Szent István University

Measuring and modeling grasslands' carbon balance components

The main points of the thesis

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THE ANTECEDENTS AND AIMS OF THE WORK

Knowledge on the effects of vegetation on the atmospheric greenhouse gas balance (the sum of emission and uptake) is becoming more and more important. Exchange of greenhouse gases between the biosphere and the atmosphere is essentially affected by the functioning of the vegetation and soil, and by the land use practices, as well. CO_2 is the most important one out of the three main greenhouse gases. The soil and the vegetation are the most important in influencing the CO_2 balance, while N_2O is emitted by mainly by soils and CH_4 by grazers – not considering anaerobic soils here -, and the latter may exchange with soils too. Atmospheric level of greenhouse gases rises permanently because of the pollution by industry, agriculture or transport. Estimation of the emission related to human activity is relatively straightforward, but role of ecosystems is no less important when trying to construct the GHG balance for a given period. The European Union has started several research projects (Carboeurope IP, Nitroeurope IP, Carboocean IP etc.) in the last decade aiming the description of the greenhouse gas exchange, mainly the sink/source characterization of ecosystems.

Temperate grasslands cover large areas of the Earth's surface, and they are located in one of the regions where the impact of global climate change is predicted to be high due to increasing aridity and also because of shrinkage of forests.

In grasslands most of the carbon can is below-ground (in the soil organic matter and in the below-ground plant parts). This feature provides temperate grasslands with many characteristics, which might be essential from the global carbon cycling aspect, because the assimilated carbon may be stored in the soil for a long time. In order to learn and quantify the role of temperate grassland ecosystems in carbon cycling and to predict their responses to a possible climate change, intense measurements on their CO_2 exchange are required.

Productivity of our research object communities are mostly limited by the quantity and unequal distribution of rainfall, but this statement is actually true for almost the all area of Hungary. In case of a long-lasting spring-summer drought, the annual carbon balance may be negative despite of the fact that drought usually also decrease root and soil respiration. If this is the case for several subsequent years, there is high risk of opening up and desertification of the grasslands. These dangers are mentioned in the studies describing and predicting regional effects of global climate change. It is suspected that in Hungary, mean annual temperature will rise, mean annual

precipitation will decrease and there will be a change in the distribution of rainfall, as well. These may generate desertification processes mainly in the Great Plains.
Our study was part of EU financed projects (Carboeurope IP and Nitroeurope IP), aiming to construct the greenhouse gas balance of different European ecosystems. Other parts of the study were financed by national OTKA projects.
Although studies on carbon cycling and their components are numerous, and we have large amount of general information on the topic, still the importance of the research activities conducted in locally important ecosystems to understand their role in carbon cycling is high. Measurements in the present work give insight on carbon cycling in representative and important Hungarian natural ecosystems. Methodological advances in measuring CO_2 exchange in grasslands by using the chamber techniques are also discussed.

1.2. Aims of the study

The aim of the work was double: (1) methodological questions regarding chamber measurements, and (2) measuring carbon balance components of Hungarian grasslands, with data mainly from the sandy meadow of Bugac (*Cynodonti- Festucetum pseudovinae*).

Considering the first subject, our questions were as follows:

- Is it possible to use the chamber technique for long-term monitoring of carbon balance?
- Are the data as received by the chamber method and eddy-covariance measurements, in accord?
- Which environmental factors affect the carbon balance of grasslands in different periods of the year?
- Is open path chamber method convenient for permanent measurement of soil respiration?

In the second subject, our questions were as follows:

- What is the proportion of soil respiration in the carbon balance of grasslands?

- Is there a uniform model to describe dependence of respiration activity of different soil types on environmental factors?
- What is the ratio of root and microbial respiration to the total soil respiration?
- Which biotic factors affect the level of soil respiration? Is there any connection between photosynthetic carbon uptake and soil respiration?
- What factors are influencing root respiration?
- Which factors are causing the differences between different years' estimated soil respiration sums?

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MATERIALS AND METHODS

Measurements of gross primary production (GPP) components (net ecosystem exchange, ecosystem and soil respiration) of grassland vegetation with emphasis on soil respiration constituents were carried out in this work. Different techniques for measuring ecosystem CO_2 gas exchange were compared. Separation of the rhizospheric (here roots and associated mycorrhiza) and the heterotrophic soil respiration components and description of their dependence on soil water content, temperature and photosynthetic activity of the vegetation were also the goals of the study.

Study sites

The research was conducted in different vegetations in Central Europe: sand pasture (Bugac), loess grassland (Isaszeg), dry mountain meadow (Szurdokpüspöki), open sand grassland (Vácrátót), maple oak forest (Gödöllő) and wet mountain meadow (Bíly Kríž, Czech Republic).

Most of the study sites were grasslands in Hungary with nearly the same climate, but with strongly different vegetation and soil. Soil types cover a wide range in nutrient and clay content (sand soils from low to high nutrient content, loam, brown forest soil and heavy clay).

Instrumentation

Eddy-covariance technique: Eddy-covariance stations are run on three sites: Bugac, Szurdokpüspöki, Bílý Kříź. Stations are equipped with a CSAT3 sonic anemometer and a Li-Cor 7500 open path IRGA to measure eddy fluxes of sensible and latent heat and CO_2 and several other sensors to meaure micrometeorological variables (including wind speed and wind direction, temperature and relative humidity, precipitation, global radiation, reflected global radiation, net radiation, photosynthetically active radiation (PAR), reflected PAR, soil heat flux, soil temperature, soil moisture).

Chamber techniques: Two types of chamber gas exchange measurements were carried out: closed and open system. Concentration of CO_2 and H_2O in air were measured by CIRAS-2 IRGA(PPSystems, Hitchin, UK) in the open system and LI-6200 IRGA (LI-COR Inc., Lincoln, NE, USA) in the closed system. The chamber size (60cm diameter) was the same in both systems.

Soil respiration measurements: Soil CO_2 efflux was measured by LICOR-6200 IRGA connected to a plexi hemisphere chamber from 2000 to 2005 and by LI-6400 IRGA with 6400-09 soil chamber (LI-COR Inc., Lincoln, NE, USA) from 2005.

Soil respiration measurements in open system: Development of the open soil respiration system was a part of the research work and is described in the results. Field test measurements of the new system have been conducted at two locations with different climate, vegetation and soil. The sites are eddy covariance sites in the Hungarian Great Plains (Bugac, Hungary) and in the Moravian-Silezian Beskydys (Bíly Kríž, Czech Republic).

Root respiration measurements: Roots were digged out and cleaned from soil particles on a sieve before respiration measurements (LI-6400 IRGA).

Leaf Area Index: LAI was calculated from the sunfleck/PAR-transmittance values.

NDVIb (broadband NDVI): Broadband Normalized Differential Vegetation Index calculation was based on the incoming and reflected PAR and global radiation.

Soil water content was measured by a TDR reflectometer (ML2, Delta-T Devices Co., Cambridge, UK) at 0-6 cm depth.

Soil Temperature (Ts) was measured at 5cm depth by a digital soil thermometer.

Modeling

Soil respiration data were fitted (SPSS 8) using the Lloyd-Taylor model:

$$R = R_{10}^{(E_0(\frac{1}{56.02} - \frac{1}{T - 227.13}))^2} \qquad \text{(eq.1.)}$$

where R_{10} is the respiration rate at 10 °C, E_0 is the activation energy, T is the soil temperature at 5 cm in Kelvin degrees. This model was modified after Byrne et. al. (2005) with soil water content also considered (eq.2.). With this modification it was possible to fit values of R_{10}, E_0 and the optimal soil water content for soil respiration (SWC_{opt} in eq2.) simultaneously:

$$R_s = R_{10}^{(E_0(\frac{1}{56.02} - \frac{1}{Ts - 227.13}))(-0.5\ln(\frac{SWC}{SWC_{opt}})^2} \quad \text{, (eq.2.)}$$

Statistical methods

Basic statistics for comparison of the data were as follows: calculation of average, standard deviation, and range of data sets (minimum and maximum values). Calculations and model fitting were made in Excel and SPSS8.

RESULTS

Methodological results

Closed chamber flux measurements

Closed gas exchange chamber connected to an IRGA proved to be applicable to measure net ecosystem exchange (NEE) in grasslands. Measurements were carried out on two different grassland sites, temporal and spatial variations of NEE were investigated.

The advantages of the chamber methods are: (*1*) we exactly knew where the average fluxes came from, while in the case of micrometeorological methods exact localisation of mean fluxes is not possible; (*2*) they provide information on the spatial physiological heterogeneity of the vegetation and (*3*) the lower cost acquisition compared to micrometeorological methods.

Difficulties of these measurements are discussed and possible solutions are indicated. Disadvantages of this method are: the fast temperature increase inside the chamber (chamber effect) and further, the chamber method did not allow continuous monitoring of the CO_2 gas exchange. Automatization of these systems would be expensive with a probable decrease in the reliability of the measurements.

Open chamber flux measurements

The Open system (OC) proved to be also aplicable for continuous gas exchange measurements in grasslands, especially for short (i.e. 1-2 days) measurement campaigns. Under hot and dry conditions, frequent in summer, the open system would be a better choice for gas exchange measurements than the closed one. Open chambers are simpler to use than the closed chamber systems and the chamber effect is also smaller. The disadvantages of the OC system are the problems caused by the continuous air stream (different from the natural conditions), the pressure difference between the ambient air and the chamber's headspace, and sensitivity to the CO_2 concentration fluctuations in the reference air. This method provides a continuous data set and can be automatized partially as oposed to the closed one.

The better agreement between the OC and eddy-covariance measurements in the case of the CO_2 than the H_2O fluxes might have been caused by the much lower CO_2 concentrations compared to the H_2O ones. High and increasing H_2O concentrations coupled with slow air stream resulted in lower vapor pressure deficit in the chamber than in the ambient air. Flow differences might not have caused these differences, since in that case the discrepancy between the measured fluxes would have been similar for the two gases. The solution to this problem may lie in drying the reference air stream, but this procedure is difficult for relatively large air volumes used in this system.

Soil respiration measurements in open system

A cost-effective simple system for continuous measurement of soil respiration was developed and tested. The system is operated as open and presently consists of 4 small (d:5cm, h:10.4 cm) chambers allowing soil wetting from the circumference of the chamber base and from the holes on the top (serving for overpressure elimination and giving ~10% of the surface). The chamber size is suitable to use between grass tussocks, thus making it possible to avoid the disturbance of the spatial structure of vegetation that might formed through years, while small insertion depths (up to 5mm) allow minimal in depth disturbance. Low air flow rates associated with small chamber volume and chamber design allowed to stabilize the overpressure range to 0.05 Pa - 0.12 Pa. There was no serious error during the 6 months long continuous measurements at Bugac.

Measurements of carbon balance components

Soil respiration of five different Hungarian soils

Time series of soil respiration data from five locations of strongly differing soil types were analysed in order to describe empirical relations suitable for modeling applications. Dependence of soil respiration (Rs) on soil water content (SWC) was however less frequently formulated explicitly, in spite of its practical value considering C-balance and partitioning the C-balance in drought prone ecosystems. In this study we verified the short term importance of soil water content on Rs. The wide range of soil clay contents made it possible to show the quasi linear positive relation between soil clay content and soil water content optimal for Rs. The significant negative correlation between activation energy and soil TOC (and TON) content may be explained by the availability of labile C substrates.

Significant relationship was found between soil respiration and photosynthetic CO_2 uptake. This relationship was time-delayed and the maximum correlation was found between Rs and GPP (measured 5,5 hours earlier).

Root respiration measurements

These measurements were done at the sand pasture (Bugac). We used measurements on root-free soil to estimate the ratio of root and root-

associated respiration against soil respiration. This ratio was changing between 20-60% during the vegetation period.
Dependence on root water content and temperature of root respiration was also described by eq.2. Based on this relationship the low (<12%) and high (>30%) soil water content could inhibit root respiration activity. Soil water content in this ecosystem is usually under 10% during the growing season, therefore soil water content is seriously limiting root respiration during the growing season.
Time-delayed significant relationship was found between root respiration and GPP (3,5 hours).

Annual soil respiration rates

Based on meteorological data sets the above mentioned relationships were used to estimate annual soil respiration from 2003 to 2008 at Bugac. Minimum annual soil respiration was 999 gC m^{-2} $year^{-1}$ in 2007, maximum was 1300 gC m^{-2} $year^{-1}$ in 2004. Annual rates showed significant positive relationship with annual amount of precipitation.

NEW SCIENTIFIC RESULTS

We conclude that the closed system chamber can be a useful device for gas exchange measurements, especially for short-time measurement campaigns, the obtained results could be suitable for estimation of grassland carbon balance.

Open system chamber gas flux measurements were developed and compared to other technique of carbon balance measurements (eddy-covariance). Good agreement was found between the two CO_2 gas exchange method. We described that the overestimation or underestimation of H2O fluxes depend on the flow rate through the chamber (which is also depend on the LAI in the chamber).

A new method for continuous soil respiration measurements in grasslands with low cost demand was developed on the base of the results of open system gas exchange measurements. The chamber size of the new system is suitable to use between grass tussocks, thus making it possible to avoid the disturbance of the spatial structure of vegetation. The system could be capable to operate for long periods when unattended.

We described the dependence of soil respiration of different soils on climate variables and vegetation functioning, these results can be used for soil respiration modeling. Parameters of the model can be modeled on the base of the soil characteristics. Optimum soil water content of soil respiration was determined as a function of the clay content and activation energy of the soil respiration could be expressed as a function of the total organic carbon content of the soils.

We found a time-delayed significant relationship between soil respiration and photosynthetic CO_2 uptake and between the root respiration and CO_2 uptake. This delay was longer in the case of soil respiration (5,5 hours) and shorter (3,5 hours) in the case of root respiration.

We estimated the ratio of root and root-associated respiration against soil respiration (changing between 20-60%). Dependence on root water content and temperature of root respiration was also described.

Based on these results we modeled annual soil respiration rates in sand pasture (Bugac). We found significant relationship between the modeled annual soil respiration and the annual precipitation.

CONCLUSIONS AND PROPOSITIONS

Closed and open gas exchange chambers connected to an IRGA were useful devices to measure net ecosystem exchange and its components in grasslands, but closed systems used in this study did not allow continuous monitoring of the CO_2 gas exchange. The open system chambers do not need automated door-opening, and it could be easier and faster to perform the measurements even in special conditions (drought, hot). Open system enables longer unattended operation periods (days), but not real long-term (weeks or months), so these chamber techniques can not substitute, but complete the eddy-covariance method with a focus on the different components of carbon balance.

Based on the results of the open system NEE measurements, this method was succesfully adopted for soil respiration measurements. Main advantages of the new system are the small size of chambers, which allows to measure between grass tussocks, the continuous measurement of soil CO_2 efflux (reliable operation through long time periods) and of environmental variables, the cost effectiveness (compared to standard systems) and the lower probability of technical failures due to the simple system design. With this new system better partitioning of eddy flux measurements could be made, seasonal and annual soil respiration could be measured. We hope to get answer to the question, what are the ratios of the different soil respiration components to each other and to GPP in different seasons and under different extremes of weather, like drought.

Soil respiration could not be modeled only on the base of temperature dependence in periodically dry or arid ecosystems. Soil respiration was strongly affected by soil water content in the investigated ecosystems, and should be noted in modeling. Seasonal Rs-SWC relation is expected to follow an optimum curve and can be described together with the Rs response to temperature by a response plane as fitted by eq. 2.. The fitting procedure gave statistically significant R_{10}, E_0 and SWC_{opt} coefficients for Rs data of the five different soils. Ecosystem carbon balance models or partitioning methods of net ecosystem exchange could be more accurate using these relationships.

Root respiration seemed to be more dependent on soil moisture than microbial respiration, further investigations needed to clear the carbon source of Rs (SOM or new carbon) during drought periods. The importance of determining the age of carbon lost from the soil under climate change has been elucidated, also considering the threaten posed by the possible positive feedback effect.

Knowledge on the response curves of the soil respiration components to the driving variables may help us to get closer to the accurate estimation of the ecosystem respiration and carbon balance. Methodological innovations of this work can provide more effective measurements of ecosystem gas exchange components.

SCIENTIFIC PUBLICATIONS IN THE SUBJECT OF THE DISSERTATION

Publications in English with IF:

- T. G. Gilmanov, L. Aires, K. Akshalov, V. Allard, C. Ammann, M. Aubinet, M. Aurela, J. Baker, D.Baldocchi, J. Balogh, M. Balzarolo, L. Belelli, Z. Barcza, C. Bernacchi, C.Bernhofer, V.S. Baron, J. Berringer, P. Beziat, D. Billesbach, J. Bradford, K.Brehe, N. Buchmann, E. Ceschia, P. Cellier, Shiping Chen, D. Cook, C. Corradi, R.Coulter, R. Czerny, E. Dellwik, A. Detwyler, H. Dolman, M. Dourikov, W. Dugas, J. Elbers, W. Emmerich, W. Eugster, D. Fitzjarrald, L. Flanagan, A. Frank, J. Fuhrer, D. Gianelle, T. Griffis, T. Gruenwald, M. Haferkamp, Guo Haiquang, N. Hanan, R. Harding, L. Haszpra, M. Heuer, J. Heilman, A. Hensen, S. Hollinger, A. Jacobs, D. Janous, W. Jans, D.A. Johnson, M. Jones, T. Kato, G. Katul, G. Kiely, W. Kutsch, G. Lanigan, T. Laurila, P. Leahy, S. Li, A. Lohila, V. Magliulo, A. Manzi, M. Marek, R. Matamala, T. Meyers,, P. Mielnick, A. Miyata, E. Moors, J. Morgan, C. Moureaux, M. Nasyrov, J. Olejnik, J. Olesen, W. Oechel, C. Owensby, D. Papale, C. Pio, J. Prueger, A. Raschi, C. Rebmann, M. Reichstein, H. da Rocha, N. Rogiers, N. Saliendra, M.J. Sanz, K. Schelde, R. Scott, P. Sims, R.H. Skinner, H. Soegaard, J.-F. Soussana, M. Sutton, A. Suyker, T. Svejcar, M. Torn, Z. Tuba, S. Verma, M. Waterloo, G. Wohlfahrt, B. Zhao, G. Zhou (2009): Productivity, Respiration, and Light-Response Parameters of World Grassland and Agro-Ecosystems Derived From Flux-Tower Measurements. *Rangeland Ecology and Management* (accepted)
- Fóti Sz., Balogh J., Nagy Z., Bartha S., Ürmös Zs., Tuba Z. (2008): Temporal and spatial variability and pattern of soil respiration in loess grassland. *Community Ecology* 9 57-64. p.
- Pintér K., Nagy Z., Barcza Z., Balogh J., Czóbel Sz., Csintalan Zs., Tuba Z. (2008): Interannual variability of grasslands' carbon balance depends on soil type. *Community Ecology* 9 43-48. p.
- Horváth L., Grosz B., Machon A., Balogh J., Pintér K., Czóbel Sz. (2008): Influence of soil type on N_2O and CH_4 soil fluxes in Hungarian grasslands. *Community Ecology* 9 75-80. p.
- Czóbel Sz., Szirmai O., Balogh J., Nagy J., Péli E., Ürmös Zs,. Tuba Z. (2008): Effects of irrigation on botanical composition and carbon uptake on Pannonian loess monoliths. *Community Ecology* 9 91-96. p.
- Balogh J., Nagy Z., Fóti Sz., Pintér K., Czóbel Sz., Péli E. R., Acosta M., Marek M. V., Csintalan Zs., Tuba Z. (2007): Comparison of CO_2 and

H_2O fluxes over grassland vegetations measured by the eddy-covariance technique and by open system chamber. *Photosynthetica*, 45 288-292. p.
- Nagy Z., Pintér K., Czóbel Sz., Balogh J., Horváth L., Fóti Sz., Barcza Z., Weidinger T., Csintalan Zs., Dinh N. Q., Grosz B., Tuba Z. (2007): The carbon budget of a semiarid grassland in a wet and a dry year in Hungary. *Agriculture, Ecosystems and Environment***,** 121 21-29. p.
- Balogh J., Fóti Sz., Juhász A., Czóbel Sz., Nagy Z. and Tuba Z. (2005): Seasonal CO_2-exchange variations of a temperate semi-desert grassland in Hungary. *Photosynthetica*, 43 107-110. p.
- Czóbel Sz., Fóti Sz., Balogh J., Nagy Z., Bartha S., Tuba Z. (2005): Chamber series and space-scale analysis of CO2 gas-exchange in grassland vegetation: A novel approach. *Photosynthetica*, 43 267-272. p.
- Szerdahelyi T., Fóti Sz., Czóbel Sz., Balogh J., Nagy Z., Tuba Z. (2004): Species composition and CO_2 exchange of a temperate loess grassland (*Salvio-Festucetum rupicolae*) at present-day and expected future air CO_2 concentrations, *Ekologia Bratislava*, 23 137-146. p.
- Szerdahelyi T., Nagy J., Fóti Sz., Czóbel Sz., Balogh J., Juhász A., Tuba Z. (2004): Botanical composition and selected CO_2 exchange characteristics of temperate semi-desert sand grassland in Hungary under present-day and elevated air CO_2 concentrations. *Ekologia Bratislava*, 23 124-136. p.

Other publications in English:

- Helyes L., Tuba Z., Balogh J. and Réti K. (2005): Production ecophysiology of Hungarian green pepper under elevated air CO_2 concentration. *Journal of Crop Improvement* 13 333-344. p.
- Balogh J., Fóti Sz., Nagy Z., Czóbel Sz., Pintér K., Péli E., Tuba Z. (2005): Comparison of carbon dioxide fluxes over sandy grasslands vegetation as measured by the eddy-covariance technique and by open system chamber. *Acta Biologica Szegediensis* 49 143-147. p.
- Nagy Z., Czóbel Sz., Balogh J., Horváth L., Pintér K., Weidinger T., Csintalan Zs., Tuba Z. (2005): Carbon balance of Hungarian grasslands in years with contrasting weather conditions. *Acta Biologica Szegediensis* 49 131-132. p.
- Szerdahelyi T., Fóti Sz., Czóbel Sz., Balogh J., Nagy Z., Tuba Z. (2004): Coenological and synphysiological investigations on loess grass stands (*Salvio-Festucetum rupicolae*) on Gödöllő Hills (Hungary). *Acta Biologica Slovenica*, 47 3-11. p.
- Fóti Sz., Balogh J., Czóbel Sz., Nagy Z., Bartha S., Tuba Z. (2004): Seasonal and daily pattern, variability on spatial scale dependence on

ecosystem CO_2 exchange in a temperate Pannonian loess grassland. *Acta Biologica Slovenica*, 47 13-20. p.
- Balogh J., Czóbel Sz., Juhász A., Tuba Z. (2002): Seasonal carbon sequestration of a semi-desert temperate grassland ecosystem over a year period. *Acta Biologica Szegediensis* 46. 221-222. p.
- Czóbel Sz., Balogh J., Fóti Sz., Nagy J., Szerdahelyi T., Virágh K., Bartha S. and Tuba Z. (2002): Space-scale dependence of ecosystem CO_2 exchange in three non-forested vegetations. *Acta Biologica Szegediensis* 46 219-220. p.
- Fóti Sz., Czóbel Sz., Balogh J., Nagy J., Szerdahelyi T., Virágh K., Bartha S. and Tuba Z. (2002): Spatio-temporal variability of ecosystem exchange in three non-arborescent temperate vegetations. *Acta Biologica Szegediensis* 46. 239-241. p.
- Juhász A., Balogh J. and Tuba Z. (2002): Carbon sequestration of the poikilohydric moss carpet vegetation in a semidesert sand grassland ecosystem. *Acta Biologica Szegediensis* 46 223-225. p.

Book chapter in Hungarian

- Czóbel Sz, Horváth L, Nagy J, Szirmai O, Péli E, Nagy Z, Pintér K, Balogh J, Ürmös Zs, Marshall Z, Rabnecz Gy, Tuba Z: Üvegházhatású gázok variabilitása ls éves mérlege, valamint a légköri emelkedő CO_2-koncentráció növényökológiai hatásai. In: Klímaváltozás: Környezet - Kockázat - Társadalom. (Ed. Harnos Zs, Csete L), Szaktudás Kiadó Ház, Budapest 2008. pp. 201-227.

Publications in Hungarian:

- Fóti Sz, Balogh J, Nagy Z, Czóbel Sz, Bartha S, Tuba Z (2007): Mérsékelt övi gyepközösségek CO2-gázcseréjének kisléptékű térbeli variabilitása és mintázata, *Magyar Tudomány* 2007/10 1266-1272.p.
- Czóbel Sz, Szirmai O, Szerdahelyi T, Nagy J, Balogh J, Fóti Sz, Péli ER, Pintér K, Horváth L, Nagy Z, Tuba Z (2007): Megváltoztatott kezelésű hazai gyeptársulásaink funkcionális ökológiai válaszai, *Magyar Tudomány* 2007/10 1273-1279. p.
- Pintér K, Nagy Z, Barcza Z, Balogh J, Czóbel Sz, Fóti Sz, Weidinger T, Tuba Z (2007): Az ökoszisztéma-léptékű fotoszintetikus CO2-asszimiláció és légzés sajátosságai a mérsékelt övi gyepekben, *Magyar Tudomány* 2007/10 1280-1287. p.
- Tuba Z., Nagy Z., Czóbel Sz., Balogh J., Csintalan Zs., Fóti Sz., Juhász A., Péli E., Szente K., Palicz G., J., Horváth L., Weidinger T., Pintér K.,

Virágh K., Nagy, J., Szerdahelyi, T., Engloner, A., Szirmai, O., Bartha, S. (2004): Hazai gyeptársulások funkcionális ökológiai válaszai, C-körforgalma és üvegházhatású gázainak mérlege jelenlegi és jövőben várható éghajlati viszonyok, illetve eltérő használati módok mellett, *Agro-21 Füzetek***,** 37 123-138. p.
- Juhász A., Balogh J., Czóbel Sz., Fóti Sz., Nagy Z. És Tuba Z. (2002): Egy pannon homokpusztagyep CO_2-gázcseréjének egyéves vizsgálata eltérő (mikro)meteorológiai viszonyok között, *ELTE Egyetemi Meteorológiai Füzetek* 17 132-139. p.

Proceedings

- Balogh J., Nagy Z., Pintér K., Balogh B., Pavelka M., Darenová E., Tuba Z. (2009): Multi-chamber automatic soil respiration system for grasslands. *ICDC abstracts* T4-052
- Balogh J., Biro M., Pintér K. (2008): Root respiration in dry grassland. *Cereal Research Communications* 36 355-358. p.
- Pintér K., Barcza Z., Balogh J., Nagy Z. (2008): Continuous eddy covariance measurements of grassland's carbon balance in Hungary. *Cereal Research Communications*, 36 563-566. p.
- Nagy Z., Csintalan Zs., Pintér K., Balogh J., Czóbel Sz., Fóti Sz., Juhász A., Weidinger T., Tuba Z. (2005): Net ecosystem dynamics of grasslands on different soils in Hungary. In: Oral presentation of *XVII International Botanical Congress*, Vienna, Austria, 17-23. July 2005.
- Balogh J., Czóbel Sz., Fóti Sz., Nagy Z., Szirmai O., Péli E., Tuba Z. (2005): The influence of drought on carbon balance in loess grassland. *Cereal Research Communications* 33 149-152. p.
- Czóbel Sz., Balogh J., Szirmai O., Tuba Z. (2005): Floating chamber a potential tool for measuring CO_2 fluxes of aquatic plant communities, *Cereal Research Communications* 33 165-168. p.
- Fóti Sz., Czóbel Sz., Balogh J., Nagy J., Juhász A., Nagy Z., Bartha S. , Tuba Z. (2005): Correlation between stand photosynthesis and composition at micro-scale in loess grassland. *Cereal Research Communications* 33 197-199. p.
- Juhász A., Balogh J., Csintalan Zs., Tuba Z. (2005): The influence of the watercontent on the photosynthetic features and carbon balance of the poikilohydric moss carpet vegetation. *Cereal Research Communications* 33 235-237. p.
- Nagy Z., Czóbel Sz., Balogh J., Horváth L., Fóti Sz., Pintér K., Weidinger T., Csintalan Zs., Tuba Z. (2005): Some preliminary results of the Hungarian grassland ecological research: carbon cycling and

greenhouse gas balances under changing. *Cereal Research Communications* 33 279-281. p.

- Pintér K., Balogh J., Barcza Z., Czóbel Sz., Gyöngyösi A. Z., Horváth L., Nagy Z., Tuba Z., Weidinger T. (2004): Carbon dioxide budget above a Hungarian semi-arid grassland, *COST ACTION 627*, Carbon sequestration in European garasslands, Joint meeting of working Groups 1,2,3 and 4, Gent, Belgium, 3-6 June 2004.
- Balogh J., Nagy Z., Fóti Sz., Juhász A., Czóbel Sz., Tuba Z. (2004):Soil respiration and stand CO_2 exchange in a Central-European semi-desert sand grassland under different water regimes. *Proceedings of the III. Alps-Adria Scientific Workshop***,** Dubrovnik, Croatia, March 2004., 368-372. p.
- Czóbel Sz., Balogh J., Fóti Sz.., Péli E.R., Szerdahelyi T., Szirmai O., Nagy Z., Tuba Z. (2004): Long-term effects of irrigation and fertilization on stand CO_2 fluxes and soil biochemical processes in a Hungarian loess grassland. *Proceedings of the III. Alps-Adria Scientific Workshop***,** Dubrovnik, Croatia, March 2004., 130-134. p.
- Fóti Sz.., Czóbel Sz., Nagy Z., Balogh J., Péli E.R., Bartha S., Acosta M., Tuba Z. (2004): Small scale spatial heterogenity of soil water content and CO_2 gas exchange in natural and semi-natural ecosystems. *Proceedings of the III. Alps-Adria Scientific Workshop***,** Dubrovnik, Croatia, March 2004., 83-87. p.
- Tuba Z., Haszpra L., Weidinger T., Horváth L., Balogh J., Barcza Z., Czóbel Sz., Nagy Z., Pintér K., Tarczay K. (2003): Long-term CO_2 concentration and flux measurements in Hungary. European Geophysical Society, *Geophysical Research Abstracts*, 5 12771 p.
- Balogh J., Nagy Z., Fóti Sz., Juhász A., Czóbel Sz. És Tuba Z. (2003): Állományszintű CO_2-gázcsere és szénmérleg modell *Festucetum vaginatae danubiale* társulásban. *6. Magyar Ökológus Kongresszus Előadások és poszterek összefoglalói*, 36. p.
- Czóbel Sz., Fóti Sz., Balogh J., Nagy J., Nagy Z., Bartha S. és Tuba Z. (2003): A CO_2 gázcsere léptékfüggése fátlan vegetációtípusokban. *6. Magyar Ökológus Kongresszus Előadások és poszterek összefoglalói*, 70. p.
- Fóti Sz., Czóbel Sz., Nagy Z., Bartha S., Balogh J., és Tuba Z. (2003): Lösz és homokpuszta gyepek mezoskálájú térbeli variabilitása. *6. Magyar Ökológus Kongresszus Előadások és poszterek összefoglalói,* 93. p.
- Péli E., Balogh J., Czóbel Sz. , Fóti Sz., Juhász A., Nagy Z. Tuba Z. (2003): A *Festucetum vaginatae danubiale* társulás szénmérlegének hosszútávú vizsgálata**.** *V. Magyar Fotoszintézis Konferencia*

- Pintér K., Tuba Z., Nagy Z., Barcza Z., Weidinger T., Czóbel Sz., Tarczay K., Fóti Sz. és Balogh J. (2003): Éves szénmérleg becslése fűfelszín felett. *V. Magyarországi Fotoszintézis Konferencia*
- Balogh J., Czóbel Sz., Juhász A., Fóti Sz., Nagy Z., Tuba Z. (2002): Daily and seasonal carbon-balance of a pannonian semi-desert temperate grassland. Ljubljana, *3rd Slovenian Symposium on Plant Physiology Book of Abstracts*, 73. p.
- Czóbel Sz., Balogh J., Fóti Sz., Nagy J., Szerdahelyi T., Nagy Z., Bartha S., Tuba Z. (2002): Variability and spatial scale-dependence of ecosystem CO_2 exchange is three herbaceous vegetationsm. Ljubljana, *3rd Slovenian Symposium on Plant Physiology Book of Abstracts,* 63. p.
- Fóti Sz., Czóbel Sz., Balogh J., Nagy J., Nagy Z., Szerdahelyi T., Bartha S., Tuba Z. (2002): Variability of synphysiological processes in three non-arborescent temperate grasslands. Ljubljana, *3rd Slovenian Symposium on Plant Physiology Book of Abstracts,* 72. p.
- Fóti Sz., Juhász A., Balogh J., Csintalan Zs., Tuba Z. (2002): Seasonal carbon balance of a temperate semidesert moss vegetation. Ljubljana, *3rd Slovenian Symposium on Plant Physiology Book of Abstracts,* 72. p.