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MONITORING OF GREENHOUSE GAS EMISSIONS DURING MAIZE CULTIVATION, WITH PARTICULAR REGARD TO CARBON DIOXIDE EMISSIONS

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1. INTRODUCTION AND OBJECTIVES

The integration of sustainability aspects into agricultural production is one of the key tasks of Hungarian agricultural sector, awaiting a solution. To achieve these goals, the first step is to develop methodologies, technologies, and measurement procedures capable of quantifying the ecological footprint of agricultural production.

The monitoring of greenhouse gas (GHG) emissions can be investigated along multidisciplinary principles in agriculture, and and my research topic is therefore of great importance.. The objectives of my dissertation are the following:

- The renewal of the sustainability assessment of maize (*Zea mays* L.) in Hungary to determine the most accurate and adequate GHG emissions related to production.
- Development of a new sensor system that can be used to monitor environmental factors in field conditions.
- Setting up a variable rate fertilisation and seeding experiment to map their effect on carbon dioxide (CO_2) emissions of soil.
- Setting up a laboratory experiment to explore the magnitude of CO_2 emissions from different cultivated soils and the role of the influencing factors behind the emissions.
- The development of models based on field experiment to interpret the spatial and temporal variability of each factor.

2. MATERIALS AND METHODS

The experiments included in the dissertation were carried out in laboratory and field conditions. A newly developed monitoring sensor

system and model assessment was used to determine the greenhouse gases produced during the cultivation of maize.

The field experiment site belongs to the administrative area of the town of Polgárdi. Polgárdi is located on the Transdanubia, in the immense landscape of the Danube-Tisza basin, in the central landscape of the Mezőföld, in the small landscape group between the Danube and Sárvíz, in the Sárrét small landscape, 17 km from Lake Balaton and 33 km from Lake Velence. The area covers 366 km^2. The location of the experimental fields is between Polgárdi and Füle, next to the side road No. 7205, at an average altitude of 170 mBf at the following geographical coordinates (i) field number T1: É47.061544, K18.271158, (ii) field number T2: É47.058827, K18.262146. The genetic soil type of the experimental fields is chernozem soil; the typical soil fraction is silty loam.

The measurement system is based on the Arduino Mega2056 platform. A soil moisture, soil temperature, air temperature, humidity, air pressure and carbon dioxide concentration measurement sensor were connected to the Arduino Mega2056 platform after checking its measurement accuracy. The field experiment was set up as a large-plot field experiment adapted to the conditions set by the farmer. The duration of the experiment took two years (2020–2021). Variable rate seedings (76-72-68 thousand pieces/ha) and nitrogen application (625-498-418 kg/ha) were set, following the topographical heterogeneity of the fields. During the experiment, the role of treatments, environmental factors, ploughing, and microbial and root respiration was examined in carbon dioxide emissions. The carbon dioxide emission of agricultural

soils and the factors influencing the emission was monitored once a month over the growing seasons.

The laboratory experiment was carried out in the laboratory at the Technical Base of the István Széchenyi University, Faculty of Agriculture and Food Science, Department of Biological Systems and Food Technology [47°53'28.6"N, 17°16'15.9"E]. As the first step of the experiment, undisturbed soil column samples were taken from the 0-25 soil depth in August and October 2020 and March and August 2021. The experiment designed made it possible to monitor the carbon dioxide emissions of the soil columns from the no-tillage system (T2) and the tillage system (T1) depending on soil compaction, total organic carbon content and changes in moisture content at different times of the growing season. The soil column samples were taken from three different altitudes of the experimental field from the management zones applied average treatment.

A model calculation was performed for the sustainability study of maize cultivation. The analysis is based on the methodology given in point C of Appendix V of the REDII (Renewable Energy Directive II). To determine the greenhouse gas emissions related to the cultivation of maize, it is necessary to have yield data, related inputs and the emission coefficients, factors and rates. Emission coefficients, factors and rates are from Edwards et al. (2017), published by the Joint Research Center (JRC) of the European Commission. The regional yields and expenditures for the years 2014-2018, as well as the use of input materials, are weighted averages of data taken from the database of the Farm Accountancy Data Network (FADN) operated by the Institute of Agricultural Economics (AKI) and the statistical database of the Food

and Agriculture Organization of the United Nations (FAO). For the weighting of data, the results of the 2013 Farm Structure Survey (FSS) and the 2016 Agricultural Census (AC) of the Central Statistical Office (HCSO) were used.

To evaluate the experiments, complex statistical and modelling methods were applied, such as correlation analysis, principal component analysis, multiple linear and non-linear regression analyses, one-way and two-way analysis of variance with Tukey's HSD post hoc test, and two-sample Student's t-test.

3. RESULTS

In situ experiments investigated the effect of the different treatments (variable-rate fertilisation and seeding) on carbon dioxide emissions in different tillage systems (tillage and no-tillage). The role of soil structure in carbon dioxide emissions in ex situ experiments was investigated. Undisturbed soil column samples were taken at different times of the growing seasons in 2020 and 2021, and various measurements were performed on them.

Based on the model calculation supplemented with the new data processing methodology, the greenhouse gas emissions of maize cultivation at the regional level are lower than the limit value included in the Renewable Energy Directive (Renewable Energy Directive, REDII) adopted in 2018. The new data processing methodology ensures the sustainability certification of maize, in which the agricultural inputs consumption (fertilizers, fuels etc.) are adjusted to the official regional use.

The carbon dioxide emissions of the no-tillage system's undisturbed soil columns were higher than those derived from the conventional tillage

system in the laboratory experiment. Still, its level changed periodically during the growing season. Based on this finding, I found that more favourable conditions for microbiological activity are developing in no-tillage systems. At the same time, different environmental factors are behind the carbon dioxide emissions in the different tillage systems in the average (2020) and drought (2021) weather conditions.

It was found in the field experiment that the CO_2 emissions of the zones sown with the minimum number of seeds and treated with the minimum nitrogen dose are higher than zones treated with the maximum number of seeds and maximum nitrogen dose. Furthermore, the differences in carbon dioxide emissions caused by the difference in topography varied according to previous observations in the period of average weather conditions. However, a different trend was observed in different slope in drought weather conditions. My results also highlighted that in the year with average weather conditions, the carbon dioxide emissions of the conventional tillage system were higher. In comparison, while in the drought year, the no-tillage system had higher carbon dioxide emissions. Overall, it can be concluded that the large-scale differences in climatic factors observed in the experimental years affected the carbon dioxide emissions from the soil in space and time.

Examining the role of certain environmental and plant factors in carbon dioxide emissions, I observed that there are different factors behind soil carbon dioxide emissions in different phases of the vegetation period. While the role of root respiration can be clearly defined in the summer months (June, July, and August), the interaction of different environmental factors is behind the carbon dioxide emissions from the soil in the spring and autumn months.

4. CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the experiments, the following conclusions and suggestions were drawn:

- The measuring system developed for monitoring environmental factors - after checking the accuracy of the measurements of the built-in sensors - is suitable for determining the carbon dioxide emissions, moisture content and the temperature of the soil, as well as the air temperature, air humidity and air pressure.
- Based on the model calculations, it was found that the sustainability certification of maize cultivation is ensured by applying the new data processing methodology. No more than a 5-15 percent increase in the specific amount of GHG produced during the production of 1 ton of maize was stated with the application of the new methodology compared to the data published by NAIK MGI in 2011 on the sustainability of maize. Moreover, the differences observed in the regional agricultural input usage were adjusted in the new data processing methodology (this resulted in a 15-30% increase in the use of agricultural input usage (Sárvári, 2005; Sárvári et al., 2006; NAIK MGI 2004 - 2008)). Due to the new methodology, the consumption of agricultural inputs calculated from FADN is adjusted to the regional consumption level found in official data publications (KSH, 2013).
- The periodic change in the carbon dioxide emissions of soil column samples from different cultivated areas during the vegetation period was detected. The measurement results proved

that the differences in soil structure caused by cultivation and the combined change of different environmental factors affect the carbon dioxide emissions in tillage and no-tillage systems. Several research results have been available since the 1990s to examine the factors behind carbon dioxide emissions. At the international and Hungarian levels, Heneghan et al. (1999) and Birkás and Gyuricza (2004) possessed the most decisive results, who observed that microbial activity and plant growth affect soil carbon dioxide emissions, which can be increased or decreased by changes in environmental factors. My results coincide with Kovács (2014), Chen et al. (2017), Ray et al. (2020) and Mohammed et al. (2021), who drew attention to the role of temperature and soil moisture as the factor most influencing soil carbon dioxide emissions. The periodic change of the factors behind soil carbon dioxide emissions was observed by Reicosky et al. (2008), and later Mohammed et al. (2021) and Kulmány et al. (2022a) were the first to draw attention to the complex processes behind soil carbon dioxide emissions in different tillage systems.

- The role of variable rate seed and nitrogen fertilizer application on soil carbon dioxide emissions was investigated. In general, the measurement results proved that the CO_2 emissions of the zones sown with a minimum number of seeds and treated with a minimum dose of nitrogen are higher than zones treated with a maximum number of seeds and maximum dose of nitrogen. However, the climatic differences experienced during the experimental years strongly influenced the results, thereby a

significant volatility in the results was observed. My findings coincide with the results found in the literature. Al Kaisi et al. (2008), Wilson and Al-Kaisi (2008), and Ramirez et al. (2010) also observed a reductive effect in the carbon dioxide emissions of soils when different types and doses of nitrogen fertilizers were used. At the same time, any examples were not found in the literature on differences in carbon dioxide emissions that occur as a combined effect of the different weather conditions and nitrogen fertilization. *To support the results, I recommend repeating the experiment in the future with the same design but with a modified measurement methodology. To achieve this goal, I plan to continue the field experiment in Polgárdi.*

- The differences in carbon dioxide emissions were confirmed caused by the difference in topography (catena effect) in the period of average weather conditions. In contrast, in the drought periods, a different trend was observed at slope parts. My results coincide with the findings of Kirkels et al. (2014), Hu et al. (2016), Wang et al. (2017) and Nitsche et al. (2017) in average weather conditions, who found that slope gradient, water runoff, and erosion can affect the spatial distribution of soil moisture and nutrient content, as well as the growth of vegetation, thus indirectly the soil carbon dioxide emissions too. On the other hand, lower carbon dioxide emissions along catena were not observed in the drought weather conditions, which draws attention to the ability of no-tillage systems to retain moisture, thus influencing carbon dioxide emissions (Du et al., 2020). *To prove the differences in soil carbon dioxide emissions caused by*

the slope effect, setting up further experiments was recommended, the first step of which I set up long-term field measurements in Dióskál.

- Based on the results of my research, it was stated that the tillage system had higher soil carbon dioxide emissions in average weather conditions, while in a drought season, the no-tillage system had higher emissions. My results from the comparison of soil carbon dioxide emissions of different tillage systems coincide with the findings of Zsembeli et al. (2005), Kovács et al. (2008), Al-Kaisi and Yin (2005), Lu et al. (2015) and Alhassan et al. (2021). They observed higher carbon dioxide emissions from the tillage system in their experiments. However, the results of Oorts et al. (2007), Cheng-Fang et al. (2012) and Kulmány et al., 2022a point out that the soil carbon dioxide emissions of the no-tillage systems can be higher than the tillage systems in the average weather conditions, due to the higher soil moisture content and the resulting higher microbiological and plant activity. These findings are in line with my findings. *I recommend conducting further experiments to explore the variability between the seasonal effect and the carbon dioxide emissions of tillage systems. As a first step, field measurements were set up in Mosonmagyaróvár from 2022 to investigate the combined effect of season and tillage on soil carbon dioxide emissions.*
- Based on the results of field measurements, I concluded that there are different factors behind soil respiration in different phases of the vegetation period. While the role of root respiration can be clearly defined in the summer months (June, July, and August),

environmental factors and their combined effects are behind the carbon dioxide emissions of soil in the spring and autumn months. There are few examples in the literature of separating carbon dioxide emissions from the root and microbial respiration. According to the results of Kovács (2014), the rate of carbon dioxide emissions resulting from root respiration can reach 70-90 percent in certain phases of the vegetation period. At the same time, I did not find complex examples of research observing the seasonal dynamics of root respiration during the literature review.

5. NEW SCIENTIFIC RESULTS (THESIS)

1. The data processing for the input data required for modelling the greenhouse gas emissions generated during the cultivation of maize (*Zea mays* L.) in the IPCC methodology was updated. The expert estimates and base values (Tier 1) were removed from the method of agricultural input calculation, and it was replaced by my calculations based on the data processing method (Tier 3). The obtained results are consistent with official agricultural input consumption. The new GHG emissions values provided by the latest data processing methodology better model the ecological footprint of maize cultivation. Since 2021, the new method has formed the basis of the sustainability calculations of commodity crops (maize, wheat, barley, sunflower, rapeseed, and soy) of the Agricultural Economics Institute (AKI).

2. After checking the measurement accuracy of sensors, it was proved that the newly developed sensor system is suitable for soil and air temperature, and the carbon dioxide concentration of air and soil

moisture content to be determined. Thus, the developed sensor system can be used to monitor soil carbon dioxide emissions and environmental factors in field conditions.

3. During laboratory measurements, it was verified that the carbon dioxide emission of the undisturbed soil columns from the no-tillage system is higher than the emissions of the soil columns from the tillage system in the vegetation periods of 2020 and 2021. This statement was only proved in the middle of the vegetation periods (August), where a significant difference was observed at a significance level of $p \leq 0.05$. The higher carbon dioxide emissions from the no-tillage system result from better soil life, higher soil moisture and organic matter content, more favourable soil heat balance, more favourable soil structure and the interaction of these factors.

4. It has been statistically proven that on the chernozem genetic soil type in the Sárrét region, the role of root respiration of maize determines the carbon dioxide emissions from the soil significantly at the $p \leq 0.05$ significance level in the summer months (June, July and August). By contrast, in the so-called spring and autumn months (in March, April, May and September), environmental factors such as soil and air temperature, soil moisture, air pressure, and humidity significantly determine the carbon dioxide emissions from the soil at the $p \leq 0.05$ significance level.

6. PUBLICATIONS

6.1. PUBLICATIONS RELATED TO THE SUBJECT OF DISSERTATION

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6.2. OTHER PUBLICATIONS

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