SZENT ISTVÁN UNIVERSITY

PH.D. SCHOOL OF ENVIRONMENTAL SCIENCES

Effect of different nitrogen nutrient supply methods on soil N_2O and CO_2 production and emission-in an undisturbed soil column and pot experiment model system.

Thesis of Ph.D. Dissertation

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Background of the work, and the aims

According to reports from the Intergovernmental Panel on Climate Change (IPCC), there is now an increasing trend in atmospheric concentrations of greenhouse gases, with anthropogenic emission of greenhouse gases currently at their highest time scale. Recent climate change has a wide-ranging impact on man-made as well as natural systems (IPCC 2014)

In addition to the environmental impact of industry and transport, the agricultural sector also contributes to emission. The plant nitrogen demand is not always meet the actual available forms of nitrogen in the soil that come from soil nitrogen mineralization and the nitrogen fertilizer additions which can lead to loss of soil nitrogen. Most of this is due to nitrate leaching, but gaseous loss as nitrogen (N_2) and nitrogen oxides (NO and N_2O) mainly through denitrification can also be significant. As a result from this process, the concentration of N_2O in the atmosphere can increase, which can decompose ozone into the NO molecule in the stratosphere, thus reducing the thickness of the ozone shield. Both CO_2 and N_2O can contribute to global climate change, which, in addition to the increase in the average annual temperature in Hungary, is also reflected in the more frequent occurrence of extreme weather events. Nitrogen cycles, which are biologically closely related to soil organic matter turnover, are sensitive to these effects. For all these reasons, the study of the role of different nitrogen supply methods in the production of CO_2 and N_2O in soil atmosphere can be considered an actual task.

My PhD research work was a part of a consortial project (OTKA K 72926; K 73326, K 73768) consisting a four-level experimental system, the changes of CO_2, N_2O, and NO_x concentrations in soil-atmosphere were studied under different nutrient and water supply conditions in field, undisturbed soil column, mesocosm (large pot experiment) and microcosm experimental systems. Within this framework, my own research objectives were:

Study of the accumulation and surface emission of CO_2 and N_2O in soils treated with different nutrient supply methods under the closest natural environmental conditions in the following experimental systems:

1. The mesocosm pot experiment was conducted in the greenhouse of the Georgikon Faculty of the Pannon University. The large vessels were filled with 50 kg of soil samples taken from plots of the longterm fertilisation field experiment. Gas traps were placed in the soil to collect soil-air samples. With the same water supply and different fertilization treatments, four maize indicator plants were grown until harvest in each pots. The evaluation of impact of treatments with different doses of farm yard manure (FYM), NPK fertiliser, the combined (FYM+NPK) application and maize straw manuring was my task.

2. From the soil at the edge area of the long-term fertilizer-experiment, undisturbed soil columns were prepared, which were placed in a sunken shaft at the MTA-TAKI experimental site in Őrbottyán. In this experimental system, I also studied the depth distribution of CO_2 and N_2O with gas traps placed at a depth of 20, 40, 60 cm during the growing season using the same fertiliser treatments and maize indicator plants. Surface CO_2 emissions were measured in surface-mounted collection chambers.

I was looking for the answer to the conditions under which we can presume on higher greenhouse gas emissions and whether the related changes in microbiological activity can be detected in the soil under different nutrient supply conditions and Hungarian conditions.

Materials and methods

Pot experiment

For the experimental part of the mesocosm of the research, the soil samples were derived from the long-term fertilization experiment of the Georgikon Faculty of the Pannon University. For each mesocosm, gas traps were placed in a gas-tight funnel with a volume of 0.9 dm3 at a depth of 20 cm from the surface. The ends of the funnels were connected with impermeable silicone tubes for CO_2 and N_2O gas. The free end of the silicone tube was closed with a wooden plug, gas sampling was done through the free-hanging silicone tube.

In the case of vessels, the water holding capacity was the same (WHC = 65%), which was provided by irrigation. The indoor air temperature of the greenhouse was continuously recorded, and the average daily mean temperature of the measurement and the day before was taken into account in the correlation study. Each of the mesocosms was planted with 4 stems of maize as indicator plant. The effect of 10 treatments was studied in 30 pots (thus one treatment was repeated in a total of 3 vessels). Each gas sample was taken in 3 replicates by an appropriate syringe. Each treatment was performed with different doses of farmyard manure (FYM), with NPK fertilizer equivalent in terms of active ingredient content of FYM treatments (combinations of 27% CAN, 18% superphosphate, 60% KCl), and the ploughing of straw from corn or winter wheat in the crop rotation was used. The treatment formulations are summarized in Table 1. Organic fertilization was received as part of the small-plot long-term experiment in the autumn of 2008 in the form of soil samples, the amount of manure indicated in the table. PK fertilizer was received by the soil samples at the same time, but N fertilizer was added every spring. In 2008, we also performed the experiment in three treatments with gas traps placed on the surface (treatments 1F, 4F, and 7F), and in 2010 in the same three treatments without maize (treatments 1A, 4A, and 7A). The mesocosm experiment started with sowing in all three years, which took place on 05.08 in 2008, 04.25 in 2009, and 04.30 in 2010.

Table 1. Treatments of the pot experiment system

Numbers of treatments	Applied treatments
1	Control, without treatment
2	35 t ha^{-1} farmyard manure (applied in 2 parts within 5 years)
3	70 t ha^{-1} farmyard manure (applied in 2 parts within 5 years)
4	105 t ha^{-1} farmyard manure (applied in 2 parts within 5 years)
5	1 unit (equivalent to 35 t ha^{-1}farmyard manure) NPK fertilizer
6	2 units (equivalent to 70 t ha^{-1}farmyard manure) NPK fertilizer
7	3 units (equivalent to 105 t ha^{-1}farmyard manure) NPK fertilizer
8	35 t ha^{-1} farmyard manure and fertilizer corresponding to 640 kg ha^{-1} N 360 kg ha^{-1} P_2O_5 and 660 kg ha^{-1} K_2O
9	1 unit fertilizer and fertilizer corresponding to 640 kg ha^{-1} N 360 kg ha^{-1} P_2O_5 and 660 kg ha^{-1} K_2O
10	1 unit fertilizer and fertilizer corresponding to 640 kg ha^{-1} N 360 kg ha^{-1} P_2O_5 and 660 kg ha^{-1} K_2O and the plowing of winter wheat straw

Undisturbed soil column experiment

Six undisturbed soil columns with different treatments were used in the study. The soil columns were placed outdoors in a sunken shaft at the Őrbottyán site of the MTA ATK Soil Research Institute. These undisturbed columns come from the uncultivated border area next to the Keszthely fertilization long-term experiments at the Pannon University. As their original structure was preserved during the preparation, the study of the dynamics of the three phases (solid, liquid and gas) could be carried out in an environment near-nature condition. The soil columns were 90 cm high and 40 cm in diameter. The columns were each provided with three holes at a depth of 20, 40, and 60 cm. These holes contained 320 mm long, 12 mm internal diameter and 1.2 mm wall thickness, CO_2 and N_2O permeable silicone pipes. The ends of the tubes were sealed with butyl rubber septum, and the samplings were from there. We chose gas-permeable silicone pipes because in this case the soil-air diffuses through the pipe wall even if the soil pore space is saturated with water (Szili-Kovács et al. 2009b). To avoid collapse of the silicone tubes, a 12 mm coil spring was placed within the silicone tubes as a spacer. Soil column experiments started on 05.26 in 2008, on 05.10 in 2009, on 04.27 in 2010, on 05.02 in 2011, and on 05.03 in 2012. The six soil columns received different treatments from 2009. Each treatment was set up in the same manner as the pot experimental system except for the sixth column. One column received only FYM manure, the other two columns received NPK fertilizer equivalent to FYM manure in terms of active ingredient content, and one column received additional NPK fertilizer in addition to the FYM. With the exception of one control column and one combination-treated soil column, 4 maize indicator plants (Zea mays L.) were planted in each column. Each treatment is shown in Table 2.

Table 2. Treatments of the undisturbed soil column

Number of column	Applied treatments	Treatments of mesocosmos
1	Control, without maize	1
3	Control, with maize	1
5	105 t ha^{-1} farmyard manure applied in 2 parts within 5 years	4
2	3 units of NPK fertilizer (equivalent to 105 t ha^{-1} farmyard manure) were applied in 2 parts within 5 year (without maize)	7
4	3 units of NPK fertilizer (equivalent to 105 t ha^{-1} farmyard manure) were applied in 2 parts within 5 years (with maize)	7
6	105 t ha^{-1} farmyard manure and 3 units of NPK fertilizer (equivalent to 105 t ha^{-1} farmyard manure) were applied in 2 parts within 5 years	-

For both experimental systems, the gas samples were transported in pre-vacuumed, septum-sealed sampling tubes. Gas samples from the surface of the soil columns were transported to the laboratory of the Institute of Soil Sciences and Agricultural Chemistryochemistry of the Centre of Agricultural Researchof of the Hungarian Academy of Sciences, and samples from the inside of the soil columns were delivered to the laboratory of Szent István University Department of Chemistry. The gas samples were analyzed at the Department of Chemistry of Szent István University with an HP 5890 Series II gas chromatograph (Kampfl et al. 2007, Fóti et al. 2017, Koncz et al. 2017) (equipped with a Porapak Q column with a TCD and ECD detector). At the Institute of Soil Science and Agrochemistry of the Agricultural Science Research Center of the Hungarian Academy of Sciences, using a FISONS GC8000 gas chromatograph (equipped with a Porapak Q column, methanizer and FID detector).

Additional measurements:

FDA (fluorescein diacetate) test where the essence is that colorless fluorescein diacetate can be hydrolyzed by enzymes in the soil. Hydrolysis yields a colored end product, fluorescein (Stubberfield & Shaw 1990), and it's concentration can be measured spectrophotometrically due to its bright yellow color (Swisher & Carrol 1980; Adam & Duncan 2001; Green et al. 2005). FDA testing was also performed in 3 replicates for both the soil-column and pot-experiment studies.

SIR (substrate-induced respiration) study, the essence is that substrate which is used in a wide range in the case of microorganisms (D-glucose liquide mixture) is added to the soil, in reply the soil microorganisms respond with increasing respiration (Anderson & Domsch 1978). It has been observed that the magnitude of the respiratory response is proportional to the microbial biomass (Szili-Kovács 2004). The amount of CO_2 generated was measured by using the previously mentioned FISONS GC8000 gas chromatograph.

Calculation of carbon budget

At the beginning of the series of experiment, soil organic carbon (SOC) was also measured in 2008. In 2012, at the end of the experiment, SOC was also measured. When estimating the amount of carbon remaining in the soil (rhizodeposition), we took into account 29% of the average carbon content of the mature corn plant, as suggested by Amos and Walters (2006). Cumulative soil surface CO_2-C efflux was calculated as suggested by Gong et al. (2012).

Statistical analysis

Statistical evaluation was performed with Statistical Product and Service Solutiond (SPSS) 9 and version 16 of the same program. The effects of different factors were determined by Tukey's posthoc test supplemented variance, and the closeness of correlations between variables was determined by Spearman's rank correlation.

Results and discussion

Pot experiment

The results of the mesocosm experiment are shown in Figures 1 and 2. Treatments are marked with “F” indicate gas sampling from a surface gas trap. Treatments are marked with “A” indicate a plant-free culture vessel.

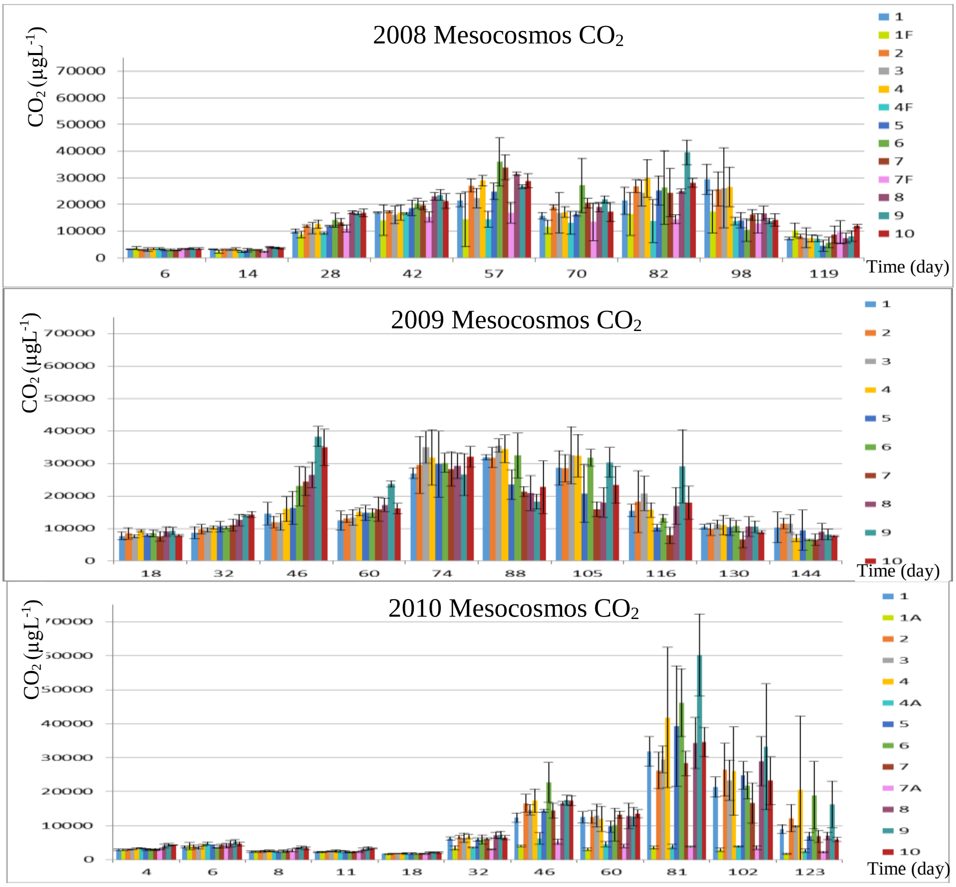

Figure 1.: CO_2 concentrations measured in the mesocosm experimental system 2008-2012. The designations of the treatments are shown in Table 1.

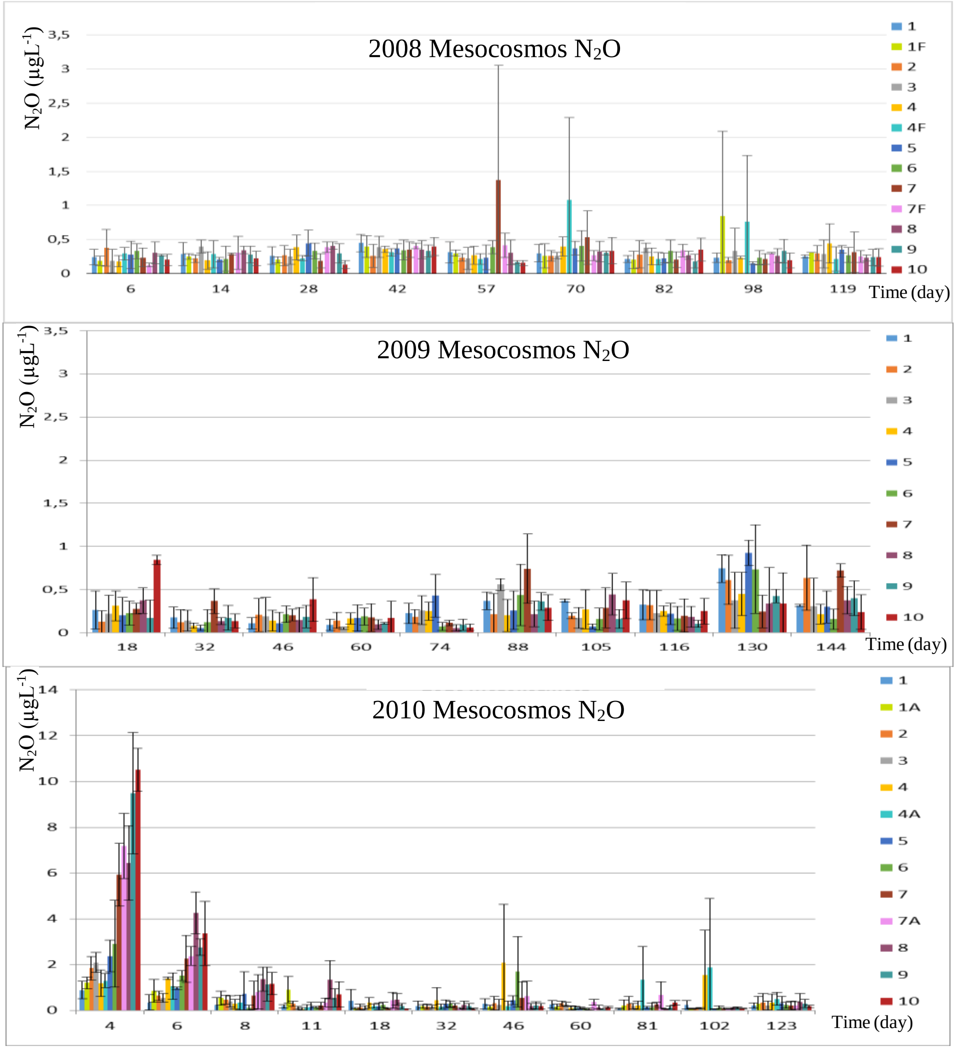

Figure 2.: N_2O concentrations measured in the mesocosm experimental system 2008-2012. The designations of the treatments are shown in Table 1.

The following effects on the formation of CO_2 and N_2O in the **pot experiment** were observed in all three years:

- In all cases the CO_2 production was significantly lower in plantless treatments than in the same plant treatments. N_2O production was also higher in the treatments with plants, than treatments without plants, however, these differences are not significant.
- The nutrient supply treatments in the majority of cases significantly increased CO_2 production in the order organic manure <mineral fertiliser <organic manure + mineral fertiliser. In 2008 and 2009, significantly higher N_2O production was observed at some times only in mineral (NPK) treatments. In 2010, when gas samples were taken on the initial (2nd, 4th, 6th) day of the experiment, in a short period of time the N_2O production was significantly higher than the control in the order of organic manure <mineral fertiliser <organic matter + mineral fertiliser. Chantigny et al. (2010), Lopez-Fernandez et al. (2007), and Pareja et al. (2019) reached similar results, but other studies, e.g. Velthof et

al. (2003) and Groenigen et al. (2004) concluded that, under appropriate conditions, organic manure results higher N_2O production.

- After the initial stagnation during the growing season, the CO_2 production started to increase significantly, and after reaching one or two maxima, the CO_2 concentration decreased to the initial level by the end of the growing season. A significant increase in N_2O production during the growing season was only measurable in the initial period of CO_2 stagnation (days 1–6). After that, there is no longer a trend in the change over time. This time shift has also been showed at the microcosm experimental level by Kampfl et al. (2007).
- The correlation analysis between the average greenhouse air temperatures and CO_2 production by Hoffman et al. (2013) confirmed a close significant relationship between the two variables ($r = 0.91$ $p <0.01$), so (with optimal water supply) the temperature greatly influenced the amount of CO2 generated.
- In most cases, the CO_2 concentration in the gas traps placed on the ground surface was significantly lower than the values measured in the samples taken from a depth of 20 cm. In contrast, N_2O production in gas traps placed on the ground surface is in most cases higher than the values measured in samples taken from a depth of 20 cm. However, this trend was not statistically confirmed.

Undisturbed soil column experiment

The results of the soil column experimental system are illustrated in Figures 3. 4. 5. 6 and 7. From 2009, each treatment is listed in Table 2.

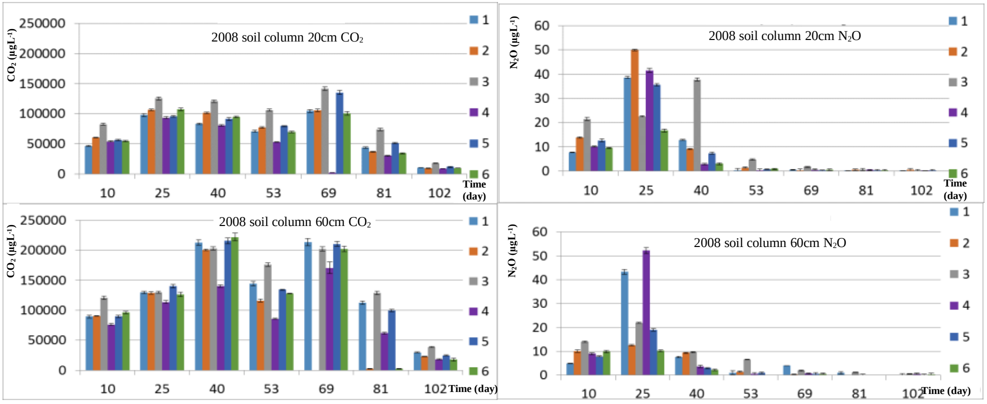

Figure 3.: Changes in CO_2 and N_2O concentration during the growing season at depths of 20 and 60 cm in 2008.

At the experimental level of the soil column, in the first year of the research in 2008 we did not apply different nutrient treatments, so the differences between the columns could be caused by their different soil moisture and individual structure (Szili-Kovács et al., 2009a). CO_2 concentration increased with depth in more than 85% of cases. Most measurements (more than 91.6%) differed significantly. However, the N_2O concentration was higher in the upper layer in the majority of cases, and did not differ significantly in the majority (74.36%) of the results in the middle and lower layers. A definite peak appeared in the N_2O concentration, the date of which - taking into account the meteorological data - coincided with the warm and rainy-rich period, therefore it is believed that the denitrification was induced by the anaerobic layers formed by these factors was responsible for the increased N_2O production (Szili-Kovács et al., 2009b).

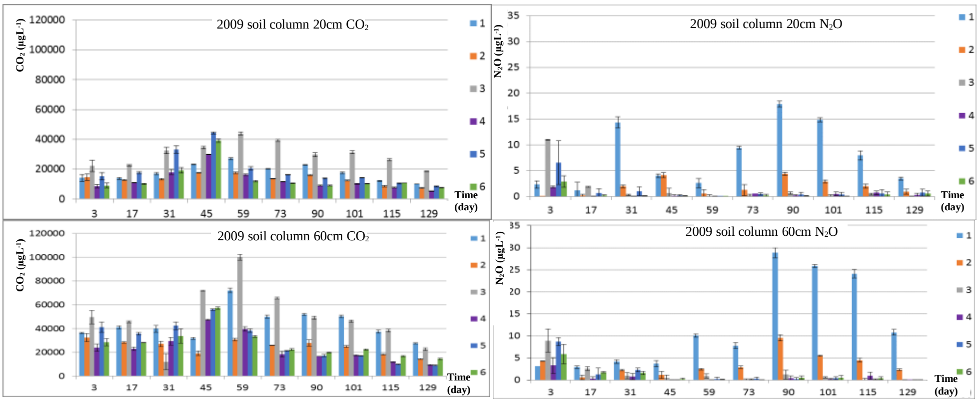

Figure 4.: Changes in CO_2 and N_2O concentration during the growing season at depths of 20 and 60 cm in 2009. The treatments are shown in Table 2

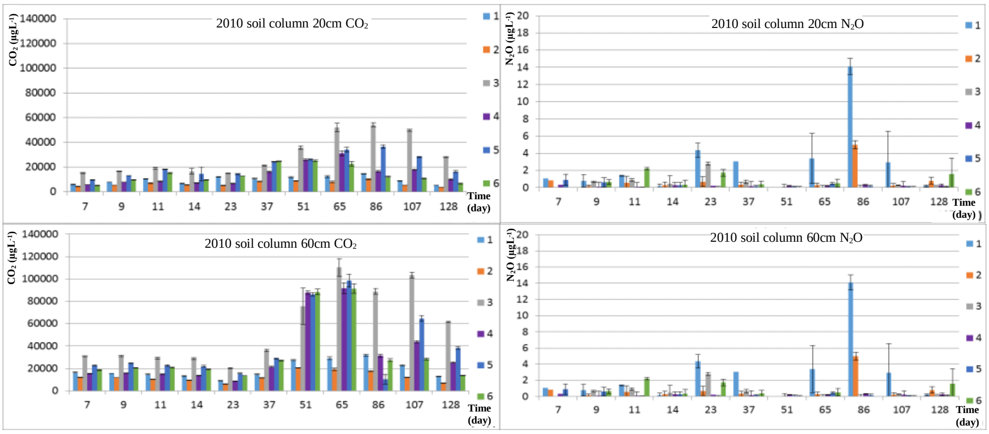

Figure 5.: Changes in CO_2 and N_2O concentration during the growing season at depths of 20 and 60 cm in 2010. The treatments are shown in Table 2.

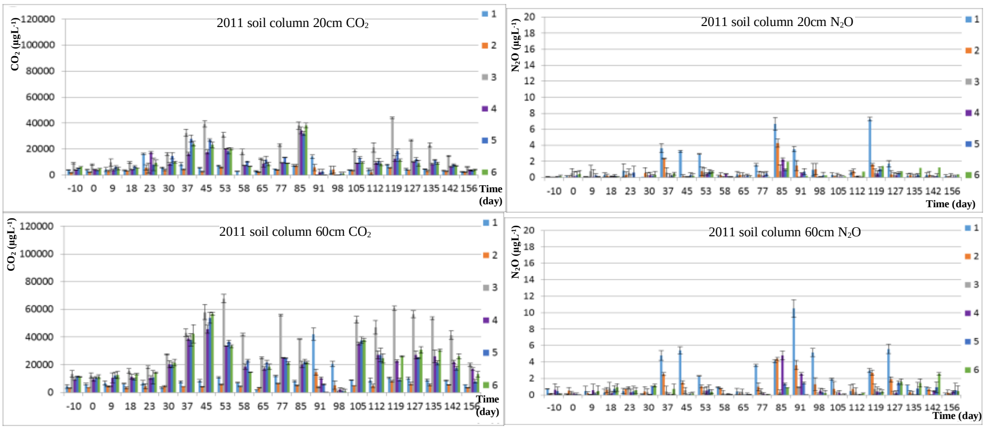

Figure 6.: Changes in CO_2 and N_2O concentration during the growing season at depths of 20 and 60 cm in 2011. The treatments are shown in Table 2.

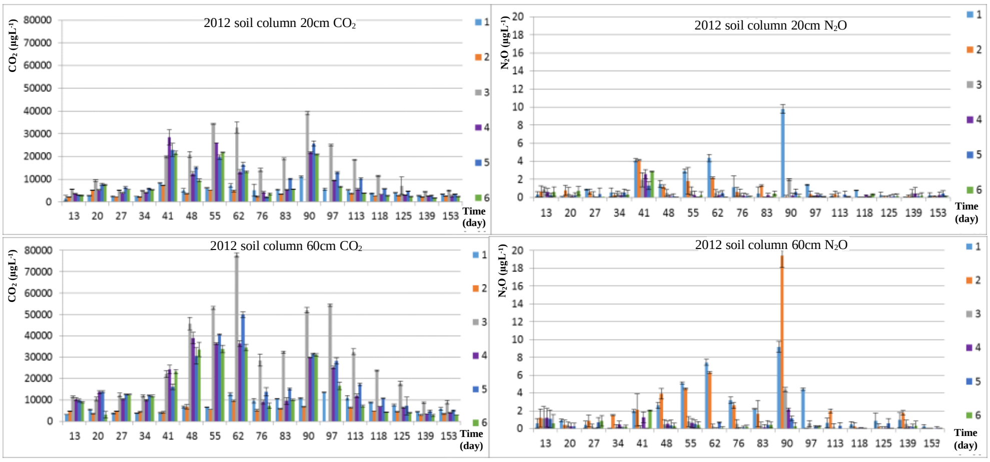

Figure 7.: Changes in CO_2 and N_2O concentration during the growing season at depths of 20 and 60 cm in 2011. The treatments are shown in Table 2

In the experiments of 2009, 2010, 2011, and 2012, the six soil columns had already received different treatments. In all four experimental years, it was observed that the level of CO_2 and N_2O concentration decreased in all columns in general in all columns compared to the first conditioning year (by more than 50%). This may have been due to the fact that root residues present in freshly prepared soil columns in 2008 may have contributed significantly to both CO_2 and N_2O formation in the first year.

In general, the following effects on the change and formation of CO_2 and N_2O concentrations in soil columns can be observed in all four years:

- As a result of the presence of plants, CO_2 production increased significantly almost throughout the growing season compared to the plant-free control, and a significant increase in N_2O production was observed in the initial period, followed by a significant decrease.
- In general, both CO_2 production and N_2O production of soil were significantly lower as a result of NPK treatment compared to the controll in plant-free soil columns.
- CO_2 production was reduced by NPK treatment in most cases even with the use of maize plants, but this decrease is less pronounced than in the case of treatments without plants. The effect of manure and NPK + manure treatment on CO_2 production was similar, however, the decrease was less pronounced compared to controls.

  N_2O production was also reduced by the effect of NPK treatment in most cases compared to plant control. In manure and NPK + manure treatments, a decreasing trend was also showed out in N_2O production for the most part, however, the assessment of this is not clear due to the high measurement uncertainty.
- During the growing season, the CO_2 concentration started to increase after the initial stagnation, and in most cases it decreased sharply towards the end of the growing season after reaching one or two peaks. Changes between successive sampling times were significant in most cases. There was no observable direction of the change in N_2O concentration over time during the growing season.
- According to the depth in columns, it could be clearly observed that the CO_2 concentration increased significantly from 20 to 40 cm, then up to 60 cm it was increased in lesser extent and not significantly in all cases. The same trend was showed out in N_2O production, although it was less clear due to greater measurement uncertainty which was caused by lesser concentration. Similar experiences were reported by Wang et al. (2013) and Nan et al. (2016).

The CO_2 gas production observed in the undisturbed soil column and in the pot experiment decreased to the initial level after the initial stagnation during the growing season, after reaching one or more peaks. In both cases, these changes showed a good correlation with the change in daily mean temperature (Szili-Kovács et al., 2009b; Hoffmann et al., 2013). The direction of the change in N_2O production over time in the soil columns did not show a clear trend, while a well-measurable increase in the pots was observed only until the 6th day after sowing in the stagnation period of the CO_2 concentration. Kampfl et al. (2007) confirmed this time shift in the dynamics of the formation of the two gases with their previous microcosm experiments.

In the undisturbed soil columns, the CO_2 concentration increased significantly from the surface to a depth of 40 cm, and no longer changed significantly between 40 and 60 cm. The same trend was observed for N_2O concentration, but less clearly due to greater measurement uncertainty. The CO_2 concentration also increased between the traps placed on the surface and at a depth of 20 cm in the pots, and the values measured here were on the order of magnitude of the values measured at a depth of 20 cm in the soil column. The change in depth of N_2O in the pots could not be justified.

In unnutrient treatments, the presence of plants in both soil column and pots increased CO_2 and N_2O production. The production of both gases decreased in the soil columns with nutrient replenishment treatments. When using farmyard manure and in the presence of a plant, this reduction is smaller than in the case of mineral fertilizer. In contrast, nutrient treatments clearly increased CO_2 production in pot experiment in the presence of plants, and less clearly also N_2O production. The increase was risen in the order of the yield-increasing effect of nutrient supply treatments (manure <mineral manure <manure + mineral manure) (Hoffmann et al., 2013). In summary, the conditions for soil-derived CO_2 and N_2O gas production and exit from the soil differ in undisturbed and cultivated soils, and this process is significantly influenced by the presence and metabolism of plants.

CO_2 emission from soil column

Emission data from the soil column experimental system are illustrated in Figure 8. Each treatment is listed in Table 2.

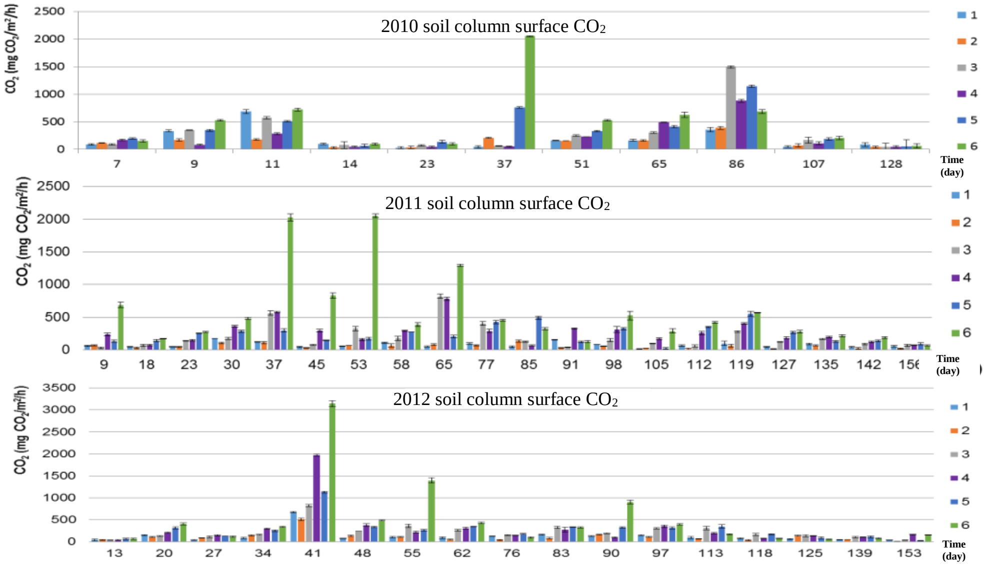

Figure 8.: CO_2 surface emissions from the soil column

CO_2 emissions from plantless soil columns were significantly lower than those from plant-containing columns. Soil columns treated with mineral fertilizers produced significantly lower

CO_2 emission values compared to soil columns without plants. In the soil columns containing with plant, the effect of mineral fertilizer treatment on CO_2 emissions was manifested in different ways over time. Farmyard manure treatment significantly increased the CO_2 emissions of the soil columns, and manure treatment supplemented with NPK fertilizer resulted in significantly, often exceptionally high values. Surface CO_2 emissions were significantly ($p < 0.05$) correlated with soil temperature ($r = 0.624$ in 2010; $r = 0.222$ in 2011; $r = 0.414$ in 2012), but a reliable correlation with soil moisture could not be detected, presumably because the humidity was relatively balanced as a result of precipitation and irrigation in case of all treatments.

Results of FDA and SIR examinations in soil column experiment system

The results of FDA and SIR testing from soil column samples are illustrated in Figures 9 and 10, with each treatment shown in Table 2.

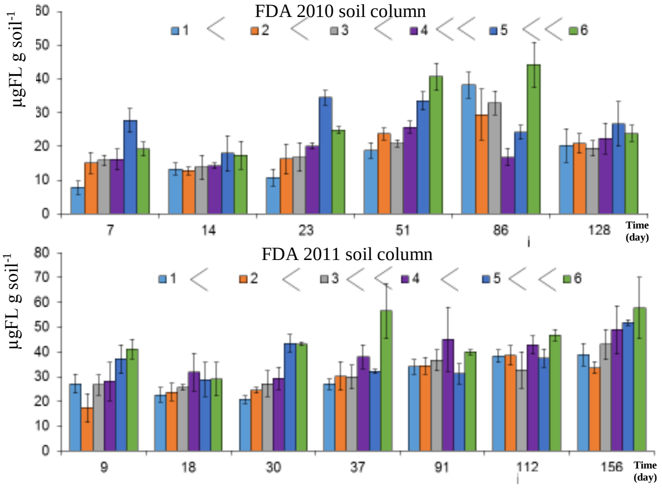

Figure 9.: FDA values for soil columns in 2010 and 2011.

FDA measurement results also showed significant differences in both sampling dates and treatments in 2010 and 2011 ($p < 0.001$). According to treatments, FDA values increased in the following order in 2010: 1 <2 <3 <4 << 5 << 6, while in 2011: 1 <2 <3 << 4 <5 << 6 (the significant difference is indicated by this sign: <<)

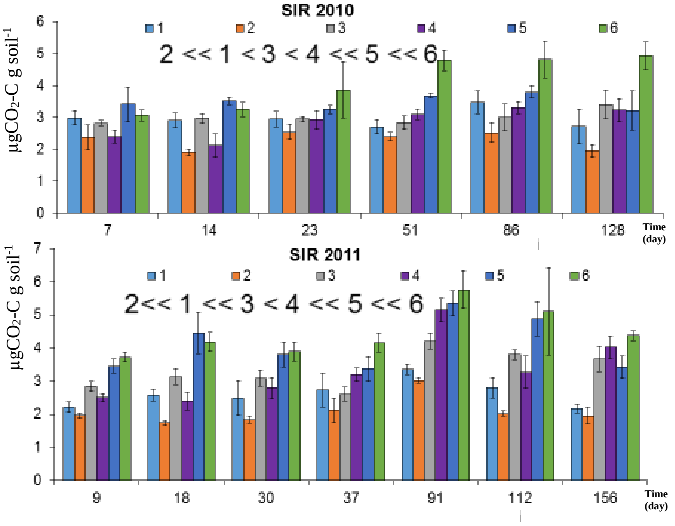

Figure 10.: SIR values for soil columns in 2010 and 2011.

According to treatment, SIR increased in the same order in 2010 and 2011, but there were differences in significant relationships between the two years. In 2010, there were significant differences between the following treatments (the significant difference ($p < 0.001$) is indicated by the << sign): 2 << 1 <3 <4 << 5 << 6, while in 2011: 2 << 1 << 3 <4 << 5 << 6. In 2010, there was a significant correlation between soil CO_2 emissions and substrate-induced respiration results measured from soil samples ($r = 0.397$ $p = 0.033$). There was also a significant correlation between CO_2 emission and fluorescein diacetate hydrolytic activity ($r = 0.492$ $p = 0.006$). In 2011, there was no significant correlation between substrate-induced respiration and CO_2 emission, but there was a significant correlation between fluorescein diacetate hydrolytic activity and CO_2 emission ($r = 0.62$ $p < 0.001$)..

Calculation of carbon budget of soil columns

The simplified carbon balance estimated from four years is shown in Table 3. For more information on carbon balance calculations, see Molnár et al. (2016).

Table 3. Estimated carbon balance during a four-year period (g C m^{-2}). The treatments are shown in Table 2.

Treatments	C input		C efflux	C balance
	from remaining parts of plants	farmyard manure		
1	0	0	229	negative
2	0	0	251	negative
3	337	0	625	negative
4	910	0	699	slight positive
5	666	2020	756	positive
6	1073	2020	1291	positive

Results of FDA examinations in pot experiment system

Microbial activity may have been greatly influenced by the amount of nutrient applied, as pointed out by Iovieno et al. (2009). Based on Figure 11, I illustrate the effect of nutrient treatment on microbial activity. Nutrient abundance may also have increased the rate of denitrification. Analysis of variance showed that the majority of samples (59%) showed a significant difference compared to the untreated control.

After performing the correlation analysis, I obtained a significant correlation between CO_2 production and enzyme activity ($r = 0.227$ $p < 0.001$).

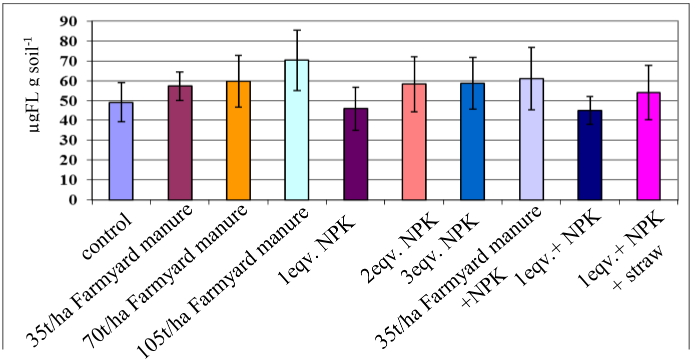

Figure 11.: Mean values of fluorescein concentrations in pot experiment system

New scientific results

My results show that CO_2 and N_2O production changes in a similar way during the growing season of maize plant, both at the pot and soil column experimental levels. Different fertilizer-treatment effects and plant growing influence can be detected. At the soil column test level, the depth effect was obvious for CO_2 but not for N_2O.

The following new scientific results can be formulated in my work.

1. At the mesocosm experimental level, CO_2 and N_2O concentrations varied in different treatments during the growing season of maize plant in a similar way and mostly according to a maximum curve. When sampling was sufficiently frequent, the maximum N_2O concentration precedes the maximum CO_2 in time. By the end of the growing season, both CO_2 and N_2O concentrations were declined and stabilized. Gas production was particularly affected by:
    - 1.1 Effect of nutrient. The available nutrient generally significantly increases CO_2 production in the order organic <NPK <organic + NPK fertilizer. This trend was also observed for N_2O, but within a few days of treatment, the gas concentration decreases significantly and stabilizes. Plenty of nutrient increased microbial activity, but FDA and CO_2 production showed only a weak positive significant correlation.
    - 1.2 Effect of temperature. A strong positive correlation is observed between CO_2 production and temperature.
    - 1.3 Plant Impact. Significantly higher CO_2 concentrations were observed in all cases in treatments containing the plant primarily due to the effects of root system, the rhizosphere and the phenophases of plant. A similar trend could be detected for N_2O, but the differences were not significant.
2. According to my results, CO_2 and N_2O production changes during the growing season in the soil columns in a similar way as in the pot experiment system. However, the microbiological correlations were more pronounced depending on the plant and the nutrient supply. CO_2 and N_2O production and CO_2 emissions were greatly affected:
    - 2.1 Effect of nutrient. Plenty of nutrient in the presence of the plant generally significantly increased surface CO_2 emissions. NPK treatment without plants resulted in significantly lower CO_2 emissions compared to controls without plants. Taking into account the surface CO_2 emissions, I showed that the nutrient effect resulted in a positive carbon balance in the order NPK <manure <(NPK + manure).
    - 2.2 Effect of temperature. A middle positive correlation is usually observed between CO_2 production and temperature.
    - 2.3 Plant Impact. CO_2 production was significantly increased compared to the plantless control which can also be explained by different root activity associated with plant phenophases. CO_2 emissions from plant-free soil columns are significantly lower than those from plant-containing columns. There was a significant increase in N_2O production in the initial short period, followed by a significant decrease.

Conclusion and suggestions

Reviewing the Hungarian and international literature, it can be stated that a number of research results can be obtained on soil greenhouse gas losses, which show a very diverse picture. Research of this kind points out that there are also significant differences between different plant feeding methods in terms of greenhouse gas emissions, soil carbon balance and other losses. Due to the rational use of resources, efforts should be made to select the optimal plant nutrition in all circumstances, minimizing negative impacts. For this reason, I consider it important to continue further detailed research on the correlations between gaseous losses and nutrient supply between Hungarian cultivation conditions. Because each influencing factor is only valid under certain circumstances, long-term experiments are needed to explore these influencing factors. From our own and international literature data, it can be seen that the microbiological effect is a significant influencing factor for soil-based gas losses. Based on my results, comparing the mesocosm pot and soil column experimental system, it can be concluded that the large soil column experimental system was more effective than the mesocosm pot system in monitoring background microbiological effects. Since the original structure of the soil is preserved in this experimental system, the structure-dependent soil properties are also preserved, including the microbiological community. As it was also pointed out by Ruamps et al. (2011), such an experimental system preserves the original structure of the soil, so the structure-dependent soil properties that affect soil biological processes are also preserved (Tóth et al. 2009).

If two or more experimental systems are used, it is fortunate that the systems use the same type of measuring instruments that measure the same factor, not only for the main test parameter, but for all environmental factors.

In the case of further studies of this kind, I consider it advisable to automate the measurements of various environmental factors, so that a more accurate picture of their effects could be obtained. The ideal solution is to use closed large-scale phytotron modeling, but the costs of this are orders of magnitude higher.

Publications related to the topic of the dissertation

1.1. Jurnal articles

1.1.1. With impact factor

Erik Molnár, Tibor Szili-Kovács, Ilona Villányi, Mónika Knáb, Ágnes Bálint, Krisztina Kristóf, György Heltai CO_2 efflux and microbial activities in undisturbed soil columns in different nitrogen management PLANT SOIL AND ENVIRONMENT 62:(9) pp. 402-407. (2016) IF 1.225

E. Nótás, **E. Molnár**, D. Ruzsa, Z. Csoma, K. Debreczeni, Gy. Heltai: Effect of N fertilizer forms and soil moisture levels on the N gaseous losses.APPLIED ECOLOGY AND ENVIRONMENTAL RESEARCH 12:(2) pp. 589-599. (2014) IF: 0.456

1.1.2 Non-IF (peer-reviewed) journal article

1.1.2.1 Non-IF (peer-reviewed) foreign language journal article

T. Szili-Kovács.; **E Molnár**, I Villányi.; Á Bálint.; Gy. Heltai.; A. Anton: Soil respiration and microbial activity of undisturbed soil columns under different nitrogen management. Acta microbiologica et immunologica hungarica 58: pp. 224-225. (2011)

Hoffmann, S.; Berecz, K.; Kristóf, K.; Szili-Kovács, T.; Simon, Sz.; **Molnár E**. (2010): Studies on the agronomic and environmental aspects of low to high level organic and mineral fertilization in long-term field and model pot experiments. Növénytermelés: 59, pp. 157-160.

1.1.2.2. Non-IF (peer-reviewed) Hungarian language journal article

Heltai Gy. Anton A. Hoffman S. Szili-Kovács T. Kampfl Gy. Kristóf K. **Molnár E**. Horváth M. Bálint Á.:Ásványi- és szervestrágyázás hatása a CO_2 és N_2O gázok képződésére a talajban AGROKÉMIA ÉS TALAJTAN 62:(1) pp. 143-162. (2013)

1.1.2.3. Other evaluable Hungarian language journal articles

1.2 Conference-proceedings

1.2.1 Conference publications in foreign languages

1.2.1.1 Full-length conference publications in foreign languages

1.2.1.2 Foreign language abstracts

T. Szili-kovács , **E. Molnár** I. Villányi, Á. Bálint, Gy. Heltai, A. Anton: Soil respiration and microbial activity of undisturbed soil columns under different nitrogen management. 16th international congress of the hungarian society for microbiology July 20-22, 2011, Budapest, ISSN 1217-8950 p. 225

E. Molnar, K. Kristof, M. Horvath, Gy. Heltai : Development of sampling and measurement techniques for detection of greenhouse gas emission of agricultural soils. XIV Hungarian - Italian Symposium on Spectrochemistry & 54 Annual Meeting of Hungarian Spectroscopists Sümeg, 2011.10.05-07. ISBN 9970-22-9 p. 50

Bálint Á., Hoffmann S., Berecz K., Kristóf K., Kampfl Gy., Nótás E., Horváth M., Gyarmati B., **Molnár E.**, Anton A., Szili-Kovács T., Heltai Gy.: Influence of N-fertilization methods on NOx and CO_2 production on model experiments and on grain yield in field experiments., Proceedings of the 17th Nitrogen Workshop – Innovations for sustainable use of nitrogen resources. 26-29 June 2012, Wexford, Ireland. pp. 126-127. ISBN: 1-84170-588-8., 2012

Hoffmann S., Lepossa A., Bálint Á., **Molnár E.**, Heltai, G.: Comparative study of some agronomic and environmental effects of mineral and organic fertilization with maize (Zea mays L.) in field and model pot experiments., 19. ISTRO konferencia, (Montevideo) Abstract, 2012

1.2.2 Conference publications in hungarian language

1.2.2.1 Full-length conference publications in Hungarian language

1.2.2.2. Hungarian language abstracts

Kristóf, K.; **Molnár, E.;** Heltai, Gy.; Bálint, Á.: Mezőgazdasági talaj CO_2, NO, N_2O gázemissziójának mérése mikrokozmosz kísérleti rendszerben, IX Környezetanalitikai Konferencia, 2009. október 08. Sopron, Hungary, ISBN 9789639970007 p. 40

Molnár, E: Ásványi és szerves trágyázás hatása a talaj CO_2 és N_2O gázemissziójára mezokozmosz kísérleti rendszerben, Tudományos Diákköri Konferencia, Szent István Egyetem, 2009. november 25., SZIE Gödöllő, Hungary, ISBN 9789632691428 p. 241

Molnár, E: Ásványi és szerves trágyázás hatása a talaj CO_2 és N_2O gázemissziójára mezokozmosz kísérleti rendszerben, XII. Országos Felsőoktatási Környezettudományi Diákkonferencia. 2010. április 6-7., Nyugat-magyarországi Egyetemi Kiadó Sopron, Hungary, ISBN 9789639883505 p. 83

Kristóf, K.; **Molnár, E.**; Heltai, Gy.: Mikrokozmosz technika alkalmazása a talaj üvegházhatású, nitrogéntartalmú gázemissziójának mérésében LIII. Magyar Spektrokémiai vándorgyűlés, 2010. 06.30-07.02., Hajdúszoboszló, ISBN 9789639970052 p 70

Szili-Kovács T. **Molnár E**. Villányi I. Knáb M. Bálint Á. Heltai Gy. Anton A.: CO_2 kibocsátás és mikrobiális aktivitás bolygatatlan talajoszlopban ásványi és istállótrágya kezelések hatására kukorica jelzőnövénnyel. Debrecen, 2012.11.23 Budapest: MTA ATK Talajtani és Agrokémiai Intézet, 2012. pp. 61-64. (ISBN:978-963-89041-6-4)

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Molnár E.; Kristóf K.; Heltai Gy.; Szili-Kovács T.: Különböző trágyázási hatások a N_2O, CO_2 produkcióra és a CO_2 emisszióra bolygatatlan talajoszolop kísérleti rendszerben. Második Környezetkémiai Szimpózium, Dobogókő, 2013. október 10-11 p39
http://mta.hu/data/cikk/11/39/11/cikk_113911/2KKSZKiadvany2vegso.pdf

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