Szent István University

Farm scale greenhouse gas balance

The main points of the PhD thesis

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BACKGROUND AND AIM OF THE STUDY

Livestock is not only threatened by climate change (NARDONE et al. 2010) but also contributes to it by 10 to 25%, based on livestock's share in total greenhouse gas emission (FAO 2006, SCHWARZER 2012). Under the pressure of climate change livestock still needs to support an expected 20% increase in food demand between 2002 and 2050 (FAO 2006). Therefore, to maintain food security, livestock has to adapt to climate change and to reduce its greenhouse gas (GHG) emission (SMITH et al. 2014). Decreasing GHG emission (CO_2, CH_4, N_2O) and increasing carbon sequestration in livestock systems could be achieved by several management technologies, thus livestock is not just a problem but a solution in combating climate change (SOUSSANA et al. 2010, BELLARBY et al. 2013).

Agricultural lands play a key role in reducing greenhouse gas emission and enhancing carbon sequestration (CONANT 2010). Despite this, carbon sequestration potential of livestock-supporting grasslands, i.e. their climate change mitigation potential, is not accounted in certain life cycle assessments (OPIO et al. 2013). However, permanent grasslands sequestrate 0.01–0.3 Gt carbon, which potentially offsets 4% of the world's GHG emission (SOUSSANA 2008).

Within agriculture the different grassland managements (grazing, mowing) are characterized by varying net ecosystem carbon balances (NECB, CHAPIN et al. 2006) and also with different net greenhouse gas balances (NGHG, SOUSSANA et al. 2010). NECB provides the net accumulation rate of carbon, while NGHG provides the net sink activity of the total GHG's at a grassland or at a farm level (SOUSSANA et al. 2010).

The most important flux (F) in estimating NECB and NGHG is the carbon-dioxide (CO_2) capture of the plants, i.e. the gross primary production (GPP) (Fig. 1). The carbon from the plants enters to the animals and to the soil, while it is respired back to the atmosphere by the ecosystem respiration (Reco). The difference between the GPP and Reco is the net ecosystem exchange (NEE). At farm-scale besides NEE, lateral carbon (C) fluxes should be also taken into account to calculate total carbon flux of the ecosytem. These includes the carbon export of animal products ($F_{Canimal\_product}$), and manure ($F_{Cmanure}$), and the export (F_{Chay}) and import of the hay and the forage ($F_{Cforage}$). Methane (CH_4) is the second most important greenhouse gas of the livestock system (Fig. 1). CH_4 is emitted by the grazing animals via fermentation ($F_{CH4-fermentation}$) and by the decomposition of manure ($F_{CH4-manure}$) (SOUSSANA et al. 2010). A small amount of methane could be captured by the soil via the methanotroph bacteria ($F_{CH4-soil}$). Nitrous oxide (N_2O) is the third most important greenhouse gas of the livestock system (Fig. 1), which is emitted from the soil via the denitrification and nitrification processes ($F_{N2O\text{-}soil}$). It is important to note that the global warming potential (GWP) of the CH_4 and N_2O is 34 times and 298 times higher, respectively as the GWP of the CO_2 on a 100 years' time period.

Our study was part of the EU financed AnimalChange (EU FP7) research program (www.animalchange.eu). The research was conducted by the MTA-SZIE Plant Ecology Research Group (http://nofi.szie.hu/content/mta-szie-plant-ecology-research-group/). This study is the first farm scale greenhouse gas balance estimate in Hungary. Besides greenhouse gas balances I have deeply analyzed the vegetation composition of the grazed and mowed sites and also compared the soil respiration (Rs) of the two treatments to understand the drivers behind the GHG fluxes.

The aims of the study

1. To estimate the net greenhouse gas balance (including carbon-dioxide, methane and nitrous oxide) of a grey cattle farm.
2. To compare the net greenhouse gas and net ecosytem carbon balance between a grazed and a mowed site of the farm.
3. To compare the vegetation between the grazed and mowed site.
4. To compare the soil respiration between the grazed and mowed site.
5. To develop a soil respiration model which includes biotic parameters and to study the possibilities to estimate soil respiration via vegetation indices derived from digital camera.
6. To propose climate change mitigation management technologies.

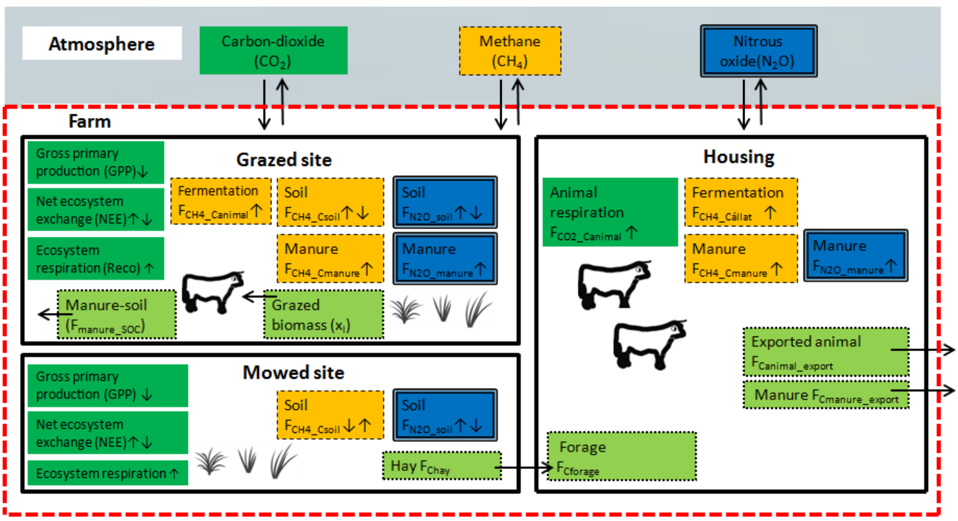


Figure 1. Farm scale greenhouse gas and carbon fluxes at a grazed and mowed site, as well as at the loose housing system. Arrows pointing up (to the atmosphere) and lateral directions (right) represents losses (emission), while arrows pointing down represents gains (sink) to the ecosystem.

MATERIALS AND METHODS

Research site

Our study was conducted at a grey cattle (*Bos taurus primigenius podolicus*) farm of the Kiskunság National Park in Hungary (Bugac, 46°41'28"N, 19°36'42"E, 114 m a.s.l.) (Fig. 2). The farm consisted of grazing (1070 ha), mowing areas (847 ha) and a loose housing system (4 ha). Sampling sites for grazed and mowed managements where adjacent to each other (250 m apart) and were both 1 ha. The climate is dry continental, with a mean annual sum precipitation of 575 mm, and a mean annual temperature of 10.4°C (2003-2014). The soil is chernozem type sandy soil. The vegetation is species rich sandy grassland (steppe). Grazing is permanent at least in the last 40 years. The experimental mowed area (1 ha) was fenced from the grazing area in 2011.

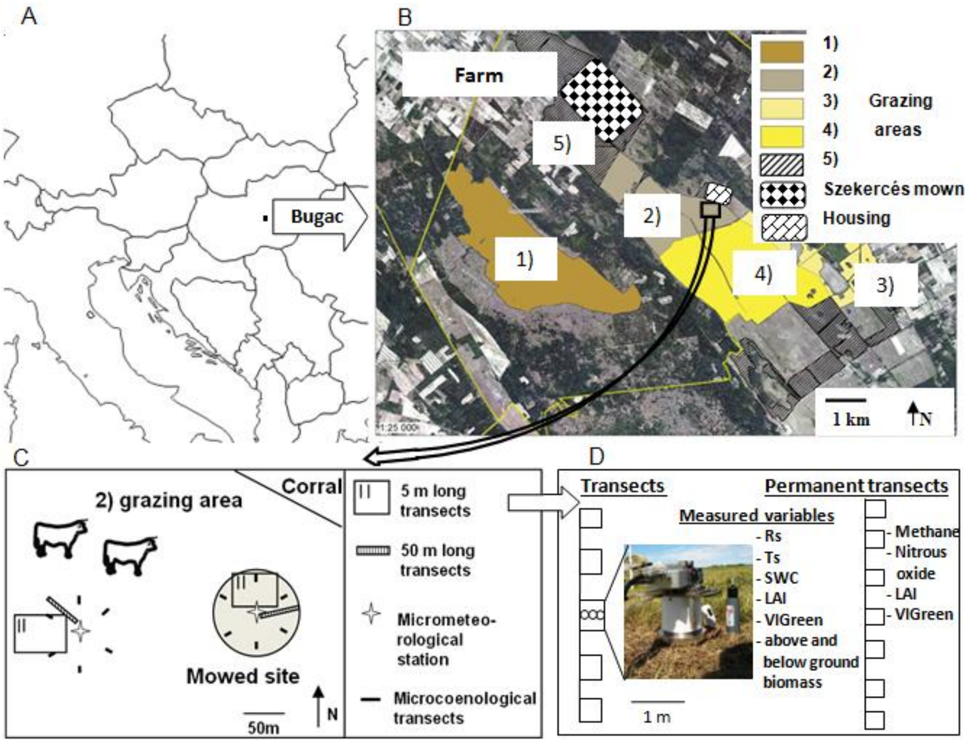


Figure 2. Map of the research site (http://d-maps.com) (**A**), map of the grazing and mowing areas at the grey cattle farm of the Kiskunság National Park (Bugac, Hungary) (**B**), experimental design at the grazed and mowed site (**C**), sampling transects with the measured parameters (Rs: soil respiration; Ts: soil temperature, SWC: soil water contant; LAI: leaf area index; VIGreen: green vegetation index) (**D**). The photo on D) shows the head of the Rs measurement system (LICOR).

Micrometeorological measurements

On both grazed and mowed sites air temperature (T_{air}, ºC), relative humidity (RH, %) and wind speed (m s^{-1}) was half hourly measured between 2011 and 2013. Due to the vicinity of the two sites (250 m), precipitation and photosynthetically active radiation was only measured at the micrometeorological station of the grazed site (Fig. 2).

Vegetation studies

Microcoenological survey was carried out at both grazed and mowed sites 7 times between 2011 and 2014 to infer, if any, differences and changes in vegetation structure, which might affect greenhouse gas fluxes. Phenological survey was carried out parallel with the ecophysiological (biomass, soil respiration measurements) survey. Measurement campaigns were carried out bi-, to three weekly between 2011 and 2013 (52 fully successful campaign).

Farm scale carbon and carbon-dioxde flux measurements

Net ecosystem exchange (NEE)

CO_2 flux (net ecosystem exchange, NEE) and its components (GPP and Reco) were measured parallel with eddy covariance technique on both grazed and mowed sites (CSAT3 sonic anemometer, Li-7500 IRGA). Due to extensive management animals were scattered around the total grazing area and only occurred for a few days/weeks in the footprint of the eddy covariance measurements. Therefore, year round animal respiration ($F_{Canimal}$) was estimated separately based on SOUSSANA et al. (2010).

Soil respiration

Soil respiration (Rs, LICOR-6400, LICOR-6400-09) and its main drivers; soil temperature (Ts), and soil water content (SWC) were measured bi-, to three weekly between 2011 and 2013, along 5-meters-long transect on both sites (Fig. 2 d). For data analysis Kruskal-Wallis and Mann-Whitney-Wilcoxon test was used in R.

Dependency of Rs from abiotic and biotic (biomass) drivers was tested by different soil respiration models. Soil respiration data were first fitted using the Lloyd Taylor model (1). This model was improved by model (2) which included the addictive effect of SWC on Rs. Model was further improved by adding the effect of below ground biomass (3), above ground biomass (4), leaf area index (5), above ground green biomass (6), and green vegetation (VIGreen) index (7). Models were fitted in SigmaPlot 8.0 (SPSS Inc).

Biomass and soil carbon measurements

Above ground biomass was sampled in each sampling quadrate along the 5-meter-long transects at both grazed and mown site (Fig.2 d). Below ground biomass samples were taken by the soil core method (5 cm Ø, 0-30 cm depth) from each quadrates. Plant materials and soil samples were oven-dried at 85 °C for 48 h. Dry soil was sieved (1 mm Ø) to separate below ground biomass from the soil. Amount of herbage removed by grazing animals was estimated according to Vinczeffy (1993). Soil organic C content was determined by the Institute for Soil Sciences and Agricultural Chemistry (Hungary) according to the Hungarian Standard (MSZ-08-0012-6:1987).

Estimating biomass dynamics by vegetation indices

Leaf area index (LAI, m^2 m^{-2}) was measured from light interception data (derived from a CEP-40 ceptometer), measured at each measurement campaigns at each quadrates (Fig. 2.d). VIGreen index was derived from red, green, blue (RGB) photographs made by a commercial digital camera (Canon Eos 350D) at the quadrates (Fig. 2d). VIGreen index (%) is the normalized difference of reflected green and red light (GITELSON et al. 2002). NDVI (normalized difference vegetation index) data from LANDSAT satellite was used to estimate the correlation between biomass and remote sensed vegetation data (data were processed with QGIS).

Estimating lateral carbon fluxes

Lateral carbon fluxes included the exported animal products ($F_{Canimal\text{-}product}$), the exported manure ($F_{Cmanure}$), exported hay ($F_{Chay}$) from the mowed site to the housing, and the imported forage from the mowed site to the housing ($F_{Cforage}$) (data from Kiskunság National Park). Carbon loss due to fire did not occur at the site, and other potential carbon losses (erosion, leaching, VOC) were neglected due to site condition.

Estimating the methane and nitrous oxide fluxes of the farm

Soil methane ($F_{CH4\text{-}soil}$) and soil nitrous oxide ($F_{N2O\text{-}soil}$) was measured parallel with static chamber technique on both sites bi-, to three weekly between 2011 and 2013 along 7-meters-long permanent transects (HORVÁTH et al. 2010). The concentration of the sampled gases were measured by a gas chromatograph (HP 5890 II, Waldbronn, Germany) at the Ecology Laboratory of the Forest Research Institute (Hungary).

Fermentation ($F_{CH4\text{-}animal}$), and manure ($F_{CH4\text{-}manure}$) methane flux, and manure nitrous oxide flux (F_{N2O_manure}) was estimated based on the IPCC (2006) methodology.

Farm scale net ecosystem carbon balance (NECB) and net greenhouse gas balance (NGHG)

Based on CO_2 (NEE), lateral C, and CH_4 fluxes (converted to C) the net accumulation rate of carbon (net ecosystem carbon exchange, NECB, by CHAPIN et al 2006; net carbon storage, NCS, by SOUSSANA et al. 2010) was calculated for the grazed and mowed site as well as for the housing system and for the whole farm. NEE is one of the component within the balances which is negative if the ecosytem is a sink (carbon gain) for the CO_2, while it is positive if the ecosytem is a source for the CO_2 (carbon loss). A negative sign before NEE stands for changing this direction, i.e. a positive balance will represent a net gain by the ecosystem. The NECB for the grazed site was calculated as follows (adding negative fluxes reduces the balance):

$$NECB_{grazed} = -NEE_{grazed} + F_{Canimal} + F_{CH4\_animal} + F_{CH4\_manure} + F_{CH4\_soil\_grazed} \quad (1).$$

At the mowed site the NECB was calculated as follows:

$$NECB_{mowed} = -NEE_{mowed} + F_{CH4\_soil\_mowed} + F_{Chay} \quad (2).$$

The NECB related to the housing system was calculated as follows:

$$NECB_{housing} = F_{Canimal} + F_{Canimal\_export} + F_{Cforage} + F_{Cmanure} + F_{CH4\_Cmanure} + F_{CH4\_Canimal} \quad (3).$$

For the calculation of farm-scale NECB first the farm-scale NEE was calculated based on the proportion of the grazed (56%, A_g=0.56), and mowed areas (44%, A_m=0.46) in the total area of the farm. At farm scale the NECB was calculated as follows:

$$NECB_{farm} = -NEE_{grazed} \times A_g + NEE_{mowed} \times A_m + F_{Canimal} + F_{CH4\_Canimal} + F_{CH4\_Cmanure} + F_{CH4\_Csoil\ grazed} \times A_g + F_{CH4\_soil\ mowed} \times A_m + F_{Canimal\ product} + F_{Cmanure} \quad (4).$$

To compare the fluxes of the grazed and mowed sites the t-test was used, while among systems (grazing, mowing, housing, farm) ANOVA was used.

Net greenhouse gas balance (NGHG)

NGHG was calculated based on SOUSSANA et al. (2010) for the grazed and mowed sites and for the housing system, as well for the whole farm as follows:

$$NGHG = k_{CO_2}(NECB + F_{CH_4-C}) + GWP_{CH_4}F_{CH_4} + GWP_{N_2O}F_{N_2O} \quad (5),$$

where k_{CO2} is the carbon-dioxide equivalent of the carbon (44/12), *NECB* is net ecosystem carbon balance, $GWP_{CH4}F_{CH4}$ (g CO_2eqv. m^{-2} $year^{-1}$) is the total methane flux in global warming potential [GWP_{CH4}=34], and $GWP_{N2O}F_{N2O}$ (g CO_2eqv. m^{-2} $year^{-1}$) is the total nitrous oxide flux in global warming potential (GWP_{N2O}=298) for the given system (i.e. grazing, mowing, housing, farm).

RESULTS

The management intensity at the farm

The grassland was maintained by the Kiskunság National Park via grazing and mowing (Fig. 3.) The livestock density between 2011 and 2013 was 0.64±0.03 livestock unit per hectare (one livestock unit was 381kg), which is an extensive management. The estimated grazed biomass (53.88±6.65 g C m^{-2} $year^{-1}$, X_l) was lower than the measured harvested hay (93.72±31.19 g C m^{-2} $year^{-1}$, F_{Chay}), hence the carbon use intensity was higher at the mowed site.

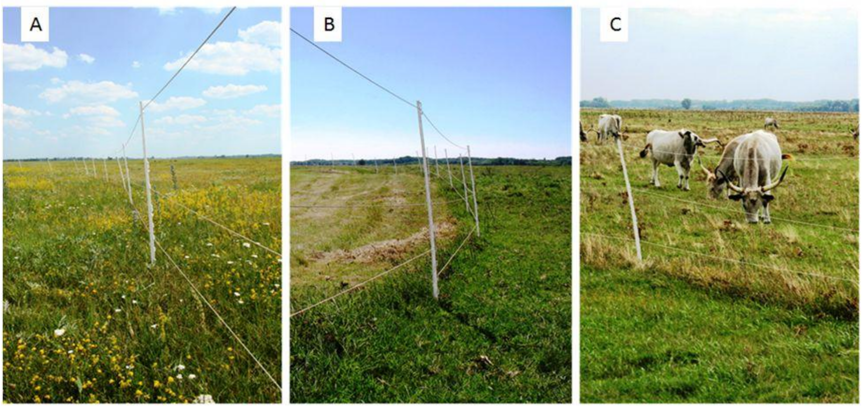


Figure 3. The experimental mowed site (left to the electrical fence) and the investigated grazed site (right to the electrical fence) before mowing and at the beginning of the grazing period on the 19th of June 2012 **(A)**, after mowing and grazing on the 4th of July 2013 **(B)**, and during the regeneration period of the mowed site and during autumn grazing on the 23th of September 2013 **(C).**

Microclimate

Mean annual temperatures during the study period (10.14 °C, 10.76 °C and 10.79 °C in 2011, 2012, 2013, respectively) were close, or rather above to the ten-year average (10.4°C, 2003-2014). In 2011 and 2012 annual sums of precipitation (436 and 381 mm, respectively) were lower, while in 2013 (590 mm) sum of precipitation was close to the ten-year average (575 mm). In 2011 we observed that the evapotranspiration (486 mm) was higher compared to the actual precipitation (444 mm), thus we assumed that water was stored in the soil from the very wet previous year (961 mm). Yearly averages and temporal dynamics of soil temperature and soil water content did not differ between the grazed and mowed sites despite the different management. However, large differences observed among years as the soil water content decreased from 2011 to 2013 at both sites.

Vegetation composition

We found 89 species on the grazed site, while 90 species on the mowed site (a total of 109 different species). The most common species on both sites were similar (*Poa* spp., *Carex* spp., *Festuca pseudovina*, and *Cynodon dactylon*). There were no differences between the grazed and mowed sites in species richness, species density, Shannon diversity index and in the species-area curves. Based on Rényi diversity profil, Sørensen index and the PERMANOVA analysis (analysis of variance using distance matrices) the two sites were also similar. Possible effect of mowing was only observed in 2011 after the first mowing, when the abundance of the legumes decreased more from spring to fall on the mowed site than on the grazed site. During the phenological survey we observed that the fluctuations of the relative cover of the most common species on the grazed and mowed sites were similar, expect for the *Medicago falcata* (leguminous) which showed a sharp decrease after the first mowing in 2011.

Farm scale carbon-dioxide and carbon fluxes

Net ecosystem CO_2 exchange

Fluctuations of cumulative net ecosystem exchange (NEE) were similar between the grazed and mowed sites before the mowing and grazing events (spring) at all years (2011-2013) (Fig. 4). Later on the course of cumulative NEE became different at the two sites due to management activities. During early summer of 2011 the net carbon uptake was lower at the mowed site compared to the grazed site due to higher R_{eco} and higher soil respiration at the mowed site. Sudden removal of the biomass at the mowed site caused a sharp decrease in GPP (Fig. 4) – in contrast to grazing which was more continuous – which resulted a lower carbon sink (NEE) at the mowed site compared to the grazed site during all years. The autumn of 2012 was relatively wet which contributed to an increase of GPP (i.e. more gain of carbon by the ecosystem) at both sites but it was more intense at the mowed site (Fig. 4). Higher GPP (and biomass) at the mowed site was probably due to early mowing and due to the continuous grazing pressure at the grazed site, which led to higher regeneration potential of the vegetation at the mowed site compared to the grazed site. However, higher GPP accompanied with higher R_{eco} and with higher Rs, thus finally it led to lower net carbon sink (NEE) activity at the mowed site compared to the grazed site during 2012 autumn. In 2013 summer, just as in previous years, the sudden removal of the biomass at the mowed site, after mowing, caused a lack of potential to capture CO_2; hence the GPP suddenly decreased in 2013 too. This resulted in lower net carbon gain (NEE) at the mowed site compared to the grazed site in 2013 autumn. On average of the three years the R_{eco} was higher by 1-7%, while the GPP was lower by 3% at the mowed site compared to the grazed site. This resulted in a 58% lower cumulative NEE at the mowed site (61.33±46.76 g C m^{-2} $year^{-1}$) compared to the grazed site (142.65±40.07 g C m^{-2} $year^{-1}$) on average.

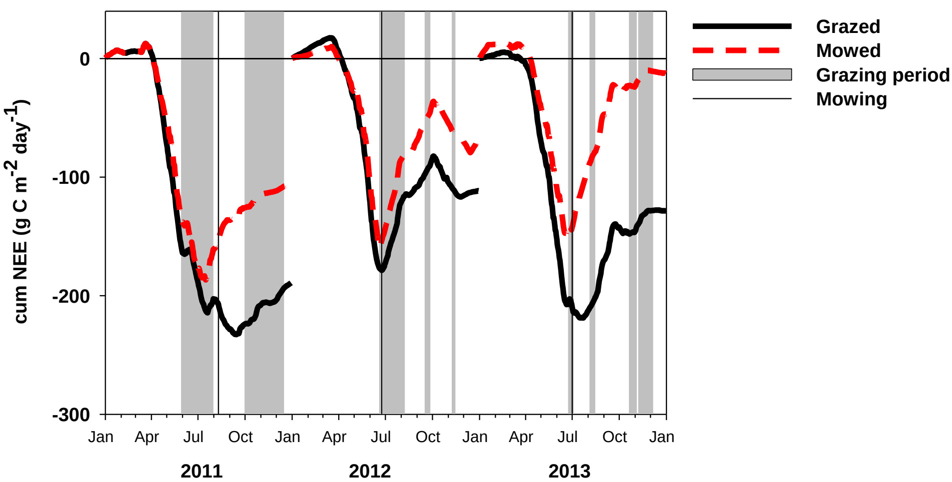


Figure 4. Yearly cumulative net ecosystem exchange (NEE) at the grazed and mowed sites (negative is a sink for the ecosystem)

The highest carbon sink activity (and biomass) was observed in 2011 at both sites, probably due to the prolonged effect of the very wet year of 2010, which provided soil water in 2011. The carbon sink activity (NEE) accounted for 99.16% of the sink activity of the farm (Table 1.)

In contrast to our results carbon sink activity (NEE) was higher by 10% (SOUSSANA et al. 2010), and by 48% (SENAPATI et al. 2014) at the mowed site in other studies compared to the grazed site. However, the mowed sites received 10% (SOUSSANA et al. 2010) more precipitation, and 50% more fertilization (SENAPATI et al. 2014), respectively compared to the grazed site, which provides inadequte comparsion among grasslands.

Soil respiration

The annual dynamics of soil respiration (Rs) was similar at the two sites and amongst years. Using paired Rs averages by measurements campaigns between the grazed and mowed sites Rs was 11% higher at the mowed site (5.79 µmol CO_2 m^{-2} s^{-1}), compared to the grazed one (5.19 µmol CO_2 m^{-2} s^{-1}) as shown by the slope of the linear regression (Fig. 5). Differences in above ground biomass between the grazed vs. mowed sites acted as a differentiating factor in terms of Rs response between the two sites, while no differences were observed in the abiotic drivers (SWC, Ts) of Rs between the two sites. Strong biomass dependency of Rs was also supported by the improvement of the goodness of the soil respiration models when biotic drivers (above ground biomass, green biomass) and proxies of biotic drivers (LAI, VIGreen) were included in the Rs models, besides abiotic drivers.

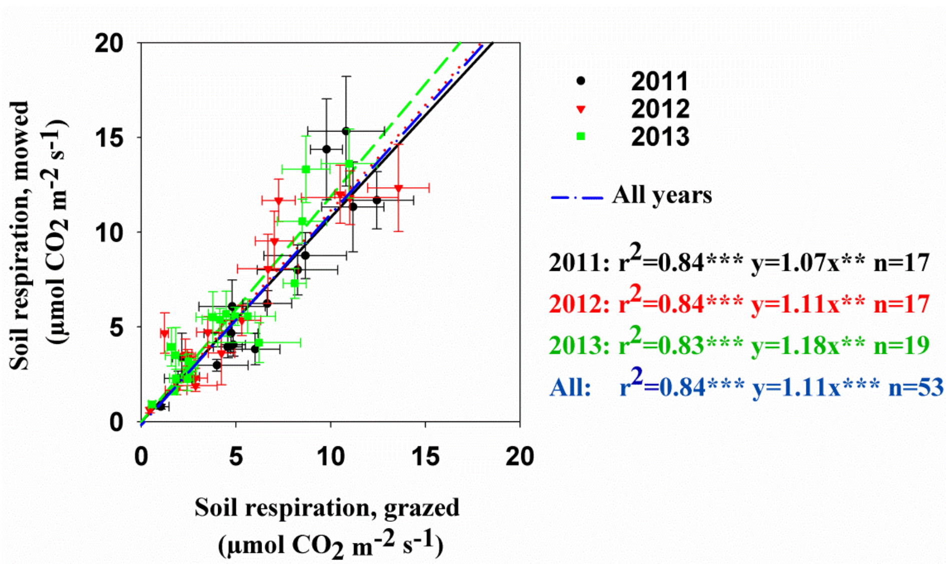


Figure 5. Soil respiration at the grazed versus at the mowed site. One point represent the average and standard deviation of one measurement campaign.

Soil respiration model was improved by others as well by incorporating biotic parameters (LAI, growth rate, below ground biomass) in the model (JIA AND ZHOU 2009). However, in our study we included a vegetation index (VIGreen) in the model which could be remotely estimated. We have also found a strong link between soil respiration and VIGreen on both sites (Fig. 6). This could provide a fast estimation (hours) of Rs at larger spatial scale (hectare), after calibration.

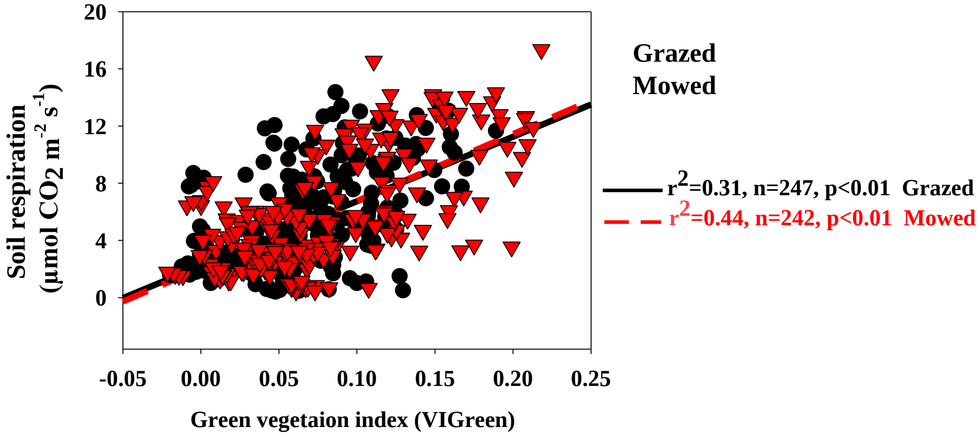


Figure 6. Correlation between soil respiration and green vegetation index (VIGreen)

Biomass and soil carbon measurements, estimating biomass dynamics by vegetation indices

Biomass growth was similar at the grazed and mowed site before the mowing and grazing event (Fig. 7). Biomass accumulation lasted longer at the mowed site than at the grazed in 2011 and 2013, because grazing started earlier then mowing; thus the biomass at the mowed site reached higher value compared to the grazed site. In 2012, due to early mowing and due to rainy autumn, the mowed site showed higher regeneration capacity then the grazed site; thus the biomass was double compared to the grazed site. We found a strong correlation between the above ground biomass and the vegetation indices measured on field (LAI, VIGreen) and estimated from satellite images (NDVI). Thus vegetation index can be used to infer biomass differences. In the line with the biomass differences between the grazed and mowed site the green vegetation index (VIGreen) was also higher at the mowed site by 12% compared to the grazed site. Besides above ground biomass below ground biomass was also higher at the mowed site compared to the grazed site. Significant differences in soil carbon and nitrogen content already existed prior to the experiment (2011) between the grazed and mowed sites. The soil organic carbon content in the upper 15 cm of the soil was 4.51±0.98 kgC m^{-2} at the mowed site and 5.20±0.64 kgC m^{-2} at the grazed site.

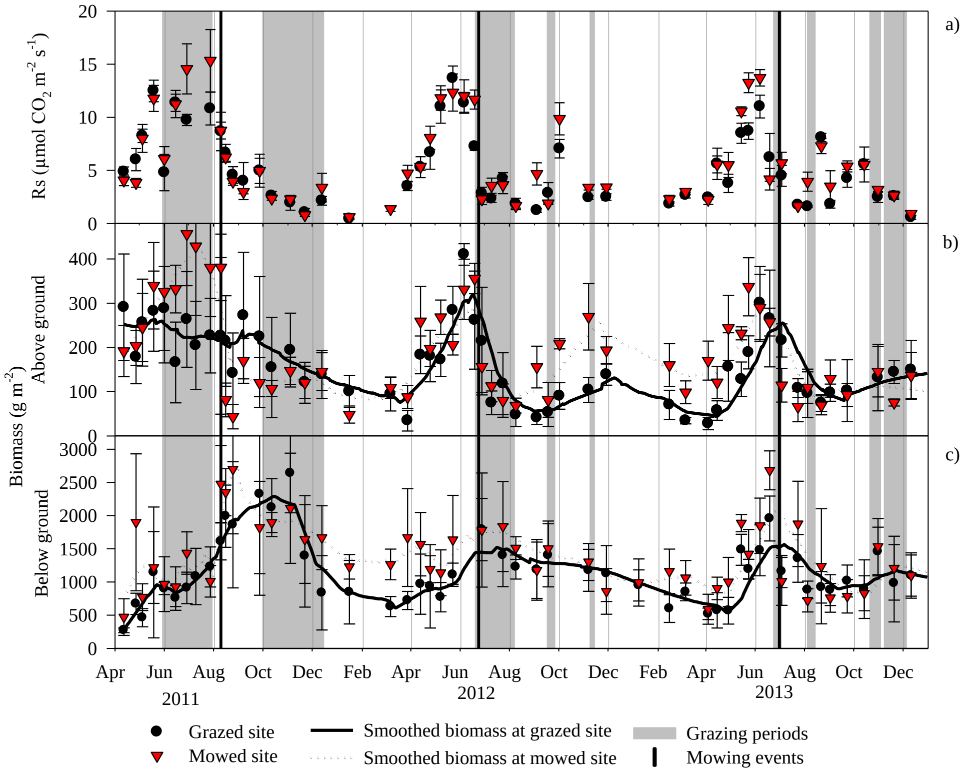


Figure 7. Above and below ground biomass dynamics and soil respiration (Rs) changes at the grazed and mowed sites.

Methane fluxes of the farm

Soils were a weak net sink for CH_4 (F_{CH4_soil}) at both grazed and mowed sites and no differences observed between sites. Soil CH_4 sink accounted for 0.84% of total farm scale greenhouse gas sink activity. CH_4 emission due to fermentation ($F_{CH4\_Canimal}$) was 65.99±3.03 g CO_2eqv. m^{-2} $year^{-1}$ (in carbon-dioxde equivalent at farm scale). This emission accounted for 22% of total farm scale greenhouse gas emission. Manure CH_4 emission (F_{CH4_manure}) was half compared to the methane emission from fermentation.

Nitrous oxide fluxes of the farm

Soils were a net source for N_2O at both grazed (0.090±0.004 g N_2O m^{-2} $year^{-1}$) and mowed (0.084±0.027 g N_2O m^{-2} $year^{-1}$), sites and no differences observed between the sites at either years. Soil N_2O emission accounted for 9% of total farm scale greenhouse gas emission.

Manure N_2O emission varied according to the number of animals at the grazed site and at the housing system (Table 3). Manure N_2O emission accounted for 5% of total farm scale greenhouse gas emission.

Net ecosystem carbon balance (NECB) of the farm

The grazed site was a sink, while the mowed site was a source for total carbon accumulation (NECB, Fig. 8.). This was due to the significantly higher carbon sink activity (NEE) of the grazed (58%) compared to the mowed site, and to the large amount of harvested hay (F_{Chay}) exported from the mowed site. Even though that there were extra emissions at the grazed site (animal respiration, fermentation), compared to the mowed site, these did not reduce the NECB of the grazed site below to level of the mowed site (Fig. 8.). The housing system appeared to be a net sink for the carbon due to the high amount of imported forage ($F_{Cforage}$)(Fig. 8).

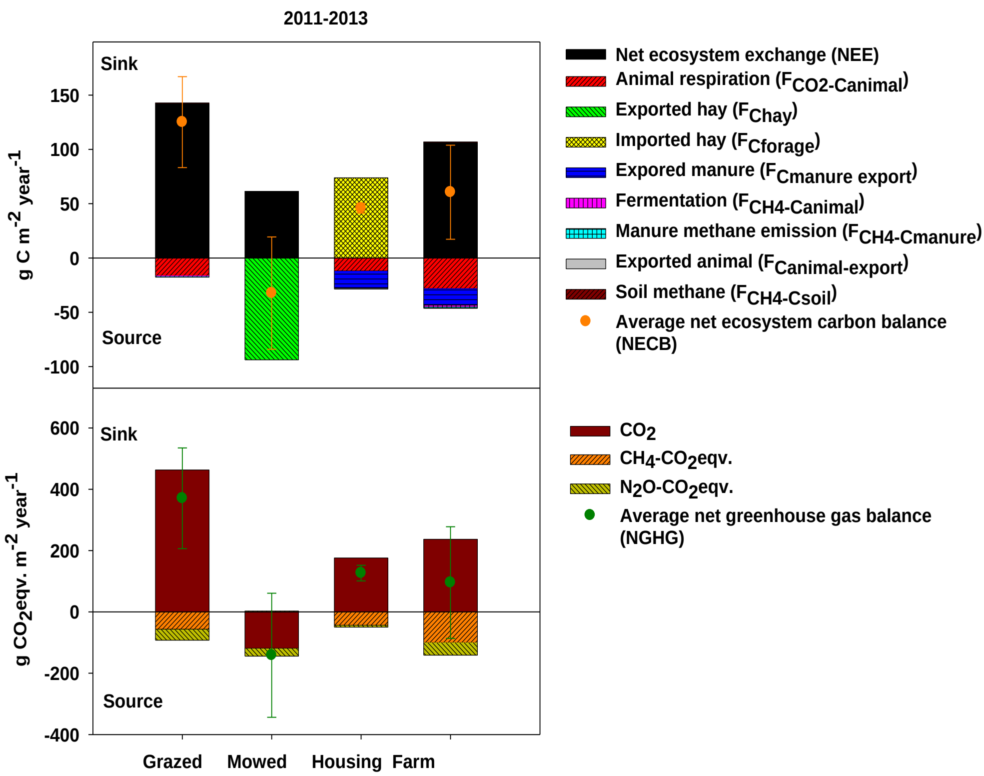
At farm scale the livestock system was a net sink for carbon (60.58±43.34 gC m^{-2} $year^{-1}$)(Fig. 8). At farm scale the loss of carbon at the mowed site is a gain of carbon at the housing system. Net carbon accumulation (NECB) at farm scale was due to the high amount of carbon captured at the grazed site (and also for the mowed site for a lesser extent), which compensated the loss of carbon via respiration of animals ($F_{CO2\text{-}Canimal}$), fermentation ($F_{CH4\text{-}Camimal}$) and manure ($F_{CH4\text{-}Cmanure}$) methane emission. Our results is in the line with the literature as mowed sites lost carbon, due to the removed hay, in contrast to the grazed sites (HASZPRA et al. 2010, NECB as NCS by SENAPATI et al. 2014).

Net greenhouse gas balance (NGHG)

Combining all greenhouse gases (CO_2, CH_4, N_2O) and carbon fluxes in carbon-dioxide equivalent based on equation 5. we found that the grazed site was a net sink, while the mowed site was a net source for the greenhouse gases in 2011-2013 (Fig. 8., Table 1). At the grazed site the methane was responsible for the total emissions by 60.92%, while the nitrous oxide for the remaining 39.08%. Gas fluxes between grazed and mowed site differed significantly. The net source GHG activity of the mowed site was due to the low cumulative NEE and duo to the high amount of exported hay (Fig. 8., Table 1).

At the housing system the NGHG was a sink for GHG due to the relatively low emission of methane (manure, fermentation) and nitrous oxide (manure) in CO_2eqv. compensated by the high imported forage (Fig. 8., Table 1).

At farm scale the livestock system was a net sink for the greenhouse gases (Fig. 8., Table 1). Carbon sequestration (NEE) was just as high as it could compensate (offset) the farm-scale carbon, methane and nitrous oxide emission (Fig. 8., Table 1). It has to be noted that the average NGHG sink capacity of the farm during 2011-2013 was only due to the high carbon sink activity (NEE) for both grazed and - to a lesser extent - for mowed sites in 2011. In 2012 the farm sink activity was near zero, while in 2013 the farm was a weak net source for greenhouse gases. If the NEE would have been 25% less compared to the observed yearly values (assuming that the other fluxes would remain the same), than the farm would have turned to be neutral for greenhouse gas emission. Rotational grazed and mowed areas in the literature were a net source for the greenhouse gases (-272 g CO_2eqv. m^{-2} $year^{-1}$), while cut only mowed areas were source (-141 g CO_2eqv. m^{-2} $year^{-1}$), and grazed only pastures were sink (320 g CO_2eqv. m^{-2} $year^{-1}$) for greenhouse gases (SOUSSANA et al. 2010).



8. Figure: Farm scale net ecosytem carbon balance (NECB), and net greenhouse gas balance and their components. CO_2: carbon-dioxide; CH_4: methane; N_2O: nitrous oxide Eqv.: equivalent.

Table 1. Farm scale net greenhouse gas balance (NGHG) and its components in carbon-dioxide equivalent (2011-2013). Negative signs represent sink for the ecosystem, while positive signs are net sources (emission) of the ecosystem. Standard deviations are in brackets.

Legends:

NEE	net ecosystem exchange
$F_{CO2\_Canimal}$	respiration of the animals
F_{Chay}	exported hay from the mowed site
$F_{Cforage}$	imported forge to the housing system
$F_{Cmanure\_export}$	exported manure from the housing system
$F_{Canimal\_product}$	exported animal product
$F_{CH4\_Canimal}$	fermentation methane emission of the herd
$F_{CH4\_Cmanure}$	manure methane emission
F_{CH4_Csoil}	soil methane flux, in carbon-dioxide equivalent
$F_{N2O\text{-}soil}$	soil nitrous oxide flux
$F_{N2O\text{-}manure}$	manure nitrous oxide flux
CO_2	carbon-dioxide
CH_4	methane
N_2O	nitrous oxide

(The table is on the next page.)

Management	-NEE	$F_{CO2\text{-}C\text{-}amimal}$	F_{Chay}	$F_{Cforage}$	$F_{Cmanure\ export}$	$F_{Canimal\text{-}export}$	$F_{CH4\text{-}Canimal}$	$F_{CH4\text{-}Cmanure}$	$F_{CH4\text{-}Csoil}$	$F_{N2O\text{-}soil}$	$F_{N2O\text{-}manure}$
	[g CO_2 eqv. m^{-2} $year^{-1}$]										
Grazed	523.11 (146.91)	-59.86 (7.39)	0	0	0	0	-38.17 (8.68)	-21.72 (2.68)	3.52 (5.44)	-27.94 (1.64)	-8.21 (1.81)
Mowed	224.89 (171.45)	0	-343.64 (223.36)	0	0	0	0	0	3.09 (3.72)	-25.62 (8.96)	0
Housing	0	-43.61 (2.67)	0	271.04 (11.46)	-49.61 (16.33)	-1.51 (0.58)	-27.87 (1.7)	-15.82 (0.97)	0	0	-5.98 (1.71)
Farm	391.61 (144.37)	-103.48 (4.75)	0	0	-49.61 (16.33)	-1.51 (0.58)	-65.99 (3.03)	-37.54 (1.73)	3.33 (4.68)	-26.92 (4.87)	-14.2 (1.77)

Management	CO_2	$CH_4\text{-}CO_{2eqv}$	$N_2O\text{-}CO_{2\ eqv}$
	[g CO_2eqv. m^{-2} $year^{-1}$]		
Grazed	463.25 (152.81)	-56.37 (8.86)	-36.15 (2.47)
Mowed	-118.75(189.69)	3.09 (3.72)	-25.62 (8.96)
Housing	176.31 (31.04)	-43.64 (2.67)	-5.98 (1.72)
Farm	237.01 (166.04)	-100.2 (9.44)	-41.11 (6.64)

Management	NGHG
	[g CO_2eqv m^{-2} $year^{-1}$]
Grazed	370.72 (164.13)
Mowed	-141.28 (202.37)
Housing	126.68 (25.43)
Farm	95.70 (182.12)

NEW SCIENTIFIC RESULTS

1. **The first farm scale greenhouse gas balance of a livestock farming system in Hungary have been estimated.** We showed that the extensive grey cattle farm near Bugac, during favourable soil water condition, was a net sink for the greenhouse gases**.**

2. **We found that the grazed site was a net sink for carbon (NECB) and for greenhouse gases (NGHG), in contrast to the adjacent mowed site (Fig. 8).** At farm scale 35% of the emission was accounted for the animal respiration, 22% for the animal fermentation, 17% for the manure export (and related carbon-dioxide emission), 12% for the manure methane emission, 9% for the nitrous oxide emission of the soil, 4,5% for the nitrous oxide emission of the manure, and 0,5% for the animal export.

3. **We found that the vegetation composition was similar between the grazed and mowed sites** (even after the third year of mowing introduction at the grazed site). Management change was only observed after the first mowing, when the cover and abundance of the legumes decreased at the mowed site.

4. **We found that the soil respiration was higher at the mowed site, compared to the grazed site,** due to higher biomass at the mowed site and due to different biomass-dynamics between the two sites (Fig. 5)

5. **We improved the goodness of the soil respiration model fit by incorporating biotic drives (biomass, vegetation indices) besides abiotic drivers in the soil respiration model.** We showed that soil respiration could be estimated by handhold digital camera, following field calibration (Fig. 6).

CONCLUSIONS AND PROPOSITIONS

1. **In the farm scale greenhouse gas balance the carbon capture potential represents the only reliable sink capacity of the farm. Therefore it has to be maintained, supported and it has to be taken into account in the greenhouse gas inventories, and life cycle assessment dealing with grasslands and livestock systems, because this is often neglected in inventories (IPCC 2006, SCHWARZER 2012, OPIO et al. 2013).**

2. **Extensive grazing proved to be prosperous compared to mowing in climate change mitigation; therefore grazing should be favoured instead of mowing where possible.**

3. **We propose to use the extended version of the improved soil respiration model, which includes biotic parameters (biomass) besides abiotic ones (soil temperature, soil water content), to estimate the variability of soil respiration (KONCZ et al. 2015).**

4. **We proposed a new method to estimate soil respiration. We showed that soil respiration could be estimated by vegetation indices derived from digital camera.** This provides new opportunities to remotely estimate soil respiration within a few hours, from a larger areas (hectares). To estimate soil respiration via photos, field measurements of soil respiration and vegetation indices are needed for calibration.

REFERENCES

- BELLARBY, J., et al. (2013): Livestock greenhouse gas emissions and mitigation potential in Europe. In: *Global Change Biology*, 19(1), 3–18. p. doi: 10.1111/j.1365-2486.2012.02786.x
- CHAPIN, F.S., et al. (2006): Reconciling carbon-cycle concepts, terminology, and methods. In: *Ecosystems*, 9, 1041–1050. doi:10.1007/s10021-005-0105-7
- CONANT, R. T., et al. (2010): Measuring and monitoring soil organic carbon stocks in agricultural lands for climate mitigation. In: *Frontiers in Ecology and the Environment*, 9(3), 169–173. p. doi:10.1890/090153
- FAO [2006.]: Livestock's long shadows: environmental issues and options. Rome: FAO, 356 p.
- GITELSON, A., KAUFMAN, Y. J., STARK, R., AND RUNDQUIST, D. (2002): Novel algorithms for remote estimation of vegetation fraction. In: *Remote Sensing of Environment*, 80(1), 76–87. p. doi:10.1016/S0034-4257(01)00289-9
- HASZPRA, L., et al. (2010): Atmospheric trends and fluctuations – Trends and temporal variations of major greenhouse gases at a rural site in Central Europe. 29-47 p. In: Haszpra, L. (Eds.): *Atmospheric Greenhouse Gases: The Hungarian Perspective*. Springer, 393 p. doi:10.1007/978-90-481-9950-1_3

- HORVÁTH, L., et al. (2010): Estimation of nitrous oxide emission from Hungarian semi-arid sandy and loess grasslands; effect of soil parameters, grazing, irrigation and use of fertilizer. In: *Agriculture, Ecosystems and environment*, 139(1-2), 255–263. p. DOI:10.1016/J.AGEE.2010.08.011
- IPCC [2006]: Guidelines for national greenhouse gas inventories. Volume 4: Agriculture, forestry, and other land use, Chapter 10: Emissions from livestock and manure Management. (Eds.:Eggleston S., et al.) Hayama, Japan: IGES. 87 p.
- JIA, B. R., AND ZHOU, G. S. (2009): Integrated diurnal soil respiration model during growing season of a typical temperate steppe: effects of temperature, soil water content and biomass production. In: *Soil Biology and Biochemistry*, 41(4), 681–686. p. doi:10.1016/j.soilbio.2008.12.030
- NARDONE, A., et al. (2010): Effects of climate changes on animal production and sustainability of livestock systems. In: *Livestock Science*, 130(1-3), 57–69. p. doi:10.1016/j.livsci.2010.02.011
- OPIO, C., et al. (2013): Greenhouse gas emissions from ruminant supply chains – A global life cycle assessment. Food and Agriculture Organization of the United Nations (FAO), Rome.
- SCHWARZER, S., (2012): Growing greenhouse gas emissions due to meat production. UNEP GEAS Releases Alert on GHG Emissions from Meat Consumption. UNEP GEAS Bulletin, October, 1–40 p.
- SENAPATI, N., et al. (2014): Net Ecosytem Carbon Balance measured in a mowed and grazed temperate sown grassland shows potential for carbon sequestration under grazed system. In: *Carbon Management*, 5(2), 131–144. p. doi:10.1080/17583004.2014.912863
- SMITH P., et al. (2014): Agriculture, Forestry and Other Land Use (AFOLU). 811–922. p. In: EDENHOFER, O., R. et al. (Eds.): *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 1435 p.
- SOUSSANA, J. F., et al. (2010): Mitigating the greenhouse gas balance of ruminant production systems through carbon sequestration in grasslands. In: *Animal: An International Journal of Animal Bioscience*, 4(3), 334–50. p. doi:10.1017/S1751731109990784

SCIENTIFIC PUBLICATIONS IN THE SUBJECT OF THE DISSERTATION

IF, SCI articles:

- KONCZ, P., BALOGH, J., PAPP, M., HIDY, D., PINTÉR, K., FÓTI, Sz., KLUMPP, K., NAGY, Z. (2015): Higher soil respiration under mowing than under grazing explained by biomass differences. In: *Nutrient Cycling in Agroecosystems*, 103, 201-215. p. doi:10.1007/s10705-015-9732-3 (IF: 1.89)
- KONCZ, P., BESNYŐI, V., CSATHÓ, A. I., NAGY, J., SZERDAHELYI, T., TÓTH, Zs., PINTÉR, K., BALOGH, J., NAGY, Z., BARTHA, S. (2014): Effect of grazing and mowing on the microcoenological composition of a semi-arid grassland in Hungary. In: *Applied Ecology and Environmental Research*, 12, 563-575. (IF: 0.58)
- FÓTI, Sz., BALOGH, J., NAGY, Z., HERBST, M., PINTÉR, K., PÉLI, E., KONCZ, P., BARTHA, S. (2014): Soil moisture induced changes on fine-scale spatial pattern of soil respiration in a semi-arid sandy grassland. In: *Geoderma*, 213, 245-254. p. doi:10.1016/j.geoderma.2013.08.009 (IF: 2.34)

Peer-reviewed article

- PAPP, M., BALOGH, J., PINTÉR, K., FÓTI, Sz., KONCZ, P., MARIAN, P., DARENOVA, E., NAGY, Z. (2014) Homoki gyep CO_2-kibocsátásának vizsgálata új, nyílt rendszerű automata mérőeszközzel. In: *Agrokémia és talajtan*, 63, 329-340.

Conference proceedings (international):

- KONCZ, P., PINTÉR, K., HIDY, D., BALOGH, J., PAPP, M., FÓTI, Sz., HORTVÁTH, L., NAGY, Z. (2015): Farm scale greenhouse gas budget; grazing is smart. Climate Smart Agriculture, Global Science Conference, Montpellier, Le Corum, 16-18. March 2015. L3.1 Climate adaptation and mitigation solutions, Book of abstracts p. 193.
- KONCZ, P., BESNYŐI, V., CSATHÓ, A. I., NAGY, J., SZERDAHELYI, T., TÓTH, Zs., PINTÉR, K., BALOGH, J., NAGY, Z., BARTHA, S. (2014): Effect of grazing and mowing on

the microcoenological composition of a semi-arid grassland in Hungary. VIII. Carpathian Basin Biological Symposium – I. Sustainable development in the Carpathian Basin, Budapest, Book of Abstracts, 45-46. p.

- FÓTI, Sz., BALOGH, J., NAGY, Z., PINTÉR, K., PÉLI, E., KONCZ, P., BARTHA, S. (2011): Assay of optimal sample size of soil respiration in a dry sandy grassland. Carbon in a Changing world, Rome, 2011. October 23-26. Book of Abstracts, p. 63.

Conference proceedings (Hungarian):

- BALOGH, J, FÓTI, Sz., PINTÉR, K., CSERHALMI, D., PAPP, M., KONCZ, P., NAGY, Z. (2012): A talajok CO_2-kobocsátásank jelentősége a hazai gyepek szénforgalmában. *Kitaibelia*, 17, 9. p.
- NAGY., Z., BALOGH, J., CSERHALMI, D., KONCZ, P., PAPP, M., PINTÉR, K. (2012): Gyepek CO_2-forgalmának évek közötti változékonysága. *Kitaibelia*, 17, 44.
- BARTHA, S., FÓTI, Sz., BALOGH, J., PÉLI, E., MARGÓCZI, K., CSETE, S., BÍRÓ, M., CSATHÓ, A. I., CSERHALMI, D., KONCZ, P., NÉMETH, Z., PAPP, M., SUTYINSZKI, Zs., SZENTES, Sz., TÓTH, Zs., MOLNÁR, K., KARI, A., SZERDAHELYI, T., NAGY, Z. (2012): A mikrocönológiai szerkezet és a szünfiziológiai működés összefüggései homoki gyepekben. *Kitaibelia,* 17, 75.
- FÓTI, Sz., BALOGH, J., NAGY, Z., PINTÉR, K., PÉLI, E., KONCZ, P., BARTHA, S. (2012): A talajlégzés optimális mintaelemszámának és a mintavételi elrendezést befolyásoló tényezők. *Kitaibelia,* 17, 97.
- KONCZ, P., BALOGH, J., PINTÉR, K., NAGY, Z. (2012): Szén(-dioxid)-fluxus összehasonlítása kaszált és legelt füves ökoszisztémákban; az első év sikereinek summája. *Kitaibelia*, 17, 109.
- BALOGH, J., FÓTI, Sz., PINTÉR, K., PAPP, M., CSERHALMI, D., KONCZ, P., MARIAN, P., DARENOVA, E., NAGY, Z. (2012): Talajok CO_2 kibocsátásának mérése új, automatizált technikával. Magyar Ökológus Kongresszus, Keszthely, 2012. szeptember 5-7. Programfüzet, Előadások és poszterek összefoglalói, p. 28.
- KONCZ, P., BALOGH, J., PINTÉR, K., NAGY, Z. (2012): Kaszálás és legeltetés hatása a bugaci gyep szénmérlegére. Magyar Ökológus

Kongresszus, Keszthely, 2012. szeptember 5-7. Programfüzet, Előadások és poszterek összefoglalói, p. 61.

- FÓTI, Sz., BALOGH, J., NAGY, Z., PINTÉR, K., PÉLI, E, KONCZ, P., BARTHA, S. (2012): A talajlégzés finomléptékű términtázatának függése az abiotikus kényszerektől. Magyar Ökológus Kongresszus, Keszthely, 2012. szeptember 5-7. Programfüzet, Előadások és poszterek összefoglalói, p. 46.

Lecture, conference poster (international):

- BESNYŐI, V., VADÁSZ, Cs., MÁTÉ, A., ANDRÁZ, C., NINA, J., CSATHÓ, A. I. KELEMEN, A., KOMOLY, C., KONCZ, P., KUN, R., MOLNÁR, Zs., SZABÓ, G., ZIMMERMANN, Z., BARTHA, S. (2014): Diversity and fine-scale spatial organization of microhabitats in species rich natural grasslands. „II. Sustainable development in the Carpathian Basin" international conference, Budapest, Zoo and Botanical Garden, 11-12. December 2014. Poster.
- KONCZ, P (2014): In situ soil and biomass sampling for carbon and nitrogen measurements. Livestock and climate change training, Gödöllő, Szent István University, 29th October 2014. (practical training)
- KONCZ, P., BESNYŐI, V., CSATHÓ A. I., NAGY, J., SZERDAHELYI, T., TÓTH, Zs., PINTÉR, K., BALOGH, J., NAGY, Z., BARTHA, S. (2014): Effect of grazing and mowing on the microcoenological composition of a semi-arid grassland in Hungary. "VIII. Carpathian Basin Biological Symposium – I. Sustainable development in the Carpathian Basin" international conference, Budapest, 21-23. November 2013. (presentation)
- PINTÉR, K., HIDY, D., KONCZ, P., BALOGH, J., CSERHALMI, D., PAPP, M., NAGY, Z. (2013): Grazing vs. mowing: measuring and modelling the CO_2 balance of two differently managed grassland. 27-28 June 2013, 2th AnimalChange Meeting, Dublin. (poster)
- KONCZ, P., PINTÉR, K., BALOGH, J., CSERHALMI, D., PAPP, M., NAGY TIBORNÉ DÉRI, H., HIDY, D., NAGY, Z. (2013): Biomass duration of grazed and mowed grasslands. 27-28. June 2013, 2th AnimalChange Meeting, Dublin. (poster)

Lecture, conference poster (Hungarian, only first author):

- KONCZ, P., et al. (2015): Az ország első farm szintű üvegházgáz mérlege. 10. Magyar Ökológus Kongresszus, Veszprém, 2015. augusztus 12-14.
- KONCZ, P., et al. (2012): Kaszálás és legeltetés hatása a bugaci gyep szénmérlegére, 9. Magyar Ökológus Kongresszus, Keszthely, 2012. szeptember 5-7.
- KONCZ, P. (2012): Szén-dioxid fluxus összehasonlítása kaszált és legelt füves ökoszisztémákban. II. Szakkollégiumok konferenciája, Környezetvédelem Szekció. Szent István Egyetem, Kollégium B épület, 2012. május 7.