Tillage Intensity and Tillage-Induced CO_2 Loss

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Field experiments were done to measure the effect of different primary tillage methods on the CO_2 flux from soil and to evaluate the effect of conservation tillage tools on short-term CO_2 emissions. The experiments were conducted on a clay loam soil winter wheat field and a corn field. The three tillage treatments included stubble mulching (disc harrow, mulch tiller, chisel plough), primary tillage (disc harrow, moldboard plough, and chisel plough) and secondary tillage (combined seedbed maker). The control treatment was no-till with soil and residues left by the harvester. The CO_2 flux from the tilled soil surface was measured by a portable closed-chamber tester. Moldboard ploughing produced the roughest soil surface and the highest initial CO_2 flux and maintained the highest flux throughout the experiment. The moldboard ploughing caused higher CO_2 loss than less intensive tillage such as chisel ploughing, mulch cultivating, or disc harrowing. Primary tillage caused higher CO_2 emission in the fall than seedbed preparation did in the spring. These results support increased use of new and improved forms of conservation tillage equipment and offer a significant potential for preserving or increasing soil C levels while decreasing carbon dioxide emissions.

Keywords: CO_2 flux, tillage, climate change, greenhouse gases

1. Introduction

The increase of CO_2 in the atmosphere has attracted interest due to the potential of global warming and the prospects of using soil as storage for carbon. Improved agricultural practices provide great potential for increasing carbon sequestration and decreasing the net emission of carbon dioxide and other greenhouse gases. Information is needed on the short-term impact of various tillage methods on C flow and on the dynamics of the agricultural production system.

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Any increase in soil carbon produces important benefits for the sustainability and productivity of the agro ecosystem. Many land management practices, such as conservation tillage, promote carbon accumulation and also prevent erosion, thereby improving air and water quality. This has the potential to increase soil productivity and the profitability of farming systems.

1.1. Greenhouse Gases and Tillage Intensity

The concentration of greenhouse gases in the atmosphere has increased steadily since about 1850. Deforestation, conversion of farmland, and other agricultural activities have contributed to the total increase so far (Post et al. 1982). CO_2 is the most significant greenhouse gas, because the increase in its concentration causes about 50% of the total radiative effect (Rodhe 1990). The concentration of CO_2 in the atmosphere was about 280 ppm in around 1850 and 365 ppm in 1996, and it is increasing at the rate of 0.5%/year. If this trend continues, CO_2 concentration will be approximately 600 ppm during the 21st century (OSTP 1997).

Improved agricultural practices afford great potential for increasing carbon sequestration and decreasing the net emission of carbon dioxide and other greenhouse gases. However, politicians have not recognized the threat of the emission of these gases. Since the 1980s considerable scientific information has been collected about the potential for agricultural lands to sequester C (Lal et al. 1995a, b, 1998a, b). The available information, however, has not been synthesized into a form that land managers and politicians can readily use to mitigate CO_2 emissions in relation to the potential greenhouse effect.

Intensive agricultural production systems that include intensive tillage result in soil degradation and erosion that impact soil, water, and air quality. It is imperative that a balance be reached between the short-term use of the soil and the long-term sustainability of this valuable resource. The effects of conservation tillage and residue interactions on greenhouse gas fluxes and soil carbon should be evaluated. Soil scientists have studied the dynamic nature of soil carbon from an agronomic perspective but not from an environmental context. Thus, more information is needed to advance the current understanding of how agricultural production systems can be modified to enhance environmental quality. Many aspects of improved soil management research needs are related to the impact of land use as affected by tillage methods. Soil and crop residue management systems can play a major role in greenhouse gas emissions optimization to minimize impact on climate change. Information is needed to understand how tillage management interacts with biological dynamics of the carbon cycle and how to shift the balance toward increased carbon sequestration and improved soil quality.

The possibility of global greenhouse warming due to rapid increase of CO_2 is receiving increased attention. This concern is warranted because potential climatic changes could result in increased temperature and drought over present agricultural production areas (Wood 1990). Thus, agriculture's role in the overall global carbon balance must be understood. We need direct measurements to quantify CO_2 flux as affected by agricultural management practices.

There is a definite need for information on the impact of tillage on CO_2 emission from soil and how farming practices can be managed to minimize this impact on global climate change. Information is needed on both the short-term effect of agricultural management decisions and the long-term effects, as they may affect global climate change. Direct evidence on the effect of the tillage method on CO_2 flux rates is limited.

Over the past two decades conservation tillage has been developed mainly for erosion control. However, recent concern regarding global climate change emphasizes the importance of conservation tillage and how it can be implemented on many soils to help reduce soil C losses. While tillage and cultivation result in loss of soil carbon and nitrogen (Campbell and Souster 1982; Mann 1986), the direct influence of tillage on CO_2 flux is variable and highly interactive. Variation in the soil CO_2 flux can result from the interaction of many factors. Soil loosening should improve accessibility of oxygen necessary for the decomposition and respiration of organic matter which result in CO_2 release.

1.2. Measurement System for Gas Flux

Limited measurements are available on CO_2 evolution immediately after tillage in the field. Hendrix et al. (1988) were unable to detect any stimulation of CO_2 release immediately after ploughing using aluminum cylinders of 10 cm diameter and the alkali-absorption method. In the present study, gas fluxes were measured by a closed chamber system. The atmosphere immediately above the soil surface was enclosed by the chamber and the change in concentration of CO_2 or N_2O was measured after an hour. This change was a result of net emission from the soil and enabled gas flux to be determined. Gas sampling in this way can be done either manually or by automated closed chambers. The manual chambers (Clayton et al. 1994) were cylinders of 0.4 m diameter, pushed into the soil to a depth of 50 mm and with the headspace enclosed with an aluminum lid. Gas samples were taken with syringes or aluminum sampling tubes and subsequently analyzed in the laboratory by gas chromatography. In order to assess the effects of no-till drill slits on N_2O flux, small manual chambers (steel cylinders of diameter 73 mm) were pushed into the soil to a depth of 30 mm so as either to enclose a drill slit or the area between drill slits. These chambers were enclosed by close-fitting plastic caps containing an injection port. The automatic chambers (0.7×0.7 m) had an automated lid closing and sampling system that allowed the remote collection of gas samples at programmed time intervals. Samples were collected and pumped into one of 24 isolated copper loops attached to two rotary valves. The entire valve/loop assembly was removed, transported to the laboratory for automated gas chromatographic analysis, and replaced by a duplicate in order to preserve continuity of sampling. Gas diffusivity was measured in situ in the tillage experiment by measuring the rate of escape of Freon from a chamber enclosing the soil surface (Ball et al. 1997).

The CO_2 flux from the tilled soil surfaces was measured using a large portable chamber described by Reicosky (1990) and Reicosky and Lindstrom (1993). Measurements for CO_2 flux were initiated within 5 min of the last tillage pass. Briefly, the chamber (volume of 3.25 m^3 covering a horizontal land area of 2.67 m^2) with mixing fans running was moved over the tilled surface until the chamber reference points aligned with plot reference stakes. It was then lowered and data was rapidly collected at 2 s intervals for a period of 80 s to determine the rate of CO_2 and water vapor increase. After the appropriate lag times, data for a 30 s period were used to convert the volume concentration of water vapor and CO_2 to a mass basis, then linearly regressed as a function of time to reflect the rate of CO_2 and water vapor increase within the chamber, expressed on the basis of a unit of horizontal land area.

1.3. Objective

Information is needed on the short-term impact of various tillage methods on C flow and dynamics within an agricultural production system. Our objective was to measure the effect of different tillage methods on the CO_2 flux from soil.

2. Materials and Methods

2.1. Experimental Conditions

The experiments were conducted on clay loam soil in Western Hungary (Enying Farm Ltd., *Table 1*). The experiments were started in July 2003 and finished in April 2004.

Table 1. Experimental conditions

No. of measurement	Operation	Weather conditions	Date
1.	Stubble mulching on wheat stubble	Dry, sunny, 28°C	15.07.2003
2.	Primary tillage on corn stubble	Dry, windy, 20°C	23.09.2003
3.	Secondary tillage on corn field	Dry, windy, 23°C	29.04.2004

The time of drilling winter wheat on the no. 1 experimental field was in the last ten days of October 2002 and it was harvested in the first ten days of July 2003.

The short-term influence of tillage on soil CO_2 evolution was assessed by recording two series of successive measurements. Each series included a pre-tillage measurement to assess "base line" flux uniformity, followed by three different post-tillage measurements to compare fluxes within tilled and undisturbed plots.

On the no. 2 experimental field, corn was harvested in the last ten days of September. The short-term influence of primary tillage on soil CO_2 evolution was assessed by recording two series of successive measurements to compare fluxes using different machines.

The secondary tillage treatment was done on a primary-tilled area during spring, 2004 using a Syncrogerm 6M machine (*Table 2*) for seedbed preparation.

Table 2. Treatment specification

No. of measurement	Operation	Machine	Working depth, cm
1.	Stubble mulching	Rába-IH disc harrow + Güttler roller Komondor mulch tiller Kverneland CLE chisel plough	15 15 25
2.	Primary tillage	Rába-IH disc harrow + Güttler roller Kverneland BB 115 plough Kverneland CLE chisel plough	20 25 35
3.	Secondary tillage	Syncrogerm 6M seedbed maker	10

Commercially available tillage implements were used for the tillage done in this experiment (*Figures 1–5*). The tractor and tillage implement combination was driven along the experimental plot. One minute after the

Figure 1. Rába-IH disc harrow + Güttler roller

Figure 2. Kverneland CLE chisel plough

Figure 3. Kverneland BB 115 plough

Figure 4. Komondor mulch tiller

Figure 5. Syncrogerm 6M seedbed maker

tillage, the portable chamber was placed over the measurement area and the gas exchange measurement was performed. Two measurement series were made to get the initial flux of CO_2 immediately after the tillage. The gas exchange measurements were repeated on a regular cycle. In such a way each experimental area was tested at least once. The earliest test was done an hour after the initial tillage and the latest test was performed three hours after the initial tillage.

2.2. Instrumentation

Soil CO_2 fluxes were measured in situ using an INNOVA 1312 Multi Gas Monitor with a closed chamber system. The atmosphere immediately above the soil surface was enclosed by the chamber and the change in concentra-

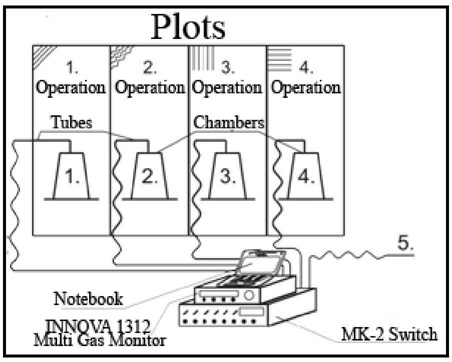

Figure 6. Measuring system

Figure 7. INNOVA 1312 Multi Gas Monitor

Figure 8. TESTO 535 CO_2 tester and portable chamber

Figure 9. The test car and the portable chambers

tion of CO_2 was generally measured every 15 minutes after the chamber closure. However, in some cases it was measured after either 30 or 60 minutes. Therefore the net emission from the soil was measured thus enabling gas flux to be determined. After a field validation process performed with the INNOVA system, the TESTO 535 CO_2 tester was used for the further tests (*Figures 6–9*) because the INNOVA was too expensive.

3. Results and Discussion

3.1. Stubble Mulching

The CO_2 flux as a function of time for each tillage treatment in the first 85 to 105 minutes can be seen in *Figures 10–12* and a comparison is shown in *Figure 13*.

No considerable differences were observed immediately after the tillage. The CO_2 flux measured during 85 to 105 minutes showed some advantage with the mulch tiller where the rear part (spring loaded crumbler) of the machine was effective.

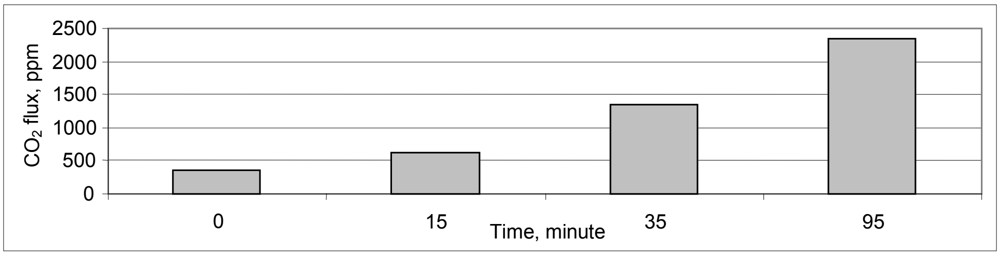

Figure 10. CO_2 flux versus time after chisel ploughing

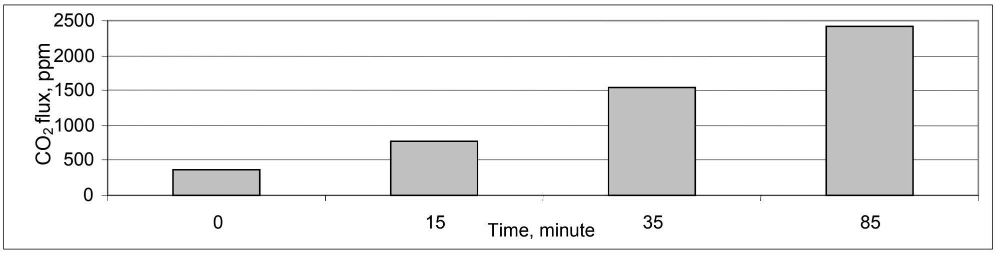

Figure 11. CO_2 flux versus time after disc harrowing

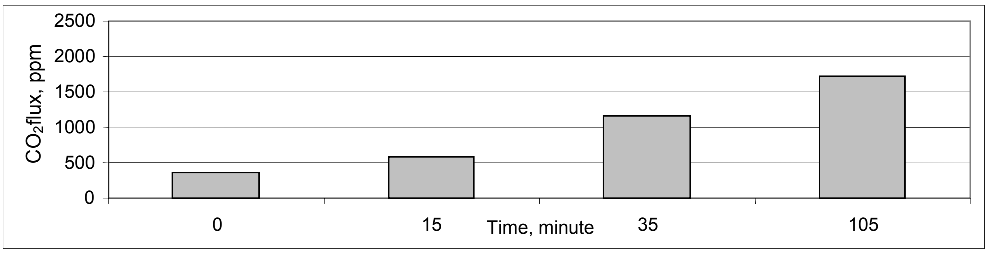

Figure 12. CO_2 flux versus time after mulch tilling

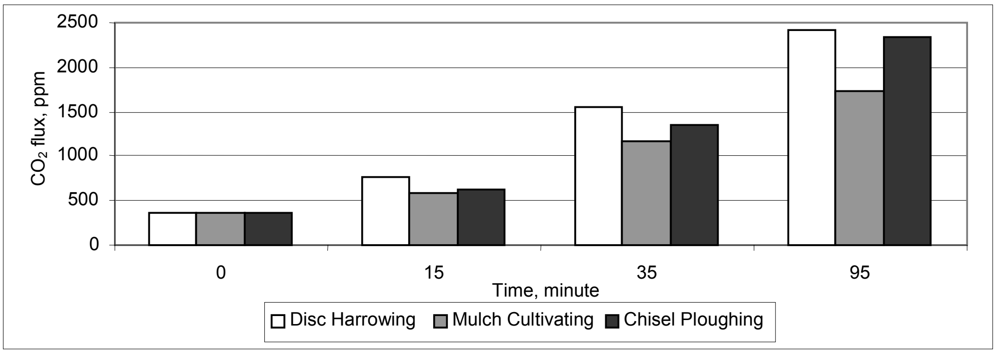

Figure 13. CO_2 flux versus time after stubble mulching

3.2. Primary Tillage

The CO_2 flux as a function of time for each tillage treatment in the first 2.5 hours can be seen in *Figures 14–17* and a comparison is shown in *Figure 18.* In the case of chisel ploughing, the emission was measured along the shank and between the shanks, and an average value was calculated.

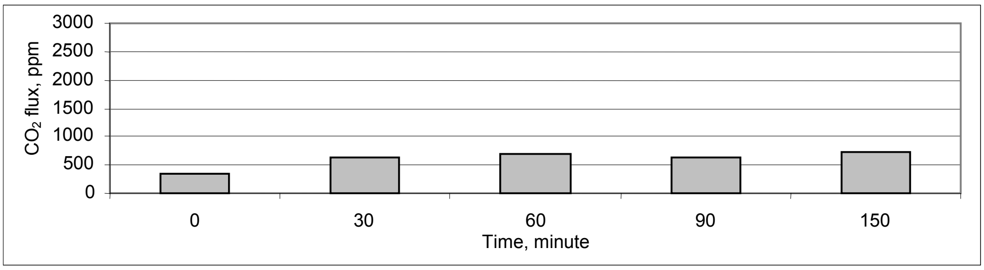

Figure 14. CO_2 flux versus time in the reference chamber

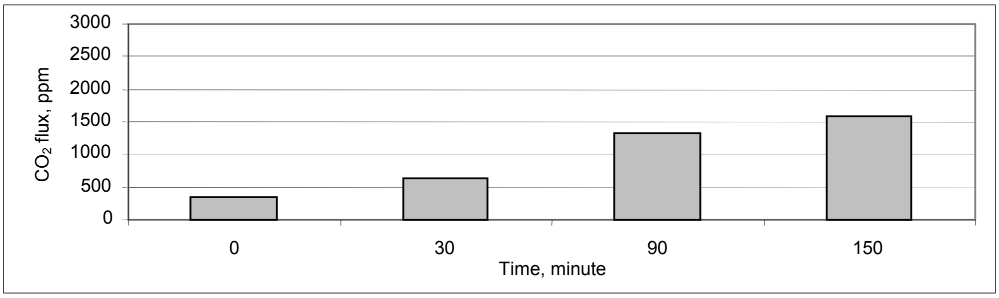

Figure 15. CO_2 flux versus time after disc harrowing

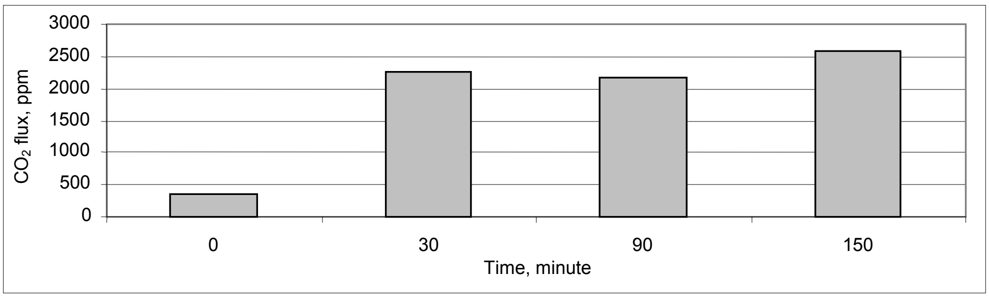

Figure 16. CO_2 flux versus time after ploughing

Relatively high CO_2 fluxes were measured in the case of intensive soil disturbance where the soil surface was rough and the porosity was high. The initial fluxes were relatively large from the surface tilled with a mold-board plough, but in this case the increase was not high later on *(Figure 16).* However, the fluxes from the soil surface tilled with the disc harrow *(Figure 15)* and the chisel plough *(Figure 17)* showed a continuous increase.

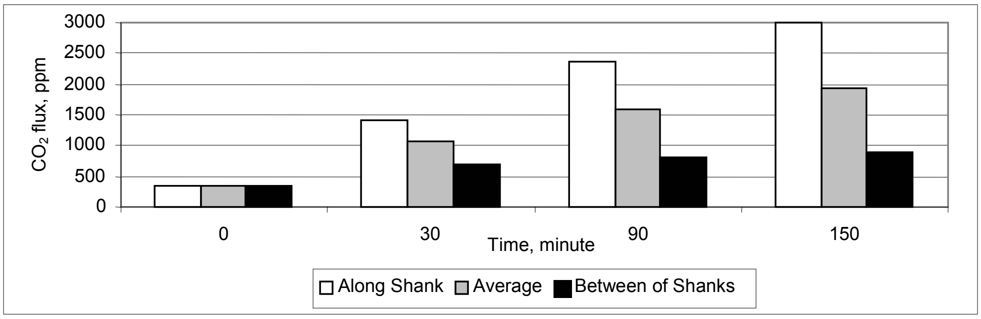

Figure 17. CO_2 flux versus time after chisel ploughing

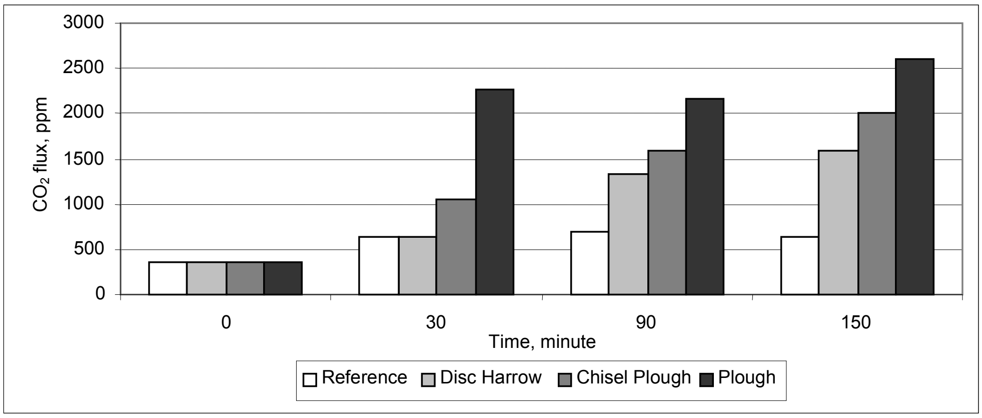

Figure 18. CO_2 flux versus time after different operations

3.3. Secondary Tillage

The CO_2 flux after seedbed preparation as a function of time for each primary tillage pre-treatment in the first 90 to 120 minutes can be seen on *Figures 19–22* and compared in *Figure 23.*

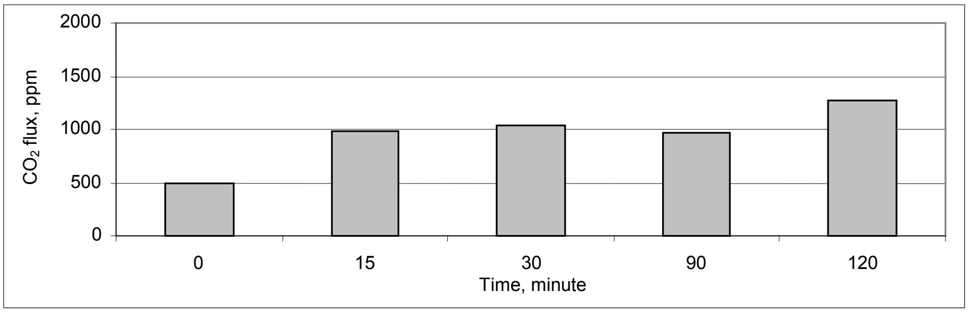

Figure 19. CO_2 flux versus time after disc harrowing

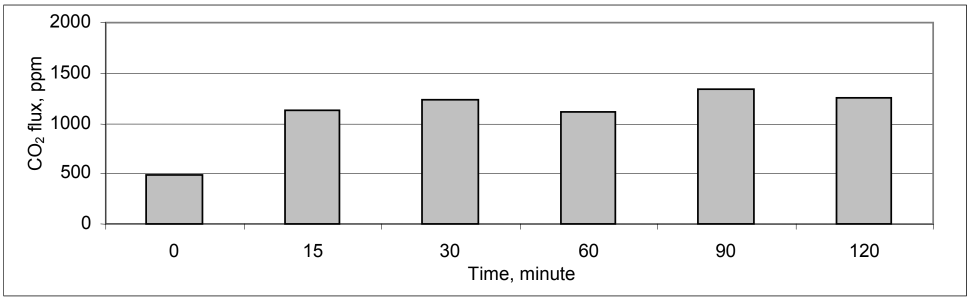

Figure 20. CO_2 flux versus time after mulch tilling

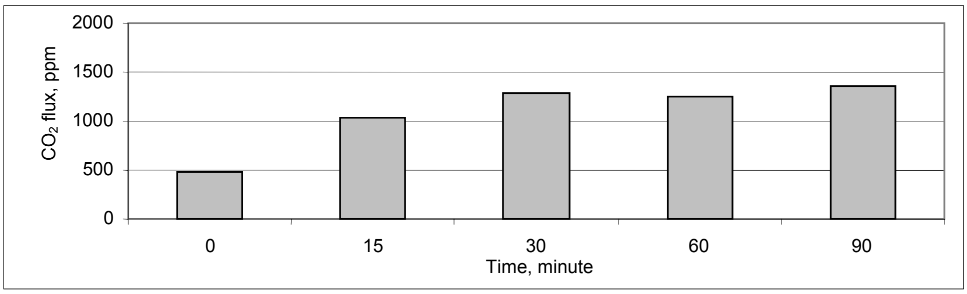

Figure 21. CO_2 flux versus time after chisel ploughing

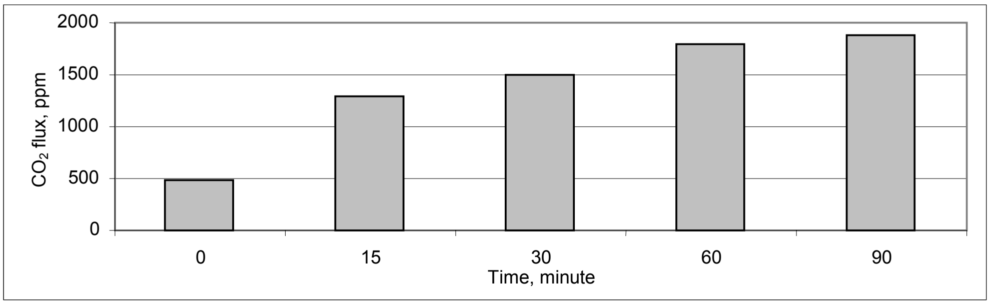

Figure 22. CO_2 flux versus time after moldboard ploughing

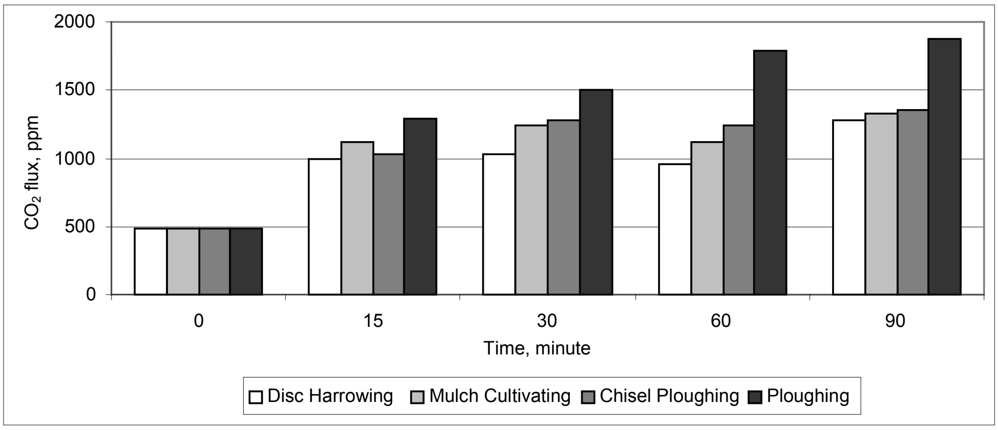

Figure 23. CO_2 flux versus time after different operations

The long-term (seasonal) effect of the different methods of primary tillage was observed after seedbed preparation. All conservation tillage implements produced less CO_2 than the moldboard plough. Because the conservation tillage implements were primarily designed to leave crop residue on the surface, they have a secondary benefit that results in less CO_2 loss.

4. Conclusions

Conclusions drawn from the results of the field experiments are as follows:

– The methods and instruments used for CO_2 emission measurement in the field have to be further developed to improve the accuracy of the measurements.

– The weather conditions, primarily the temperature, have a great influence on the soil CO_2 emission. However, with temperatures below 10°C there is no significant difference between the various tillage methods used for the experiments.

– Intensive tillage to a definite depth, such as moldboard ploughing, results in a rough soil surface. As a consequence, this kind of tillage causes an essential carbon loss in the soil. The plough loosens the soil which allows fast CO_2 and oxygen exchange. Ploughing incorporates residue into the soil which feeds the microbial population. In the case of conservation tillage, the majority of the residues are left on the soil surface, therefore only a small portion is in close contact with the soil moisture and the microorganisms.

– The primary tillage implements can be evaluated according to the CO_2 emission after tillage. The highest emission was measured with the moldboard plough, a high emission was experienced with the chisel plough, the emission was low with the heavy disc harrow, and the lowest emission occurred with the mulch tiller.

– It was concluded that the efficient operation of the different primary tillage implements has a principal influence on the soil carbon loss via CO_2 emission.

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