still has to be solved without harming the environment. The recycling provides a solution for the application problem which spares this activity of great costs.

The use of refuse paper as secondary raw material opposes the interests of waste incineration. The seemingly economical process of burning needs an ever-increasing heat content in the dry refuse. Secondary raw material use extracts one of the components with high heat content from mixed communal refuse. However, the recycling of paper is twice as economical as burning.

Types of refuse paper

In the European Union CEN (Centre Européene de Normalisation, Bruxelles) created the European bill of standardised qualities of refuse paper in 1994 amalgamating the experiences of individual nations. Hungary introduced the bill in the following year despite the fact that it was not the member of the EU at that time.

BIR (Bureau of International Recycling, Brussels) and CEPI (Confederation of European Paper Industries, Brussels) prepared the modernisation of the above-mentioned standard by 1999. This enables a five-level classification of refuse paper and groups refuse paper according to its origin and type into the following categories: mixed-low quality (A), moderate (B), good quality (C) and containing only unbleached cellulose (kraft) (D). In addition to the fourth category of unbleached fibre refuse paper, this standardisation creates a fifth group: special refuse paper requiring unique technologies (E) *(Table 1)*.

Table 1. Refuse paper categories as suggested by CEPI and BIR

Refuse paper of mixed quality (A)	**Refuse paper of moderate quality (B)**	**Good quality refuse paper (C)**	**Unbleached fibre refuse paper (D)**	**Special refuse paper (E)**
Mixed 1, uncategorised	Newspapers with max. 5% of coloured parts inside	Lightly coloured, mixed edge refuse	Corrugated box – factory refuse	Mixed paper and card board
Mixed 2, categorised	Unsold newspapers, no coloured parts inside	Bindery refuse***	Corrugated box – factory refuse (celluloses and semi-celluloses);	Mixed wrapping paper types;
Card board	Unsold newspapers, no coloured parts inside or flexo-pressure	Torn, white refuse	Corrugated box – factory refuse (kraft- and test liner)	Liquid containing boxes
Corrugated cardboard from stores	Edge refuse from printing house, little printer's ink	White writing***	Used corrugated boxes I (only kraft-liner and semi-celluloses fluting)	Kraft packing paper
Used corrugated cardboard	Edge refuse from printing house, little printer's ink *	White business publication	Used corrugated boxes, minimum one kraft-liner layer;	Wet-solid label paper
Unsold periodicals	Edge refuse from printing house, printed	Computer publications ***	Used sacks;	Unprinted, white, wet-solid paper
Unsold periodicals*	Edge refuse from printing house, printed *	Printed white celluloses card board	Used sacks with PE cover	Printed, white wet-solid paper
Phonebook	Office papers, classified	Slightly printed white celluloses card board	Unused sacks	
Newspaper (min.50%) and periodical I.	Coloured writing	White, painted publication***	Unused sacks with PE cover	
Newspaper (min.60%) and periodical II.	White book***	White, printed cardboard	Used kraft papers	
Periodical (min. 60%) and newspaper*;	Coloured periodical***	White, slightly printed card board	Unused kraft papers	
Public brochures**	Carbon free copier	White, unprinted card board	Unused shopping bags	
	White PE covered cardboard	Unprinted newspaper		
	PE covered card board***	Bleached, wood containing, painted or unpainted, unprinted paper		
	Fat. computer publications	Bleached, wood containing, painted paper, unprinted		
		White painted paper, unprinted**, ***;		
		White edge refuse; unprinted		
		White edge refuse; unprinted ***;		
		Unprinted, white celluloses card board		

Note: Fat.: contains wood, * : no adhesives, ** : classified, *** : wood free refuse paper

The differentiation within types enables collectors and paper manufacturers to realise technologies that suits the paper to be manufactured and the setting of technical parameters which fit the paper recycling machines much better.

This new standard, complemented with modifications, will fail to give appropriate guidance – mainly because of lack of information – about the quality of refuse paper and the derivable recycled fibres, giving the collectors a difficult task.

In our experimental work we used a significant quantity of the quality "coloured periodicals***", mostly advertisement prints.

The aim of this research work was to find a method for recycling coloured refuse paper in a way that avoids the costly chemical de-inking process for the removal of additives and pigments. The use of coloured refuse paper – as an alternative raw material option – avoids the process of chipping round wood raw material (a very energy intensive technology) since pre-processed paper can be cut into smaller fractions with a properly chosen post-processing technology.

We decided to use coloured periodicals from the category of moderate quality refuse paper (B) because they are used in great quantities and are appropriate for producing board-based, organic composite products after suitable mechanic preparation without adhesives.

2 METHODS

2.1 Materials used, preparation

The selected raw material was refuse paper of almost homogeneous quality. It was coloured, highly glossy paper grade from household wastes. This paper grade consisted of magazines, newspapers, leaflets, catalogues and programme guides. The samples were selected from different, separate containers. The plastic contaminants and metallic buckles were removed by hand after the sorting process. We used the principle of gradualism during preparation following the recycling guidelines of the wood industry.

2.2 Disintegration, determination of fibre dimensions according to ISO 3310

Disintegration was performed using a VIKING GE 110 dis-integrator. The paper fractions were further disintegrated using a Retsch Mühle SK1 equipment, maintaining the length of the fibres. During the disintegration process a conidur sieve was used, which changed the surface of fibres due to the influence of heat and wet state. This surface modification helped the adhesion between the fibres at a later stage. The characterization of the fibres was performed at a fibre moisture content of 8–10% with a particle size analyser. The sampling was a random selection from the pulp. The pulp was classified using 10 different sieves. After the proper vibrating time, the distribution of the fibre fractions was automatically calculated, recorded and displayed.

The parameters for analysis were as follows:

- **A**: vibrating amplitude (mm)
- **T**: vibrating time (min)
- **T_m**: interval between 2 vibration (s)
- **m**: mass of the initial sample (g)

The parameters for the first trial:

1. A= 1.5 (mm); T= 30 (min); T_m= 10 (s); m= 29.8 (g)

The parameters for the second trial:

2. A= 2.5 (mm); T= 30 (min); T_m= 5 (s); m= 24.4 (g)

The parameters for the third trial:

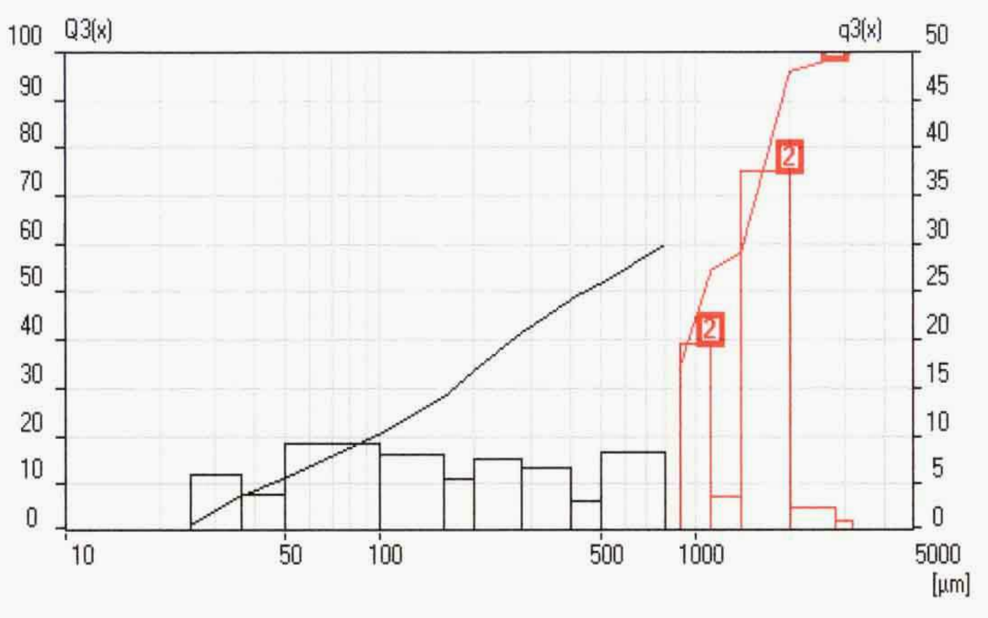
3. A= 2.0 (mm); T= 40 (min); T_m= 5 (s); m= 21.2 (g)

The parameters for the fourth trial:

4. A= 2.5 (mm); T= 40 (min); T_m= 5 (s); m= 25.1 (g)

The properties of the produced panels depend on the disintegration technique, the type of the machine and the produced fibre structure. We could observe that the vibrating amplitude had to be increased from 1.5 to 2.5 mm and we had to shorten the intervals between the vibrations in order to avoid the development of fibre bundles. The fibre fractions showed appropriate differentiation when vibrating time was increased from 30 to 40 minutes.

The results were plotted in columns and solid line format according to the hole diameter of sieves and percentages *(Figure 3)*. In the course of the experiments fibres smaller than 25 µm were present in the sample in insignificant quantities. The fibre fractions were evenly distributed with good approximation. The other fibre fractions were of 36, 50, 100, 160, 200, 280, 400, 500, 800, 1000, 1250, 1400, 1600, 1800, 2240, 2800, 3150, 3550 µm.



Q3(x) – weight distribution sum %
q3(x) – weight distribution density % (marked with “2”)

Figure 3. The sample fibre fraction distribution

2.3 Mat preparation, pre-pressing

After disintegration fibres are mixed with adhesives and complementary materials in fibreboard production. There was deliberately no artificial adhesive added to the mat, but it may be used in the near future to improve the properties of the panel. A pre-calculated amount of furnish was then hand-felted into a forming box and pre-pressed into a mat *(Figure 4).*

Figure 4. Single-layer paper fibre mat

The target specific gravity was adjusted using a micro balance. Dry process panels with dimensions of 300x300x16 mm were made from the recycled paper furnish.

2.4 Heat pressing

The volumetric density together with the modulus of elasticity is increasing rapidly during heat pressing. The fibre has visco-elastic behaviour, hence the force-elongation relationship depends on time as well as velocity. Under heat treatment, the natural polymers become plastic and the given volumetric density can be reached by the application of lower pressure. The pressed material springs back less when released. However a board that is kept under constant pressure is creeping.

So heat-pressing is a complex thermo-dynamic process, in which several phenomena take place at the same time and interact with each other. The inner temperature relations during the heat-pressing is very similar to high-temperature drying, water can turn to saturated steam. During the warming phase when the temperature reaches about 100°C, it stays steady while a part of the heat is used for the water to evaporate. The maximum inner pressure has an effect on the strength properties of the panel, primarily on the z-span tensile strength. If the inner pressure reaches 1.0 N/mm^2, after opening the press, a so-called board explosion can occur which decreases z-span tensile strength. Apart from the above-mentioned factors, the geometrical properties of the fibres also determine the quality properties of the produced panel.

Fibre diameter, cell wall thickness, diameter of cell lumen and surface properties of fibres all play important roles in panel quality. The compressability of fibres depends on the ratio of cell lumen and cell wall thickness. Fibres with thin wall cells and bigger cell lumen can collapse more easily. In the case of paper fibres these disadvantageous properties can not be observed. When we increase the fine content, the panels have higher volumetric density and hence higher bending strength and swelling properties. The pressing was done using SIEMPELKAMP 600x600 mm laboratory hot-press equipment, at 185°C on average *(Figure 5).*

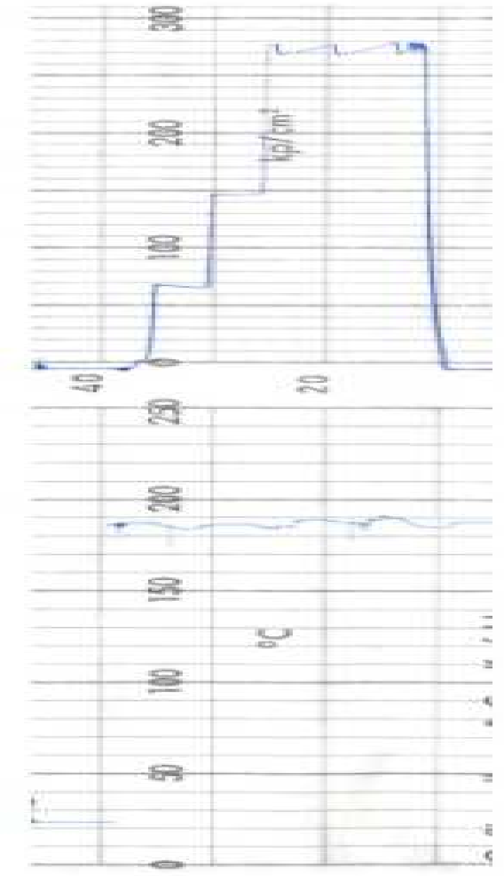


Figure 5. A sample press curve according to temperature and magnitude

2.5 Conditioning

One of the most important procedures of panel manufacturing is conditioning. If the panels are placed on each other after hot pressing they can loose their original strength rapidly. Above 70°C and at relatively high humidity, a hydrolysis effect occurs and results in strength decreasing and bond breaking. In order to avoid this, composite panels need to cool down and let be conditioned, this takes about 4–5 hours at 20°C and at 65% relative humidity.

3 RESULTS

We compared the results of our experiments with the characteristics of standard MDF panels in *Table 2 and 3*.

Table 2. Requirements of fibre panels (EN 622-1-5.)

Name	MDF thickness (mm)				
	<6	6–12	12–19	19–30	>30
Density kg/m^3 (EN 323)	560–900	560–900	560–900	560–900	560–900
Moisture content % (EN 322)	4–11	4–11	4–11	4–11	4–11
Thickness swelling 24 h % (EN 317)	30	15	12	10	8
Modulus of elasticity N/mm^2 (EN 310)	23	22	20	18	17
Internal bond (N/mm)	–	–	–	55–85	–

Table 3. Properties of organic composites

Name		Organic composite
Density kg/m^3 (EN 323)		900 kg/m^3 <
Moisture content % (EN 322)		9 ± 3
Thickness swelling % (EN 317)		80
Bending stiffness N/mm^2 (EN 310)	1000 kg/m^3	8
	1200 kg/m^3	13
	1400 kg/m^3	26
Screw holding N/mm (MSZ 2364)	1000 kg/m^3	52
	1200 kg/m^3	55
	1400 kg/m^3	58

The bending stiffness of the organic composites made without adhesives was similar to that of MDF panels. However, their density was very high.

Screw tests (Dívós 1999) showed good results. They met all the demanded requirements.

Thickness swelling values showed disadvantageous results. Paper fibres are very hygroscopic and a 2-hour-long swelling demolishes the integrity of the panel almost completely.

Still, the application of paper fibres indicate new possibilities in manufacturing fibre panel composite materials.

4 CONCLUSIONS

- Paper fibre, as raw material, has environmentally friendly properties, and the new recycling application we suggest has several potentials.
- This type of coloured refuse paper usage simplifies the recycling techniques used in the paper industry as well as in environmental protection significantly, because this proposed method is a more environmentally friendly than standard paper recycling.
- The raw material supply is simple and cheap, because this type of paper source is available in huge amounts.
- The elaboration and application of this technology can open new possibilities for paper recycling and for lignocellulose-composite materials *(Figure 6).*

Figure 6. From raw material to final product

- The coloured paper waste has visco-elastic properties, hence constant pressing provides better density distribution inside the panel.
- Hot-pressed panels need to cool down gradually and the final moisture content has fundamental impact on the eventual strength of the panels. The cooled down panels were placed on each other for several days in order to avoid later warpage. This condition helps to reach the equilibrium moisture content (9,0%). No adhesives were added to the panels so the originally used complements were activated again and participated in the bonding mechanism besides the fibre-fibre reactions and the secondary chemical bonds between cellulose molecules *(Figure 7–8).*

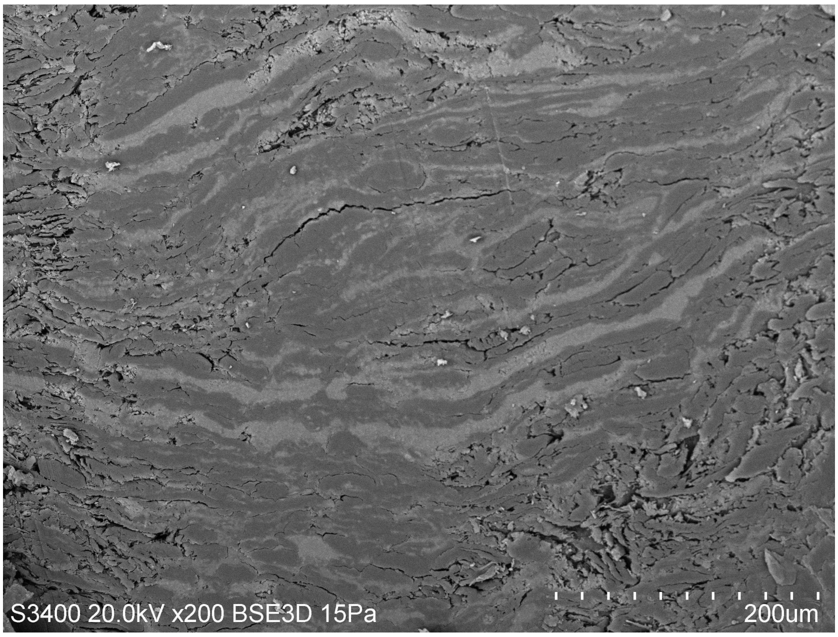


Figure 7. Fibre-fibre bonds in the panel structure
(Amplification: 200 fold)

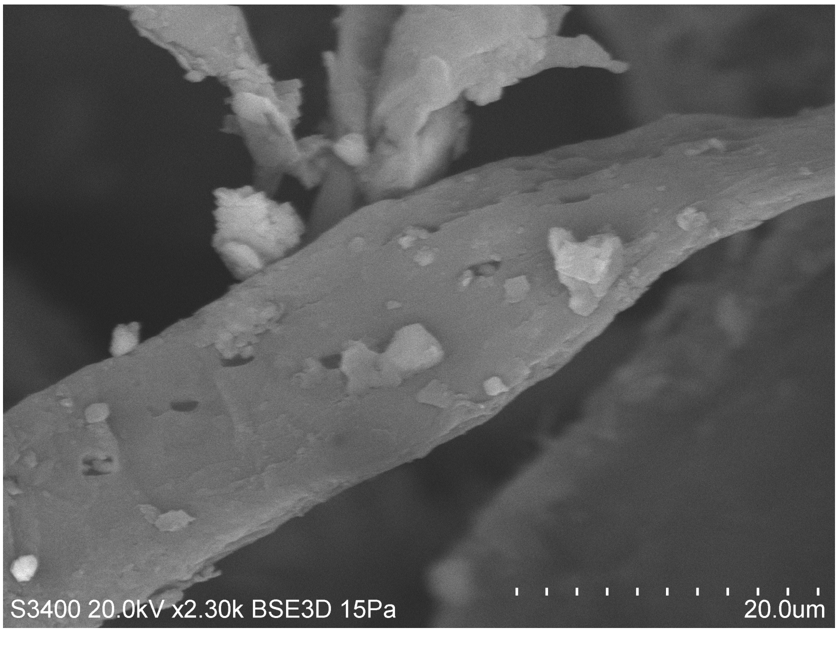


Figure 8. Activated aggregates and starch on the surface of fibre tracheid
(Amplification: 2300 fold)

The obtained results approached the requirements of the MDF panels used in the furniture industry. The cautious application of adhesives can increase some properties, decrease the thickness swelling caused by hygroscopic behaviour and improve the utilization possibilities of this new eco-product.

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Short Communications

10.37045/aslh-2011-0012 *Acta Silv. Lign. Hung., Vol. 7 (2011) 147–150*

Light-trap Catch of the Common Cockchafer (*Melolontha melolontha* L.) Depending on the Atmospheric Ozone Concentration

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Abstract – The study deals the efficiency of light trapping of the Common Cockchafer (*Melolontha melolontha* L.) (Coleoptera: Melolonthidae) in connection with the ozone concentration of air. The data of the Hungarian forestry light trap network were used for the years 1997 through 2006. We calculated relative catch values of from the number of caught insects. We assigned these to the ozone values of the respective days. For the classified date pairs regression equations were calculated. We established that the light trapping is most effective if the ozone concentration is high. As opposed to this, low ozone concentration reduces the success of the catch. Our results may be utilized in plant protection and forest protection prognoses.

***Melolontha melolontha* L. / light-trap / ozone**

Kivonat – A májusi cserebogár (*Melolontha melolontha* L.) fénycsapdázása a légköri ózonkoncentráció függvényében. A tanulmány a májusi cserebogár (*Melolontha melolontha* L.) (Coleoptera: Melolonthidae) fénycsapdás fogásának eredményességét tárgyalja a levegő ózontartalmának függvényében. Gyűjtési adataink az erdészeti fénycsapda hálózat anyagából származnak, az 1997 és 2006 közötti évekből. Az adatokból relatív fogás értékeket számítottunk. Ezeket hozzárendeltük az adott naphoz tartozó ózon értékekhez. Az adatpárokat osztályokba rendeztük és elemeztük a regressziós kapcsolatot. Megállapítottuk, hogy a levegő alacsony ózontartalmához alacsony fogás, a magas ózontartalomhoz pedig magas fogás tartozik. Eredményünk hasznosítható az erdővédelmi prognosztikában.

***Melolontha melolontha* L. / fénycsapda / ózon**

1 INTRODUCTION

The ozone concentration of the air influences the intensity of UV-B radiation, which bears an impact on the effectiveness of collecting insects by light-trap (Puskás et al. 2001). Therefore it seemed reasonable to try and find a connection also between the ozone concentration of the air and the number of insects trapped. In Hungary, ozone monitoring is carried out at four stations of the Hungarian National Meteorological Service (K-puszta, Hortobágy, Farkasfa and Nyírjes). Monitoring at K-puszta has been done since 1990 and at the other three locations since 1996. Presently10 minute average concentration values are

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detected at every station with the help of the ozone monitors. Since 1998 having been collected earlier by a local data collecting programme (SCANAIR) and stored in PCs. SCANAIR reduced 15-minute data into half-hour averages which were then entered in the data base. At the station (K-puszta), registration is performed by an Environment type monitor. A Thermo Electron type monitor at K-puszta makes also parallel monitoring possible. The ozone monitors are UV photometric ozone analysers which establish ozone concentration by illuminating with an UV lamp an air sample drawn into an absorption cell, then measuring the decline of illumination at a wavelength of 254 nm, which is proportionate to the ozone concentration. The instrument establishes the ozone concentration in ppb units, by taking samples in every 10 minutes. The data are in the range of 0–150 ppb. Database handling is described in detail by Puskás et al. (2001).

Kalabokas and Bartzis (1998), Kalabokas et al. (2000), Kalabokas (2002), Papanastasiou et al. (2002 and 2003), Papanastasiou and Melas (2006) have been studying the monthly and diurnal changes of the ozone concentration.

Ozone concentration in the summer months – from May until August – is higher than in other months of the year. There are typical daily changes. The ozone content is high from noon to evening and decreases from evening to dawn. It hits its lowest point in the dawn hours and begins to rise again in the early morning. Ozone concentrations in the atmosphere depend also on several meteorological factors (Tiwari et al., 2008).

The high concentration of ozone is detrimental to insects. For instance Kells et al. (2001) evaluated the efficacy of ozone as a fumigant to disinfest stored maize. Treatment of 8.9 tonnes of maize with 50 ppm ozone for 3 days resulted in 92–100% mortality of adult Red Flour Beetle, *Tribolium castaneum* (Herbst), adult Maize Weevil, *Sitophilus zeamais* (Motsch.), and larval Indian Meal Moth, *Plodia interpunctella* (Hübner). Biological effects of ozone have been investigated by Qassem (2006) as an alternative method for grain disinfestations. Ozone at concentration of 0.07 g/m^3 killed adults of Grain Weevil (*Sitophilus granarius* L.), Rice Weevil (*Sitophilus oryzae* L.) and Lesser Grain Borer (*Rhyzopertha dominica* Fabr.) after 5–15 hours of exposure. Adult death of Rice Flour Beetle (*Tribolium confusum* Duv.) and Saw-toothed Grain Beetle (*Oryzaephilus surinamensis* L.) was about 50% after 15–20 hours of exposure. Total adult death of all insect species was achieved with 1.45 g/m^3 ozone concentration after one hour of exposure. Valli and Callahan (1968) light-trap observations indicated an inverse relationship between O_3 and insect activity.

2 MATERIAL

We analysed the ozone data registered at K-puszta between 1997–2006 (http://tarantula.nilu.no/projects/ccc/emepdata. hzml/). The geographical coordinates of K-puszta are the following: 46° 58’ N and 19° 35’ E. Data for Common Cockchafer (*Melolontha melolontha* L.) (Coleoptera: Melolonthidae) originated from numerous light-traps which operated up to 100 km away from K-puszta in the years 1997–2006 and have caught in total 1255 beetles on 422 nights. 2627 observation data were analysed. Observation data means the catch of one trap in one night, regardless of the number of insects. The number of observations exceeds the number of the nights because light-traps operated simultaneously. As the Common Cockchafer flies from mid April to mid May in the twilight hours only, and the ozone levels change only slightly during this period, we used ozone concentration at 20 o’clock (GMT).

3 METHODS

From the catch data we calculated relative values far all the observation points. The relative catch (RC) is the ratio of the number of individuals trapped at one sampling point, in one night, and of the average number of specimens of a generation. Regression equations were calculated for relative catch and ozone data pairs.

4 RESULTS AND DISCUSSION

Regression equations and significance levels are displayed in *Figure 1*. The results suggest that the flying activity of the Common Cockchafer (*Melolontha me-lolontha* L.) increases when the ozone concentration is high.

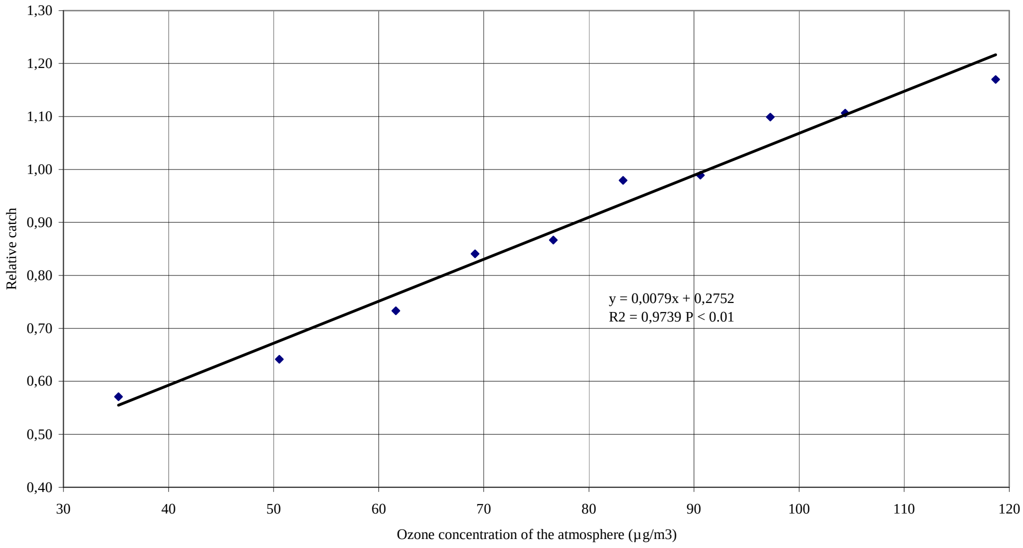

Figure 1. Light-trap catch of the Common Cockchafer (Melolontha melolontha L.) depending on the ozon concentration of the atmosphere

We suggest similar examinations on other insect species with other sampling methods (for example pheromone-, suction-, Malaise traps) to prove that high ozone concentration of air increases the flying activity also of other insect species. If this fact is verified, the influence of ozone concentration should be considered for the preparation of plant protection prognoses to increase their accuracy. Our result contradicts that of Valli and Callahan (1968), who experienced a decrease in the activity of Corn Earworm (*Heliothis zea* Boddie) with the increase of the ozone concentration. A reason for the contradiction might be that low relative catch values always refer to environmental factors in which the flight activity of insects diminishes. However, high values are not so easy to interpret. Major environmental changes bring about physiological transformations in the insect organism. The imago is short-lived; therefore unfavourable environmental endangers the survival of not just the individual, but of the species as a whole. In our hypothesis, the individual may adopt two kinds of strategies to evade the impacts hindering the normal functioning of its life phenomena. It may either display more vitality by increasing the intensity of its flight, copulation and egg-laying activity or take refuge in passivity to unfavourable environmental factors. According to the present state of our knowledge we might say therefore that both favourable and unfavourable environmental factors might equally contribute to a high catch (Nowinszky 2003).

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