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Short-term Effects of Grazing Exclusion on Net Ecosystem CO_2 Exchange and Net Primary Production in a Pannonian Sandy Grassland

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Abstract

Using portable, non-destructive own developed chambers (d=60 cm) and infrared gas analyses, the *in situ* field investigation was performed to study the seasonal and inter-annual dynamics of the stand level CO_2-flux and production of sandy grassland that has been extensively grazed for decades. Furthermore, NEE measurements and biomass samples were used to identify the initial effects of grazing exclusion on CO_2 exchange, aboveground phytomass and potential plant productivity in years of significantly different precipitation levels. A considerable inter-annual variation in all of the studied parameters was found both in the non-grazed and grazed stands. As a result of the grazing exclusion the CO_2 uptake potential of the non-grazed stand increased by 13% compared to the grazed stand. It was more significant in the extreme dry year (220%), however, in wet year slightly lower average carbon sequestration was detected at the non-grazed stand (-13%), than that of the grazed area. Significant carbon sequestration potential was only detected during wet periods in both stands. The rate of CO_2 uptake was found to be nearly six times higher in the non-grazed stand in the wet year than in the previous extremely dry year. The drought in 2003 significantly reduced the CO_2 uptake of both stands, leading to lower annual net primary production and potential plant productivity. The annual net primary production dropped by almost 40% in the extremely dry year but then it rose by nearly two and a half times in the subsequent year with adequate rainfall.

Keywords: canopy chamber, CO_2 flux, *in situ*, management, phytomass

Abbrevations: AGP - Aboveground phytomass; ANOVA - Analysis of Variance; ANPP - Annual Net Primary Production; NEE - Net Ecosystem CO_2 Exchange; PPFD - Photosynthetically Active Photon Flux Density; PPP - Potential Plant Productivity

Introduction

On about a quarter of the world's continental areas grass ecosystems represent the potential natural vegetation, some 20% of which is made up of temperate grasslands found in each continent except Antarctica (IUCN, 1999). In Europe, some 37% of all cultivated areas can be classified as grasslands (Vleeshouwers and Verhagen, 2002). Although the effects of grazing exclusion have already been studied in numerous research projects, these focused mainly on the changes of plant functional types, species number or diversity. Reeder and Schuman (2002) studied the process of carbon accumulation in the soil/plant system (down to a soil depth of 60 cm) on mixed-grass prairie and shortgrass prairie excluded from grazing and put to various (intensive or extensive) levels of grazing. Both grazed stands of the mixed-grass prairie produced significantly higher carbon content measurements than the non-grazed stand. However, in the case of shortgrass prairie, only the soil under the intensively grazed stand contained higher carbon concentrations than the soil under the non-grazed stand. These findings have led to the conclusion that the exclusion of grazing inhibited soil C mobilization. Furthermore, the volume of dead plant materials increased in the non-grazed stand. Using a degraded sandy grassland in Northern China, Su *et al.* (2005) studied for 10 years the effects of grazing exclusion on the species richness and structure of the vegetation of C_3 dominance and on soil carbon/nitrogen content. According to the findings, grazing exclusion has increased the coverage of grassland and the volume of dead plant materials. There has also been a rise in the number and coverage of annual and perennial taxa. In addition, soil has shown higher organic carbon and total nitrogen content as well as higher levels of biological activity as a result of gas exchange (soil respiration). Using a similar area, Chen *et al.* (2005) compared on a longer time scale (22 years) the primary production of a non-grazed stand, a regenerating stand excluded from grazing and an intensively grazed stand, and - based on leaf-level measurements - the photosynthetic parameters of dominant and subordinate species. The abandonment of grazing has led to an increased presence of large perennial grass species, accounting for a high share (95.4%) of AGP in the non-grazed stand. According to a comparison of the physiological parameters of the dominant and subordinate taxa present in all three types, the parameters such as net photosynthesis, transpiration, WUE and stomatal conductance of the taxa in the non-grazed stand were considerably - often significantly - higher than those of the species of the intensively grazed stand and slightly higher than those of most taxa in the regenerating stand, while their intercellular CO_2 concentration was lower.

One of the main objectives of today's international ecosystem research is to measure the cycles of the major greenhouse gases, including CO_2 considered as a key gas, in different habitats. Being subject to various factors (e.g. climate, soil, vegetation), carbon dioxide exchange and its direction may show differences. Carbon dioxide - as one of the three greenhouse gases playing a role in the gas exchange of grasslands - is influenced mostly by soil and vegetation (Soussana *et al*., 2007). Recent local (Czóbel *et al*., 2008) and international (Soussana *et al*., 2007) research has confirmed that - similarly to the studied European grasslands but excluding the extremely dry years - the studied Pannonian grassland ecosystems, integrated with soil and atmosphere, act as sinks in the exchange of trace greenhouse gases.

Attached to the GreenGrass project (EU 5th R & D), our main objective was to study for three years (2002-2004) the effects of grazing exclusion on the carbon dioxide flux and on the production of stands. The non-destructive measurements of stand level CO_2-flux were made with the use of water clean and portable, own developed plexiglass chambers.

Materials and methods

Study site and manipulation

The dry sandy grassland selected as study site is located near Bugacpuszta within the Kiskunság National Park (46°41'N, 19°36'E, 130 m amsl). Of the large (10,000 ha) territory of the dry sandy grassland subject to extensive grazing with Hungarian grey cattle for decades and displaying only minor (<3 m) terrain differences, an area of some 6 ha, taking the shape of a semicircle and separated with electric fence, was selected to represent grazing exclusion. During the grazing season (from 1 May to 31 October), the average grazing rate varied between 0.53 and 0.75 LSU/ha in the control area - adjacent to the fenced off area - subject to extensive grazing with Hungarian grey cattle. According to the results of soil sample analysis, the sandy chernozem soil of the study site is slightly alkaline (pH 7.3-8.6) with a relatively high humus and nitrogen content due to fertilization. As to the three fractions under review, sand had the largest share (60%), while clay and silt had the same respective share (20% each).

The dry sandy grassland community (*Cynodonti-Festucetum pseudovinae*) consists mostly of continental, pontic and sub-Mediterranean floral elements. As to the secondary plant community - formed as a result of grazing on sandy areas - typical in the sandy regions of the Carpathian Basin, the more delicate sand steppe species have disappeared, while the thorny-spiny or poisonous species have spread to different extent at the same time (Borhidi, 2003).

Stand level CO_2 exchange measurements

Performed between spring 2002 and autumn 2004, the non-destructive measurements affected 5-5 constant vegetation patches of the fenced non-grazed area and the extensively grazed adjacent area of the dry sandy grassland. Portable LiCor-6200 (Lincoln, Nebrasca, USA) and CIRAS-2 (PP Systems, Hitchin, UK) infrared gas analysers and ventilated, water clean own developed plexiglass chambers (d=60 cm) were used for the stand level CO_2-flux measurements (Czóbel *et al*., 2005, 2008). The time interval of synphysiological measurements varied between 50 and 90 minutes for each patch and stand. Stand level CO_2-flux measurements were performed on at least 2 selected patches of each selected stand on the measuring days. More regular measurements were performed during the intensive growth period in spring. The infrared gas analysers measured and recorded, together with the carbon dioxide values, both air temperature and photosynthetically active photon flux density (PPFD).

Biomass analyses

Above-ground phytomass (AGP) was collected from the grazed and non-grazed area along a transsect two times a year i.e. in late spring (May 2002, May 2003, June 2004) and at the end of the growing season in autumn (early November). Phytomass was fully cut to ground level on 5 quadrates of 0.4 × 0.4 m each per stand. The aboveground phytomass of each quadrate was packed in separate paper bags. Placed in a desiccator, the collected samples were air-dried at 80°C for at least 48 hours (to constant weight) and then weighed using an analytical scales. The annual net primary production (ANPP) was calculated for the constant quadrates of the grazed and non-grazed stands by adding up the seasonal (spring, autumn) mean values of the annual biomass cuts (AGP).

For the calculation of potential primary production (PPP), the area (m^2) and time (week) based production growth of the aboveground biomass (dried) was used during the growing season. For such purpose, the growing season was deemed to start when the daily mean temperature reached 5°C and to end when the daily mean temperature exceeded 5°C. The dry summer period (normally July and

August) was ignored for the purpose of calculating the autumn PPP.

Statistical evaluation

The effects of grazing exclusion were tested using Repeated Measures Analyses of Variance (ANOVA). For post hoc test the Tukey Honestly Significant Difference (HSD) with corrections (adjusted p-values for the multiple tests) was used. Data were analyzed by the R-statistical program (R Development Core Team 2009). The graphs were plotted with SigmaPlot 8.0 software. The error bars are showing SD int he figures.

Results and discussion

Net ecosystem CO_2 exchange

The range of the measured NEE mean values (Fig. 1) was similar to the values of the grassland stands of similar physiognomy published in other studies (Czóbel *et al.*, 2008; Frank *et al.,* 2002; Hunt *et al.,* 2002). The sandy grassland of the Bugac site under review did not show any significant difference between the CO_2-flux values of the grazing excluded and extensively grazed stands during the study period from 2002 to 2004 (Fig. 1). However, time-factor variance analysis showed significant differences both for the grazing excluded (F=778.63; $p<0.001$) and for the grazed (control) (F=446.33; $p<0.001$) stands in the case of NEE, indicating interannual and seasonal variances in the intensity of CO_2 fixation. The CO_2-flux values measured with chambers for 2002 - i.e. the year of the three years under review that is most similar to the 50-year average amount and distribution of precipitation - clearly indicate the periods and intensity variances of the two growing periods that is typical of continental grasslands in the temperate zone. In spring 2002, during the intensive first growing cycle, the NEE mean values were the highest of all NEE values measured in this particular year. During the several months of the dry summer period, the physiological activity of the grassland decreased substantially, just like in the case of other grassland communities (Li *et al.,* 2005; Suyker *et al.,* 2003). Due to soil and root physiological activities, this period produced positive NEE values - similarly to the data measured on Mongolian steppes by Li *et al.* (2005) - as the low level of CO_2-fixation was unable to compensate for the CO_2 volume released during drought. In the second growing period in autumn, after the dry summer season, C-fixation is strong again but - partly as a result of a decrease in the chlorophyll content of the leaves during the growing season (shown also in the typical taxa of sandy grassland (Mészáros and Veres, 2006)) - its level is lower than that recorded during the spring period. The climatic anomalies had a major impact on the temporal dynamics of the CO_2-flux in the second and third year of the study period. The drought stressed grassland showed significantly lower CO_2 fixation ($p<0.005$) for both types in spring 2003 than one year before. On top of that, most NEE values of the grazed stand measured with chambers were positive, which means that the grassland was releasing CO_2 in the relevant measuring period instead of uptaking it as would be normal for this time of the year. Despite the higher than average volume of precipitation, the physiological activity of the grassland was only slightly improved in autumn 2003, and the measured NEE mean values were lower than those measured in autumn 2002. This is a clear indication of the magnitude and impact of the drought in 2003 on the sandy vegetation. In other words, the grassland failed to achieve full regeneration. The extremely dry weather conditions of 2003, which influenced many other regions of Europe as well (Baldocchi, 2005; Ciais *et al.*, 2005), had an impact not only on the physiological activity of grasslands but also on the traditional management practices in the Bugac region (six months of extensive grazing without interruption from early May until late October), causing a suspension of the grazing for two summer months (July and August) in 2003. The higher than average volume of precipitation in 2004 (Czóbel *et al.,* 2008) significantly ($p<0.005$) increased the carbon dioxide uptake of the grazing excluded and grazed stands both in spring and in autumn if compared with the drought stress values of 2003.

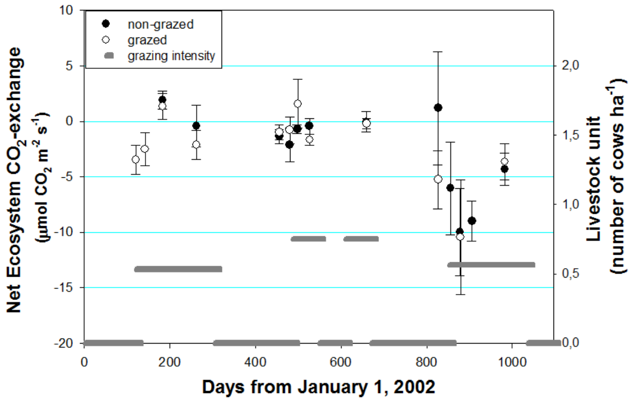

Fig. 1. Seasonal and year-to-year dynamics of NEE of grazing excluded and grazed (control) sandy grassland stands at Bugac site (Hungary) during 2002-2004 period

In the first year after the fence was installed the CO_2 uptake (release in July 2002) by the grazed grassland stand was lower in both measurements than in the case of the grazing excluded grassland stand, presumably as a result of lower PPFD. During the extremely dry spring of 2003 all three measurements showed higher CO_2 uptake for the non-grazed area coupled with similar or lower PPFD. This period saw strikingly high NEE differences in the grazed area, which may be the sign of stand instability caused by stress factors (joint effects of drought stress and grazing stress) and the result of the different CO_2 uptake and release activity of the stands under review. The NEE mean values showed the greatest differences at the time of the first measurement in the year with higher level of precipitation, which were caused by PPFD found significantly higher ($p<0.005$) for the grazed grassland stand.

When the PPFD ranges were identical, no significant differences emerged between the NEE values of the grazing excluded and grazed stands (Fig. 2). The mean values of the measurements showed only slight variances for all four comparable dates. As to CO_2 fixation, the mean values were slightly higher for the grazed stand in 2003 and for the grazing excluded stand in 2004 at the time of both measurements, while the PPFD ranges were identical. In autumn 2003 the grazing excluded stand, while in spring 2004 the grazed stand showed significantly higher variances and deviations than the other grass type.

Production studies

Following the installation of the fence (July, 2002), the volume of aboveground biomass collected on the grazing excluded area exceeded the AGP of the grazed (control) area in each year and growing season (Fig. 3). The main reason of such difference is that a part of the biomass on the extensively grazed area was consumed by the Hungarian grey cattle and that only a part of the grazed grass volume was returned to the area through the faeces of the grazing animals, increasing the concentration of organic materials and minerals. Grazing exclusion was not accompanied by the substantial short-term drop of the phytomass volume in Bugac (except for the extremely dry year of 2003), which is contrary to the findings of Virágh and Bartha (1996) obtained during the study of loess vegetation. When comparing the annual primary productions, one can clearly see the impact of the years of different weather conditions including, in particular, the amount and distribution of precipitation on AGP. In fact, AGP was lowest for both stands and cutting periods during the extremely dry year of 2003.

As a result of the considerable impact of grazing and grazing rate on biomass, the changes are indicated in a more objective manner by the data of the grazing excluded stand in Bugac. The annual net primary production of such grazing excluded stand amounted to almost 0.5 kg of dry matter per square meter (0.487 kg m^{-2}) in Bugac in 2002. Then it dropped by almost 40% in the extremely dry year of 2003 but it rose again by nearly two and a half times in the subsequent year of 2004. As far as North American prairie types are concerned, these values best approach - as confirmed by Archibold (1995) and Knapp *et al.* (1998) - the ANPP values and the interannual variability of tallgrass prairie. The seasonal and year-to-year dynamics of the AGP mean values of the grazed stand were identical with the dynamics of the grazing excluded stand. The year-to-year differences between the two sites are primarily the result of the grazing exclusion. A higher amount of annual precipitation led to higher ANPP in both Bugac grassland stands, confirming the applicability of the statement made by Huxman *et al.* (2004), based on the study results of various North American biomes, to Pannonian sandy grasslands. Biomass growth in 2004 was mainly due to the outstandingly high primary production in spring, which was reflected also in the CO_2-flux values. The 2003/2004 ANPP data recorded in Bugac showed significant differences ($p<0.005$) in both grassland stands.

The interannual variability seen in the potential productivity rate of the Bugac grassland stands (Fig. 4) is similar to the AGP differences (Fig. 3) and can be clearly correlated with the amount of precipitation in the relevant year. The analysis of the year-to-year variability of PPP reveals, for both grassland stands, that the spring differences (increase or decrease) were always greater than the AGP differences, while the autumn period brought smaller differences in all but one of the relevant cases (grazing excluded 2003 *vs*. 2004 autumn). Spring produced higher PPP than autumn in both grassland types and in all three years. The smallest difference between seasonal variances emerged in 2003 for grazing excluded stand (6%) and in 2002 for grazed stand (78%), while the greatest one was recorded in 2004 for both stands (grazing excluded stand: 370%, grazed stand: 500%).

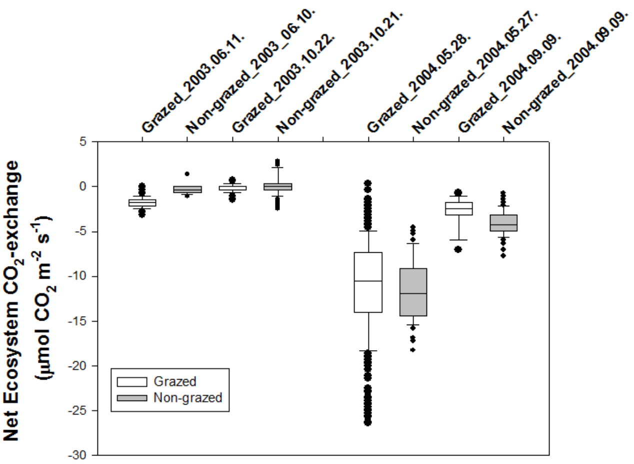

Fig. 2. The NEE values measured in similar PPFD range of grazing excluded and extensively grazed (control) sandy grassland stands at Bugac site (Hungary)

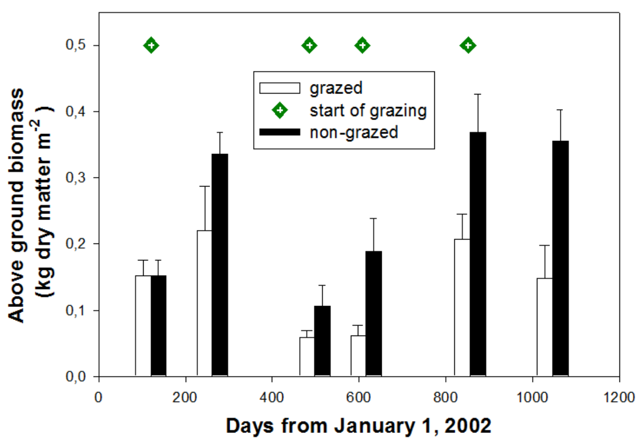

Fig. 3. Seasonal and year to year dynamic of AGP of grazing excluded and grazed (control) sandy grassland stands at Bugac site (Hungary) during 2002-2004 period

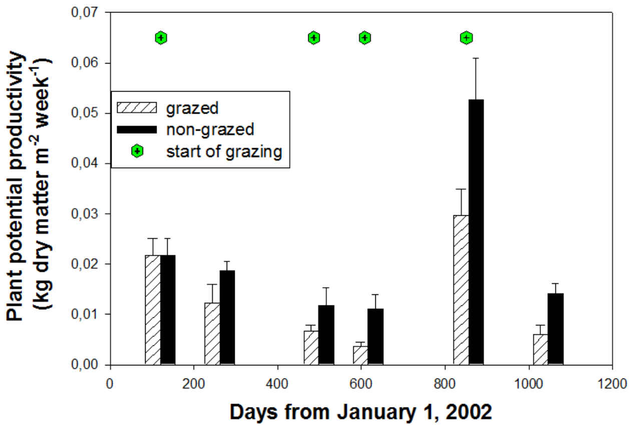

Fig. 4. Seasonal and year to year dynamic of PPP of grazing excluded and grazed (control) sandy grassland stands at Bugac site (Hungary) during 2002-2004 period

The result is surprising mostly in 2003 when the amount of precipitation increased in the second half of the growing season and it is also a sign for the different intensity of the two growing periods of Pannonian grasslands. Despite the fact that the significant primary production recorded in spring was exceeded in several years by the formation of AGP following the first cutting and lasting until the end of the growing season (Fig. 3), the intensity of the second growing period (i.e. PPP) fell behind the springtime value for both grassland types and in all years (Fig. 4). The reason is that production was delayed and took several months during the second growing period.

Conclusions

The summary of the impacts of grazing exclusion on NEE has led to the conclusion that, in the case of identical PPFD ranges, the measured CO_2-fluxes did not differ significantly between grazed stands and grazing exclusion stands. This contradicts the statement made by Chen *et al.* (2005) on the basis of leaf-level measurements, according to which most taxa of non-grazed grassland fenced off for regeneration purposes show a higher level of net photosynthesis than grazed grassland. A possible reason for the similar NEE values recorded in Bugac is that the higher biomass volume measured as a result of grazing exclusion was compensated by the higher amount of dead plant materials, the higher soil respiration intensity resulting from decomposition, the slower recycling of nutrients and the lack of fertilization in the non-grazed stand. The substantial CO_2 fixation of the stands recorded in 2004 after the extremely dry spring and summer of 2003 also indicates the quick regeneration potential of the grassland and its long-term adaptation to dry periods. Another reason for the higher NEE values recorded in the year with a higher amount of precipitation may have been the reduced grazing rate (0.75 LSU/ha in 2003 and 0.56 LSU/ha in 2004 during the grazing period). Both the seasonal and annual production data and the potential plant productivity were closely correlated with the NEE mean values of chamber measurements. According to our research findings, the CO_2 fixation of poorly structured dry sandy grassland is similar to that of loess grassland in the case of optimal water supply and phenological stage. 2003 was much drier than the average, while 2004 was much wetter than the average. The amount and distribution of precipitation in years of different weather conditions have significantly influenced grassland functions and production. Such amount and distribution differences have also affected the manipulation findings but, at the same time, permitted the study of the impacts of extreme weather conditions, which will presumably become more frequent due to global climate change, on the vegetation.

Acknowledgements

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