THESIS OF PhD DISSERTATION

SOIL CARBON-DIOXIDE EMISSION MEASUREMENTS IN DIFFERENT SOIL USE SYSTEMS

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1. Introduction and aims

The atmospheric carbon-dioxide concentration started to increase after the industrial revolution and now it reaches the 370 ppm value, which means more than 30% growth. According to climatologic researches the increase of the atmospheric CO_2 concentration contributes to global climate change because of the growth of greenhouse gas effect. Nowadays CO_2 emission originating from different sources increases with about 1% per year causing further growth in atmospheric CO_2 concentration. Although CO_2 emission of agriculture originates primarily from deforestation and fossil fuel consumption of agricultural machinery the amount of CO_2 getting into the air from soil can not be neglected either. Application of good agricultural practices and adequate soil tillage methods has not only favourable effect on soil physical properties but it could also reduce soil respiration. So soil organic matter content can be preserved and amount of CO_2 getting into the air can be reduced.

Researches about relationship between soil CO_2 emission and soil tillage have contradictory results. Most scientific literature are concerned with the short-term effect of soil tillage and don't consider when the equilibrium-state occurs after tillage. There are few results about the long-term effect of soil tillage on CO_2 emission. Evaluation of effect of soil tillage systems on soil respiration is difficult because of the lack of standard measurement methods and since the studied processes are appreciably affected by climatic conditions, by cultivated plants and by local cultivation practices.

My aim was to study in field and in laboratory experiments the long-term effect of different soil tillage systems on soil CO_2 emission. My hypothesis was that although conventional soil tillage methods increase soil CO_2 emission as a short-term effect, but they change soil structure and soil properties connected to structure as a long-term effect, so soil disturbance causes lower microbial activity and lower CO_2 emission.

During my experiments I studied the effect of soil tillage on soil CO_2 emission in two agricultural sites: one was an arable land, the other one was a peach plantation. Under field and laboratory circumstances I tried to determine the coherences between soil properties and soil respiration and to evaluate the effect of soil tillage methods from the point of view of soil CO_2 emission. My other aim was to work out a laboratory method where soil properties affecting soil respiration - as soil water content, soil temperature and structure – are constant so their effect on soil CO_2 emission can be correctly determined.

During my research the following works had to be done:

1. Studying soil CO2 emission in different soil use systems in field and laboratory circumstances. Determining and evaluating the effect of different soil disturbances on soil respiration.
2. Developing a new laboratory method to determine soil CO_2 emission and its coherence with other soil properties.
3. Studying coherences between soil respiration and different factors as soil water content, soil water potential values, microbial activity, bulk density, etc on differing disturbed soils.
4. Working out proposals about developing soil CO_2 emission methodology and about determining coherences soil respiration and other soil parameters.

2. Materials and methods

My experiments on soil CO2 emission was carried out under field and laboratory circumstances. Field measurements were carried out in a tillage treatment experiment nearby Hatvan on the experimental site of Szent István University and in a peach plantation in Vác. Laboratory measurements were carried out with soil samples originating from these two experimental sites. The chosen treatment demonstrated the different degree of soil disturbance. I studies three tillage treatments on the Józsefmajor experimental site: the direct drilling (DD), which is the treatment without soil disturbance, the ploughing as the most conventional tillage method (P: 26-30) and the disking with deep loosening (D+L: 40-45cm, which causes the deepest disturbance in soil among the studied treatments. In the peach plantation two different managed soils were chosen to my experiments: one was covered by grass, the other one was disked in every second-third week during the vegetation period.

My measurements can be summarized as follows:

2.1 Laboratory experiments

For the **CO_2 emission measurement** in the laboratory I used undisturbed soil samples (V=800cm^3) originating from the upper 10 cm layer of the soil. I carried out the measurements in climatic room under controlled circumstances. From the closed headspace of soil samples I took air samples with gas-tight syringe (Supelco) and took into vacuumed vials (Exetainer tube, Labco Ltd, UK). I determined the CO_2 content of air samples with gas chromatograph (FISONS 8000). I determined soil CO_2 emission from the change of CO_2 concentration during the incubation period.

Beside CO_2 emission measurements I determined from **soil physical properties** the bulk density and the volumetric soil water content in all measurement days after drying out the samples on 105^{o}C. I also determined soil volumetric water content from samples collecting parallel with the field CO_2 measurements.

I also determined the most important **soil chemical parameters** as total N, P_2O_5, K_2O, pH, humus content, organic carbon content, water extractable organic carbon and water extractable nitrogen (WEON, WEN) content.

Soil microbial biomass carbon and nitrogen content and substrate induced respiration was also determined as the main **soil biological properties**.

2.2 Field experiments

Soil CO_2 emission measurements in the field were carried out with the same procession than in the laboratory (air sampling, determining the CO_2 concentration of air samples. Parallel with the emission measurements I determined soil temperature with a portable soil thermometer (DTM light).

3. Results

3.1 Working out the new laboratory methods

I developed a new laboratory method during the laboratory CO2 emission measurements and with this new method the coherences between soil CO_2 emission and volumetric soil water content, soil structure and soil water potential values can be studied.

In the first stage of the development I demonstrated that in the laboratory the usage of undisturbed soil samples is more adequate for measuring soil CO_2 emission. For this experiment I compared the CO_2 emission of disturbed and undisturbed soil samples having the same volume and bulk density in five measurement days. I used soil samples originating from the two less-disturbed, the direct drilling (Józsefmajor) and the grass-covered (Vác) treatment. CO_2 emission measurement carried out on samples from the above mentioned two treatments had similar results. Higher CO_2 emission was measured from disturbed soil samples in the first measurement day, but the CO_2 emission was higher from undisturbed soil samples in the further days. Differences between CO2 emission of disturbed and undisturbed samples were significant on only one measurement day, but the tendency was the same during all measurements. For the whole database the difference between disturbed and undisturbed samples was significance ($p=0,1$). The contradictory results between the first and the other four measurement days can be explained with the collection, transportation and preparation of samples.

I examined the changes of CO2 concentration in the headspace of soil samples during a three-hour-long period to determine the optimal length of incubation period. CO_2 emission during the different long incubation period differ significantly only on one measurement day ($p<0,001$), although I noticed slight and not significant decreasing in CO_2 emission in time. So I determined the optimal incubation length in half an hour.

The interest of this newly developed method is that with this method soil CO_2 emission can be measured from undisturbed soil samples under laboratory circumstances and the measured CO_2 emission values can be evaluated in the function of soil water potential. Soil CO_2 emission in laboratory has been measured almost always from disturbed soil samples during laboratory measurements before. Nevertheless determining the coherence between soil water potential and soil CO_2 emission is more established than searching coherence between soil water content and soil respiration. Measurements carried out at similar soil water content values calculated on mass base make difficult to compare the results, obtained for soils belonging to different textural classes, because the same mass-based soil water content value in e.g. sandy and clay soils reflects totally different energetic status of water in soil. The new measurement approach makes possible to account for the effect of soil structural status and soil water potential on soil CO_2 emission.

3.2 Soil tillage effect on soil properties

Parallel with soil CO2 emission the most important physical, chemical and biological properties were also determined. The given table show the results of all measurements and the statistical comparison of the measured soil properties. Most soil chemical parameters and parameters relating to soil biological activity were the highest in the less disturbed treatments (direct drilling and grass-covered), and the differences between the values of the treatments were often statistically significant.

	Józsefmajor						**Vác**			
Examined parameters	**P**		**DD**		**D+L**		**G**		**D**	
N (mg/kg)	1947	a	2384	a	2217	a	1805	a	1298	b
P_2O_5 (mg/kg)	202	a	293	a	220	a	337	a	382	a
K_2O (mg/kg)	169	a	272	b	230	ab	387	a	244	b
pH (H_2O)	6,1	a	5,7	b	5,7	b	7,8	a	7,7	a
organic carbon (%)	1,9	a	2,4	b	2,1	a	1,3	a	1,0	a
humus (%)	3,1	a	4,2	b	3,5	b	2,3	a	1,7	a
WEOC (µg C/g soil)	19,7	a	29,7	b	17,1	a	32,4	a	14,9	b
WEN (µg N/g soil)	24,2	a	91,9	b	51,1	a	148,0	a	45,5	b
microbial biomass C content (µg C/g soil)	19,5	a	81,9	b	56,7	ab	234,5	a	52,0	b
microbial biomass N content (µg N/g soil)	3,8	a	7,1	b	3,5	a	50,0	a	9,1	b
SIR (µg C/g soil/h)	4,6	a	9,8	b	8,1	b	21,7	a	4,6	b
Saturated soil water content [v%]	51,7	a	50,3	a	49,7	a	41,9	a	41,6	a
Field capacity [v%]	32,9	a	33,9	a	34,4	a	34,5	a	32,4	b
Wilting point [v%]	16,8	a	15,9	a	17,1	a	13,1	a	12,7	a

3.3 Effect of tillage on soil CO_2 emission

3.3.1 Effect of tillage on soil CO_2 emission in the tillage treatment experiment in Józsefmajor

I summarize my results of the three laboratory experiments and of the field experiments of two vegetation period as follows:

The lowest CO_2 emission was measured in the laboratory and also in the field from the ploughing plots from the studied tree treatments (P, DD, D+L) almost on all measurement days. The measured soil CO_2 emission values differed significantly from the values measured in the DD and in the D+L treatments. No statistical difference could be detected between CO2 emission values measured in DD and D+L treatments, although soil CO2 emission was higher mostly in the DD treatment. These results are in accordance with soil chemical and biological properties.

3.3.2. Effect of tillage on soil CO_2 emission in the peach plantation in Vác

I had similar results in the two laboratory experiment and in the field experiments of two vegetation period in Vác as in Józsefmajor. Both in the laboratory and in the field experiment the soil CO_2 emission values in the undisturbed, grass-covered row were higher than in the regularly disked row. The difference was significant in almost all measurement days. These results of the peach plantation are also in accordance with soil chemical and biological properties.

3.4 Relationship between soil water content and soil CO_2 emission

I established that the coherence between soil water content and soil CO_2 emission is stronger under laboratory circumstances than in the field. During field measurements weather events (like snowmelt in spring) influencing soil structure and soil tillage causing high increase in CO_2 emission worsen these coherences. During laboratory measurements preparation of samples (sample collection and transportation) even as watering of samples worsens the coherence between these two parameters. On the base of the laboratory experiments it can be concluded that the coherence between soil water content and soil CO2 emission was the strongest in the less disturbed treatments (DD,

G) of the two experimental sites. The R^2 value was lower in case of more disturbed treatments. In the studied soil water content ranges the soil CO_2 emission increased till it reached the saturated soil water content than a slight decreasing of the CO_2 emission values started. The coherence between soil water content and soil CO_2 emission was stronger in case of experiment set up with soil samples collected in autumn than in spring. The coherence was stronger between soil water potential values and soil CO_2 emission than between soil water content values and soil CO_2 emission which supports the importance of the new laboratory method.

4. Conclusions and suggestions

Conclusions

1. I established that during laboratory CO2 emission measurements the use of undisturbed soil samples is expedient. So those experiment sets up which cause soil disturbance and set the soil into an oxygen-rich state can be avoided. Moreover leaving the samples in the original structure the structure-dependent soil properties (such as pore-size distribution, bulk density, structure of micro biota, microbial activity or evaporation), which directly affects soil respiration will be preserved.
2. In the laboratory experiment I controlled the change of CO2 concentration in the headspace of soil samples during three-hour-long incubation. After evaluation of the result I concluded the half-hour-long incubation period is ideal from the point of view of implementation and measurement accuracy.
3. After the second stage of the methodology development I concluded that watering the samples with the same amount of water makes the evaluation of results more complicated because of the differing initial soil water content of the samples.
4. I concluded that during the laboratory experiment collection and transportation of samples and preparation work by set up of the experiment (e.g. watering) significantly influence the results of the first measurement days, so these results should be handled separately.
5. I determined that soil CO_2 emission is appreciably dependent on soil chemical and biological properties.
6. It can be said that after soil tillage treatments causing bigger soil disturbance the soil CO_2 emission is increased. Soil tillage methods with smaller disturbance influence

the soil organic matter content, the main nutrient content, the microbial biomass content and the microbial activity favourably and this leads to higher CO_2 emission.

Suggestions

1. Development an instrument where soil water potential values can be set up on soil samples having big volume (cc.800cm^3) and soil CO_2 emission can be determined.
2. I suggest examining the temperature dependency and the joint soil temperature and soil water content dependency of soil CO_2 emission.
3. I suggest examining soil CO_2 emission in wider soil water content range where negative correlation occurs between soil CO2 emission and soil water content.
4. I suggest dividing the short-term and long-term effect of soil tillage with oftener measurements during the whole vegetation period. 2 or 3 day-long campaign measurements are also recommended.
5. During the evaluation of coherences between soil CO_2 emission and other soil parameters I suggest considering the time passed after the last events which alter suddenly and significantly soil structure (e.g. tillage, melting).
6. During soil CO2 emission measurements I suggest measuring soil microbial characteristics in all measurement days to determine coherences between soil CO_2 emission and in microbial parameters.

5. New scientific results

1. I developed and tested a new laboratory method for measuring soil CO_2 emission under controlled circumstances.
2. With laboratory experiments I verified the necessity of using undisturbed soil samples in determination of soil CO_2 emission. I pointed out that usage of disturbed soil samples during laboratory CO2 emission measurements can cause faults in the results.
3. I verified that soil respiration values differ directly after soil disturbance and later. According to that I showed the short term and long term effect of soil disturbance in intensively and less disturbed soils.

4. I stated that the time passed after the last events which alter suddenly and significantly soil structure (e.g. tillage, melting) must be taken into consideration during the examination of coherences between soil CO_2 emission and other soil parameters.
5. I confirmed the closeness of coherence between CO_2 emission and other parameters in undisturbed and almost undisturbed soil.

6. Publication

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