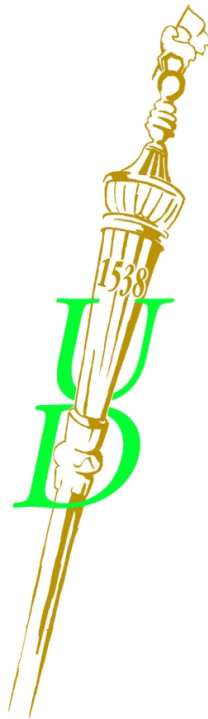


Thesis of PhD Dissertation

**EXAMINATION OF CARBON-DIOXIDE EMISSION OF AGRICULTURAL
LANDS IN KARCAG REGION**

Györgyi Kovács

Supervisor: Dr. habil. József Zsembeli



UNIVERSITY OF DEBRECEN

**Kerpely Kálmán Doctoral School of Crop Production, Horticulture and Regional
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1. BACKGROUND AND AIMS OF THE DISSERTATION

Soil is the base and place of agricultural production. The physical, chemical and biological status of the soil is determined or influenced by human activities and natural factors. Effects of different tillage systems, methods, agro-technology and agro-technical practices on soil properties are diverse. The environmental concerns are coming to the front, the analysis of anthropogenic impacts on the environment has become commonplace as well as the preliminary assessment of the impacts (preventive measures). The main tasks of the utilization of agricultural soil are to preserve the fertility and soil quality, to prevent the biological, physical and chemical deterioration in addition to competitive crop production.

Atmospheric concentrations of greenhouse gases has increased at an accelerating rate in the last two centuries (HOUGHTON, 1997; DALAL et al., 2003), and the increasing emissions of CO₂ gas can be held liable for more than the half of the estimated growth of the greenhouse effect (ZÁGONI, 2004). In agriculture, CO₂ emissions can originate from the decrease of soil organic matter, but the crop production may contribute to the CO₂ fixation in the soil (GOUDRIAAN - UNSWORTH, 1990; FOGARASSY et al., 2008).

The process of CO₂ circulation between the soil and the atmosphere is very changeable in time and space, getting more information on it could contribute to the correct assessment of environmental loads originating from different agricultural habitats and of the microbiological activity corresponding to the actual soil state. Measuring the CO₂ emission from the soil can provide several valuable information regarding soil utilisation too. Before every agricultural cultivation intervention, the knowledge of the cultivated area is very important because global problems can only be solved by understanding local ones (TAMÁS, 2001).

By applying conservation tillage not only CO₂ emissions can be kept at a low level, but at the same time decomposition and accumulation of organic matter can be balanced (BIRKÁS - GYURICZA, 2004).

Soil tillage is a cardinal factor of the development of agriculture and environment protection, and environmental preserving crop production among the natural features of Hungary.

In my view, the study of the effect of the different tillage and agronomic procedures for carbon circle of soil is actual and requires more efforts.

One of these efforts was initiated by the Kyoto University Laboratory of Soil Science, when in 2002 it launched a multi-country project, which was directed to determine the parameters that influence CO₂ emission of soil in different parts of the world (Indonesia, Japan, Kazakhstan, Ukraine, Thailand, Hungary). The Hungarian partner institutions were the Institute for Soil Science and Agricultural Chemistry Research Institute and the University of Debrecen CAS Karcag Research Institute. An infrared gas analyzer was made available by the Japanese colleagues to the Hungarian partner institutions.

I had the chance to join this research in 2005. I had the opportunity to make measurements in the cultivation experiment, to investigate the factors affecting carbon dioxide emission, to collect data and to carry out own observations and self-analyzing and evaluating work.

The problem of greenhouse gases is interdisciplinary, there is no doubt about its actuality. The main goals of my research are determined as follows:

- Further development of the method for measuring soil CO₂ emissions in field investigations.
- To analyze factors affecting CO₂ emission of soil (moisture conditions, temperature).
- To investigate some agronomic factors (tillage, plant nutrition, irrigation), which effects CO₂ emissions from soil.
- To create different estimations indicating the correlation between land use and soil fertility.
- To calculate numerical data for the carbon stock changes of soil at country and plot levels based on the IPCC methodology.

2. RESEARCH METHODS

The experimental sites

The complex soil tillage experiment

The objective of the complex soil tillage experiment, launched in 1997, was to establish capabilities and effectiveness of a soil conservation tillage system, which stops the physical degradation of soil among agro-ecological and arable ecosystems in the Trans-Tisza Region and to develop an environmental friendly energy-saving cultivation system.

The program includes: reduction of the regularly cultivated layer, leaving the ploughing tillage method, application of reduced tillage and no tillage and direct seeding, application of mulching technology, and use of deep loosening to eliminate the physical defects of the soil and the factors limiting soil fertility. The total size of the plots of the experiment is 16 ha, the conventionally cultivated (plough based) plot was set on 3.5 ha, and the reduced tillage plot is 12.5 ha. Two plants were growing in crop rotation in the four plots. The plants (wheat, maize, peas, sunflower, barley) represent the structure of crop production characteristic to Nagykunság region. The soil type of the site is meadow chernozem salty in the deeper horizons.

In order to examine the effect of different soil reclamation methods involving the application of organic manure and various chemical amendments, thin manure was distributed on a third of the plots both in the conventional and the reduced tillage system in 2006. In 2011 and 2012 a third of the area in both tillage system was treated with soil conditioner. The soil conditioner improves the structural condition and water management of the soil, and increases its nutrient content. The product manufacturer emphasizes the improvement of soil biological activity. According to the description of the product the soil conditioner provides the necessary nutrients for the mould and it increases the activity of soil micro- and macro-organisms.

The simple drainage lysimeter experiment

The measurements were carried out at the DU CAS KRI lysimeter station; I set the pot experimentation in 8 simple drainage lysimeters, where lysimeters functioned as pots. Generally the CO₂ gas emitted from the soil mainly originates from root respiration,

microbiological activity and decomposition of organic matters. In order to evaluate this process separately, I sowed grass on every second pot and left without plant cover the others, so excluding root respiration, only the amount of CO₂ from microbial decomposition could be determined. In 2008, in each series there was an irrigated unit, a reduced irrigated and a non-irrigated one. In 2009 there was no difference in irrigation. In 2011 4 units were irrigated with total doses, 2 units were irrigated with reduced doses, and 2 units were not irrigated.

The soil columns with original structure

Original structure (undisturbed) soil samples were taken with 8 sampler cylinders from the complex soil cultivation experiment, both the conventional and both the reduced cultivation plots too. In practice, often occurring problem is that unstructured, „disturbed“ soil samples are used for investigation of structure-dependent soil properties - as well as CO₂ emissions - in a laboratory. By destroying the effect of the soil structure and the pore size distribution for the rate of soil solid, liquid and gaseous phases, and their strong influence for soil biological processes and CO₂ emission (TÓTH et al., 2009). The cylinders further functioned as pots.

The grassland fertilization experiment

The measurements were carried out at the DU CAS KRI. The site of the measurements is an extensive pasture utilised by grazing sheep. The experiment was set up in four treatments, four replications, random block design. The area of each replication was 10 m². The codes of the treatments: T0 - control, T2 – 20 t/ha compost dose, T3 – 40 t/ha compost dose, T4 – 60 t/ha compost dose. The compost used in the experiment is a bio-compost, naturally produced, enriched with nutrients, sheep manure-based compost. It is odourless, free from pathogenic bacteria and weed seeds, homogenous product. It contains micro- and meso-nutrients. The compost was distributed on the plots in 2010, so it had a second-year manure effect in 2012. The soil of the experimental site is a medium meadow solonetz.

Determination of the CO₂ emission of the soil

Method to measure the CO₂ concentration

The in situ CO₂ emission of soil was measured by means of an Anagas 98 and a GasAlertMicro5wPump infrared gas analysers. The measurement range of the analysers is 0-5% with the resolution of 0.01%, they are battery supplied with motorized pump.

There are several methods and tools for the delimitation of the measuring area, these are principally similar, but there are some practical differences between them. In Hungary TÓTH and KOÓS (2006) also developed their own technique, which is more or less the same to our one, the main difference is in the method of the gas sampling and analysing. At Karcag special, individually developed sets were used consisting of a metal frame and a plastic bowl each.

I measure the CO₂ concentration of the air above the soil surface before and after a 30 minute-long incubation period. To calculate the CO₂ emission from soil the following formula was used:

$$F = d * (V/A) * (C_2 - C_1) / t * 273 / (273 + T)$$

where

F: CO₂ flux (kg m⁻² s⁻¹),

d: density of CO₂ (kg m⁻³, 1.96 for CO₂),

V: volume of head space of chamber (m³)

A: area of chamber (m²),

C₁: CO₂ concentration at time of start (m³ m⁻³),

C₂: CO₂ concentration at time of end (m³ m⁻³),

t: duration of measurement (s),

T: air temperature (C°).

Calculation of soil carbon stock with the IPCC methodology

Calculations for the change in soil carbon stock were done according to the methodology of IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry - 'the IPCC Guidelines - of the 2003 edition.

The estimation method is based on changes in soil C stocks over a finite period following changes in management that impact soil C, as shown in the next Equation:

$$\Delta C_{CC} = [(SOC_0 - SOC_{(0-T)}) * A] / T$$

$$SOC = SOC_{REF} * F_{LU} * F_{MG} * F_I$$

where,

ΔC_{CC} = annual change in carbon stocks in soils, tonnes C yr⁻¹

SOC_0 = soil organic carbon stock in the inventory year, tonnes C ha⁻¹

$SOC_{(0-T)}$ = soil organic carbon stock T years prior to the inventory, tonnes C ha⁻¹

T = inventory time period, yr (default is 20 yr)

A = land area, ha

SOC_{REF} = the reference carbon stock, tonnes C ha⁻¹

F_{LU} = stock change factor for land use or land-use change type, dimensionless

F_{MG} = stock change factor for management regime, dimensionless

F_I = stock change factor for input of organic matter, dimensionless.

Previous soil C stocks ($SOC_{(0-T)}$) and soil C stocks in the inventory year (SOC_0) for the area of a cropland system in the inventory are estimated from reference carbon stocks and stock change factors, applied for the respective time points. Here a cropland system refers to a specific climate, soil and management combination. Annual rates of emissions (source) or removals (sink) are calculated as the difference in stocks (over time) divided by the inventory time period. The default time period is 20 years.

If these data are available, we can calculate the change in soil carbon stock for a given area. To facilitate this, the IPCC requested the Colorado State University Natural Resource Ecology Laboratory to develop a computer program (IPCC Soil Carbon Tool - hereafter SCT). According to the description of the program, it is a tool that serves as estimation effect of land use change for changes in the arable and grassland soil carbon stocks in the default values set by the IPCC. Then the modifying factors must be taken into account both the original (FROM system) and 20 years later (TO system) land-use preferences. You must give the original land use (FROM system) characteristic data, the first land-use system. In my case it was always arable (cultivated long-term), since I dealt with only estimates changes in carbon stock of arable land in Hungary in this thesis.

The area shall be determined in accordance with our cultivation system (management system) within the land-use way, it is determined by the so-called ‘management factor’. To be able to determine changes in soil carbon stocks for a larger area, the area should have been divided into different climate zones and soil types. We have to classify each soil type and climate zone area on the relevant soil tillage systems and organic matter inputs under.

The climate zones of Hungary’s arable are moderately cool, dry and moderately warm dry. After determining the climate zones, they were harmonized classification for soil types, the two climate category were placed into four soil types.

According to the IPCC methodology the arable cultivation areas characterized by the following tillage systems: direct seeding, reduced tillage, conventional tillage.

According to the IPCC methodology as the input factors represent the effect changing carbon input to the soil by planting more productive crops, cropping intensification, or applying amendments; input factors include cropping systems categorised as low, medium, high, and high with manure amendments.

3. MAIN OBSERVATIONS OF DISSERTATION

Development of the method for measuring CO₂ emissions of the soil on field

A first for the delimitation of the measuring area 20 cm plastic (PVC) chambers (Ø110 mm) were used. The chambers were placed into the soil to a depth of 10 cm, and the sample space was 10 cm and 95 cm². Generally the CO₂ gas emitted from the soil mainly originates from root respiration, microbiological activity and decomposition of organic matters. In order to separate these two processes, one end of the chambers was covered with a mesh. These PVC chambers were not suitable for soil surfaces covered with grass, because the insertion of plastic chambers into the hard soil of the pasture is virtually impossible. Hence a new instrument was needed to be invented. In order to measure CO₂ emission on a larger area without deep disturbance of the soil, a special metal frame (*Fig. 1.*) was created with a matching bowl. The diameter of the frame is 44 cm, the height is 8 cm of which a 5.5 cm high frame is inserted into the soil. The

volume of the bowls is approximately 18.000 cm³ each. This set was developed further, as it was realised that a smaller set is more practical and suitable for CO₂ emission measurements on stubbles and can substitute the cylinder method that was used earlier.



Fig. 1.: The frame + bowl method

Determination of the optimal incubation term

In the saturation experiment, there was no total CO₂ saturation during five hours of closed incubation space. Linearity of CO₂ concentrations was detected in all cases proving the unsaturated state in the incubation space. The inflection point of the saturation curve and the trend line is located 30 minutes; the curve slope is until the maximum until So much time is appropriate to characterize the emissions, and longer term is not characterize the natural state. I looked at data of 10 and 20 minute incubation term also, however, the concentration values shown great standard deviation in this term. It has been proved that no more than 30 minutes incubation time is needed for the examinations based on the measurement of concentration difference.

CO₂ emission in the soil tillage experiment

Field measurements were carried out in the complex soil tillage experiment. In the investigated seven years the weather was very diverse so it created an excellent opportunity for comparison between years. *Figure 2.* shows the data of the two cultivation systems.

The CO₂ emissions of the soil are close correlation with the increasing soil moisture content. Hence environmental conditions (soil moisture content, temperature, pH etc.) decisively influence the change of soil organic matter (accumulation or reduction) and the living conditions of the soil micro-organisms.

Increased emission level was induced immediately after the cultivation intervention but on the stubble on the plot without disturbance higher emission values were characteristic. This proves that better conditions formed in the soil of reduced cultivation plot to the microbial processes. Based on the obtained results, direct correlation can be observed between the intensity of tillage and carbon dioxide emissions.

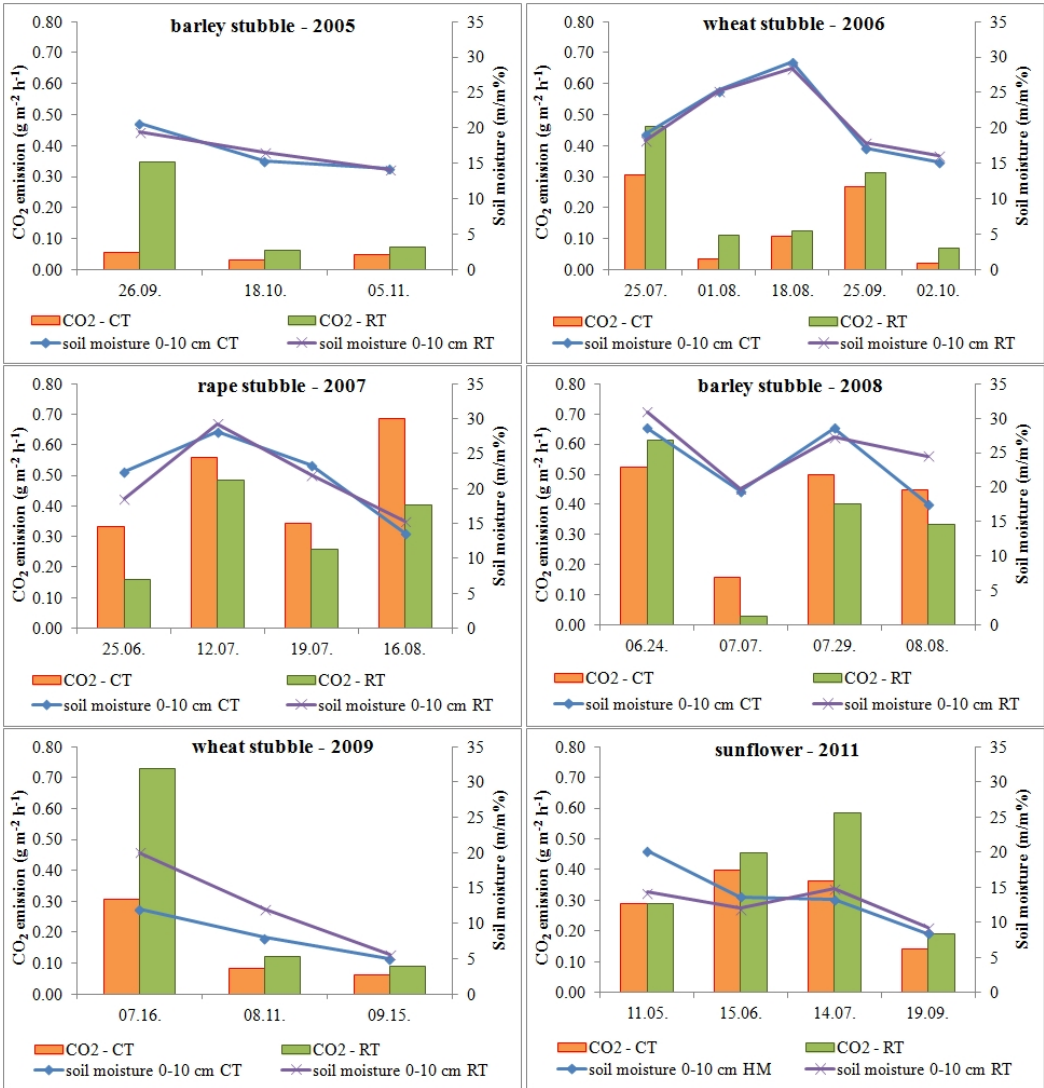


Fig.2.: CO₂ emission in the soil tillage experiment (2005-2011)

Undisturbed samples were taken from the plots with different cultivation (conventional and reduced), which were examined in pot experimentation in order to examine the

effect of different soil tillage methods on carbon dioxide emission from the soil. I got difference between of CO₂ emission of the conventional and reduced tillage soil sample. CO₂ emission levels were higher on the reduced cultivated soil columns than on conventional tillage, because reduced tillage created favourable conditions (structure, air permeability, organic matter content) for microbiological activity.

Effect of thin manure to the soil CO₂ emission

In order to increase soil fertility the types of fertilization (from thin manure to green manure) can be combined with the cultivation methods (GYURICZA et al., 2006). Enriching the soil with organic matter stimulates soil microbial processes, so it significant contribution to the success of alternative production methods, higher emissions were detected from the manure-treated fields in each case as compared to the untreated plots.

Effect of soil conditioner to the soil CO₂ emission

The soil conditioner was first applied in the soil tillage experiment in 2011. Similarly, higher emissions were detected from the treated plots compared to the untreated plots. The soil conditioner improves the physical and chemical parameters of the soil and it increases the activity of soil micro- and macro organisms, this effect was proven by CO₂ emission measurements. I found that the effect of the soil conditioner prevails faster in the reduced cultivation system than in the conventional tillage system.

Effect of sheep manure-based compost to the soil CO₂ emission

In our region the most of salt effected soils are utilized as pasture, so it is recommended to improve the grass yield with fertilization. In the treated plots I detected higher values compared to the untreated plots. Nevertheless it is obvious that organic matters added to the soil have significant influence on the microbiological activity in the soil. The highest values were observed in the 20 t/ha sheep manure based compost application plot, and here was the highest soil moisture content too. There is close correlation between the degree and intensity of CO₂ emission from the soil and the structural state and organic matter content of the soil.

The role of the root respiration in the CO₂ emission of the soil

The role of the root respiration was examined in a simple drainage lysimeter experiment. Every second pots were sown with grass, which was regularly cut back, the other pots were left without plant cover. Statistically significant difference was found in the CO₂ emissions of the soil of the plant cover units compared to the lysimeter units with bare soil surface.

The correlation between soil moisture content and the soil CO₂ emissions

With the increasing moisture content, after reaching the maximum of the microbiological activity, the reduced oxygen diffusion is the main limit. The role of the soil moisture content was examined in a simple drainage lysimeter experiment too (Fig.:3.).

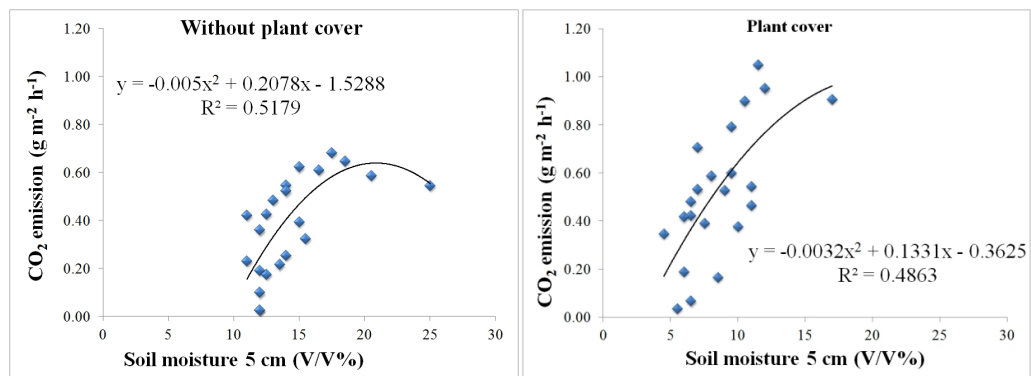


Fig.3.: Correlations between soil moisture content and CO₂ emissions

The correlation between soil moisture content and CO₂ emissions are analyzed statistically with moderate correlation between the two parameters.

Effect of temperature to the soil respiration

Changes in the soil temperature are closely related with the air temperature, since the increase of the latter involves the growth of soil temperature. I analyzed the correlation between the CO₂ emission values of the lysimeter experiment and the air and soil temperature values (Fig. 4.). The change of the air and soil temperature was correlated with soil CO₂ emissions of each treatment.

According to the crop year, the temperature values were in different temperatures intervals, also the emission values moved similarly.

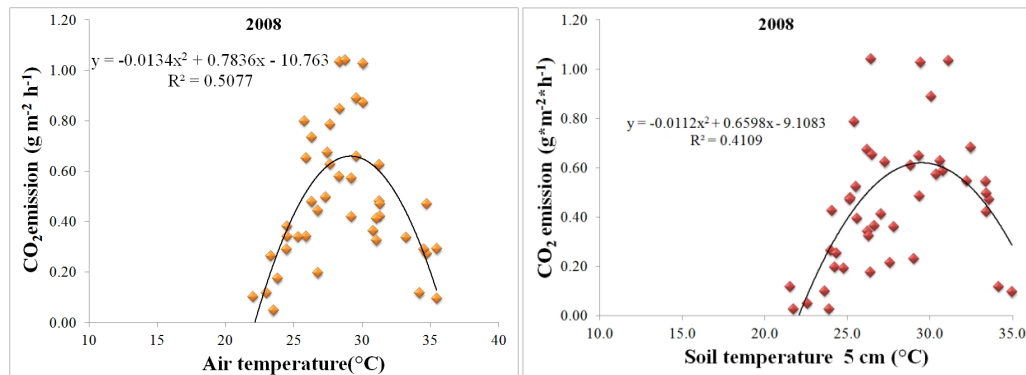


Fig.4.: Correlations between air and soil temperature and CO₂ emissions

The activity of a given enzyme composition of the soil has probably an optimum temperature, at that temperature the most enzymes are active, and above this, the activity of respiration is decreased. The phenomenon can be characterized by a bell-shaped curve.

The role of time dynamics in the soil CO₂ emissions

To examine the time dynamics of the CO₂ emissions, measurements lasting a whole day were carried out: I measure the CO₂ concentration in 2-hours intervals for 24 hours. The lowest emission values were observed in the morning (*Fig. 5.*). In the plant covered units higher emission values were observed in the afternoon and at night, which shows that the root respiration has big role in the CO₂ emission of the soil. The CO₂ emissions of the units without plant cover was always balanced during the 24 hours. The moisture preserving and cooling role of the grass cover created better conditions for the microorganisms.

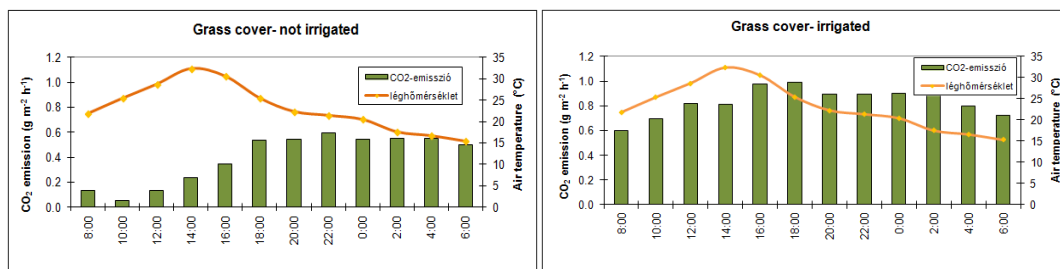


Fig. 5.: The time dynamics of CO₂ emissions in the experiments

Estimation of the change of soil carbon stock for different cultivation and climate scenarios

I chose 2006 as the base year, so I could carry out estimates the next 20-year-long period (*Fig. 6*). In my opinion, in Hungary, the potentially used tillage systems now and in the future are direct seeding, reduced tillage and conventional tillage. I took the recent and expectable spatial extension of these cultivation systems into account for the total area of the country. The total organic carbon content of the soil is increasing with changing the input factor (increasing the input organic matter to the soil), however, the extent of this increasing is different for each tillage systems. The carbon stocks of soils would be increased about 22% by changing for direct seeding with high organic matter input (which is characterized this system). If you have applied organic manuring also with this, we can expect up to a 53% growth.

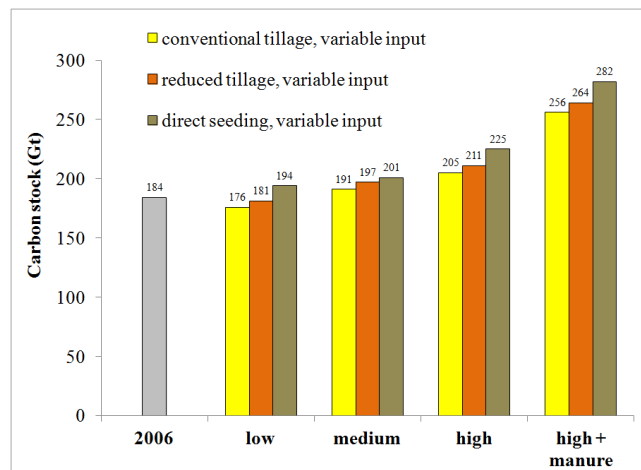


Fig. 6.: The changing of carbon stocks of Hungary's arable for different cultivation systems with variable input

As a result of changing for reduced tillage (which is also characterized with high organic matter input) we can expect increasing soil carbon stocks, although the extent of this increasing is lower. I determine the change of soil carbon stocks of the top 30 cm layer in the arable lands of Hungary 7-15% increasing applying reduced system with medium or high organic matter input compared to the 2006 base year.

About 4% decline of the amount of carbon stock is expected compared to the 2006 base year applying conventional cultivation system with low organic matter input. In my

opinion, the carbon stocks of our soils will be increased about 5-10% in the next 30 year, if the conservation tillage systems spread in the next 10 years.

The calculated carbon stocks shown for the different climate scenarios that in the whole territory of Hungary it would be warm-dry climate, the carbon stocks of our soils would be reduced, but it would be shown a similar rate compared to the reference year. The carbon stocks would be double, if the climate changes in the opposite direction, from year to year colder and wetter weather would replace the present one.

Estimate of change of carbon stocks for the cultivation experiment at Karcag

I could prove that using the IPCC method it is possible to determine the carbon stocks not only at national, but even at plot level. Using the default data of the IPCC method I quantified the change in carbon stocks of the soil of the soil tillage experiment at Karcag for a 20-year-long period. Since the experiment began in 1997, I considered the state of this year baseline. The original state (1997) characterized by conventional tillage with low organic matter input, the soil carbon stocks of the top 30 cm layer was 28.7 t ha⁻¹. Changing for reduced tillage with increased organic matter content we can account 0.17 t ha⁻¹ soil carbon stock increasing, which is higher 12% in 2017 compared to the original.

Using an improved method, the change of the carbon stocks was calculated also on the basis of the actual humus content of the soil of the soil tillage experiment. This way I got 55.9 t ha⁻¹ carbon stock, which is much higher than that calculated with the IPCC default data.

4. NEW SCIENTIFIC RESULTS OF DISSERTATION

1. To solve the most problematic part of the field CO₂ measurements, to the spatial delimitation of the measurement area a new equipment was developed. I proved the *frame + bowl* method suitable for the delimitation of different surface of the measurement area. I demonstrated that no more than 30 minutes incubation time is needed for the examinations based on the measurement of concentration difference and longer term is not characterize the natural state.

2. I proved with my field measurements that due to the moderate soil disturbance and the favourable soil conditions for microbial activity, reduced tillage system resulted higher CO₂ emission compared to the conventional tillage, though the emission was more balanced in time.

3. The examined soil fertility increasing matters like thin manure, compost and soil conditioner stimulate the soil microbial processes, and result in higher CO₂ emission of soil, which was proven by the quantification of these effects.

4. I statistically proved the role of root respiration in the soil CO₂ emission. On the basis of my measurements I quantified the difference in CO₂ emissions between plant-covered soil and bare soil surfaces.

5. I also proved that the soil temperature and soil moisture content have regulatory role in the microbiological life of the soil. The correlation between soil moisture content and CO₂ emissions were analyzed statistically with moderate correlation between the two parameters. The change of the air and soil temperature was correlated with soil CO₂ emissions of each treatment. I examined the time dynamics of the CO₂ emissions and established considering its rate the temperature is the determining factor.

6. I established that the IPCC method is suitable for the estimation of soil carbon stock and its changes. I proved that using this method it is possible to determine the carbon stocks not only at national, but even at plot level.

5. PRACTICAL UTILIZATION OF THE RESULTS

I consider the following ones from the new scientific results described in section 4 that can be used in practice:

1. To solve the most problematic part of the field CO₂ measurements, the spatial delimitation of the measurement area, a new equipment was developed. I proved the *frame + bowl* method suitable for the delimitation of different surface of the measurement area. I demonstrated that no longer than 30 minutes incubation time is needed for the examinations based on the measurement of concentration difference and longer term is not characterize the natural state.
2. The examined soil fertility increasing matters like thin manure, compost and soil conditioner stimulate the soil microbial processes, and result in higher CO₂ emission of soil, which was proven by the quantification of these effects.
3. I established that the IPCC method is suitable for the estimation of soil carbon stock and its changes. I proved that using this method it is possible to determine the carbon stocks not only at national, but even at plot level.

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List of publications related to the dissertation

Hungarian book chapter(s) (1)

1. Óri N., Füleky G., Zsigrai G., **Kovács G.**: Műtrágyázás és melioratív meszezés hatása egy csernozjom talaj szervesanyag-frakcióinak mennyiségére.
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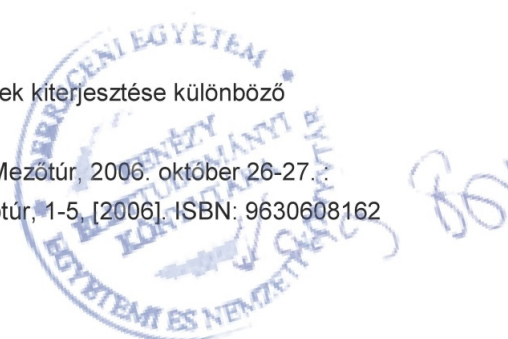
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Total IF of journals (all publications): 2,227

Total IF of journals (publications related to the dissertation): 2,227

The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of Web of Science, Scopus and Journal Citation Report (Impact Factor) databases.

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