Soil CO_2 Emission Induced by Tillage Machines

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Abstract

Human activity caused significant changes in Earth's atmosphere generated primary by greenhouse gas emission of increased energy production, industrial activity, intensive agriculture and forestry of the last century. Tillage has prominent role in the climate change mitigation and reversal. Important emitter of natural greenhouse gases is the cultivated soil. The absolute value of carbon-dioxide emission of the agricultural soils can be estimated well, although further researches are necessary in this field to establish adequate description of carbon dioxide emission from soil after different cultivation methods and tillage practices. We are studying the relations of tillage and soil carbon-dioxide emission (CO_2 flux). Our research of the last ten years pointed to the correlation of tillage intensity and short term CO_2 flux. To have information about the amount of emitted CO_2, information is needed on the intermediate-term impacts of various tillage operations. We made intermediate-term studies on different fields and measured the emitted carbon-dioxide flux of different tillage machines after tillage using validated portable chamber method. The examined operations were moldboard ploughing, field cultivating and compact disc harrowing. Investigated the results of the long term study has shown, that the quantity of emitted CO_2 by the moldboard ploughing was 36% higher while the disc harrowing and field cultivating produced only 18% and 5% more CO_2 flux as the reference plot.

Keywords: CO2 emission, tillage, soil, intermediate effect, soil greenhouse gas emission

1. Introduction

Change of our climate is basically induced by the altering concentration of the natural and artificial greenhouse gases in the Earth's atmosphere. Detailed instrument data has shown that concentrations of these gases had been increasing since preindustrial times, particularly in recent decades, largely due to human industrial, agricultural, and urbanization activities (Dunne and Harte, 2001).Changes of local climate can be well observed continuously by singular wetter effects, but long term impact of climate change is still highly uncertain, because of uncertainties in basic understanding of numerous feedbacks mechanisms of Earth's climate system (Kump, 2002). Researcher's guidelines managed to recognize the urgent operation necessity by the governments of the developed countries. Action protocols required to mitigate anthropogenic emission effects were firstrecorded under international law by the so-called Kyoto Protocol(Fodor and Peine, 2014).

The most important naturally occurring greenhouse gases are water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3) (Dunne and Harte, 2001). CO_2 is the most important greenhouse gas, because increase in its concentration causes about 50% of the total radiative forcing (Rodhe, 1990). Fundamental research is vital to develop the revolutionary mitigation strategies needed in the second half of this century and beyond (Pacala, 2004).

The agricultural sector is responsible for approximately 10–13% of total global anthropogenic emissions of GHGs, the net CO_2 exchange from agriculture soils is approximately at equilibrium, substantial mitigation potential exists in sequestering atmospheric CO_2(Smith, Grant and Desjardins, 2009). Improved agricultural practices have great potential to increase carbon sequestration and decrease the net emission of carbon dioxide and other greenhouse gases, but available information has not been synthesized in a form that policy makers and land managers readily can 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 impacts soil, water, and air quality. 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.
Tillage practices have a measurable influence on soil C storage after 5-40 years. Tillage-induced changes in soil C storage may reflect both the immediate (within 7 d) influence of tillage operations on CO_2 fluxes, and the longer-term influence of tillage on the decomposition environment. Fluxes of soil CO_2 initially were equal, then immediately after tillage increased, but fluxes along tilled and undisturbed transects became similar between 10 and 24 h after cultivation (Ellert and Janzen, 1999). Differences in soil CO_2 flux were measured after 19 days of moldboard ploughing on clay loam fields in Minnesota (Reicosky and Lindstrom, 1993). Also a gradual increase in CO_2 output from CT soil appeared to occur approximately 1 month after plowing, suggesting a lag phase between plowing and maximum soil biotic activity (Hendrix, Han and Groffman, 1988). The initial emission intensity depends on the depth of tillage (Reicosky and Lindstrom, 1993), but significant differences due to field heterogeneity can be observed during the measurements (Reicosky, 1995; La Scala *et al.*, 2000).

The moisture-free pore space of soil is filled with air, which is continuously varying with time. This air-holding pore space will be filled with water after heavy rainfall and newly refilled with air with soil drying. This process is repeating steadily with wetter turning (Stefanovits, Filep and Füleky, 1999).Soil top layer aeration has a great importance for regular activity of biological processes. Vital processes of plant roots need oxygen and the end-product of the root respiration is carbon dioxide(Sitkei, 1997).Soil respiration represents the sum total of all soil metabolic functions in which carbon dioxide is produced. It includes three biological processes, viz., microbial respiration, root respiration, and faunal respiration, and one nonbiological process, i.e., chemical oxidation which may be particularly pronounced at high temperatures. The rate of soil respiration is governed directly or indirectly by two major environmental factors, viz. temperature and moisture. It is also affected by nutrient status of the soil, soil depth, and by cultural practices, such as the application of fertilizers and crop growth(Singh and Gupta, 1977).Soil respiration is the main pathway for carbon moving from the ecosystem to the atmosphere and can strongly influence net carbon uptake from the atmosphere (Ryan and Law, 2005). Respiration is very difficult to model because soil is a complex medium that consists of a broad range of types of organo-mineral particles and aggregates and that contains numerous organisms with differing physiological processes. Soil properties vary temporally and spatially, both horizontally and vertically(Davidson and Trumbore, 1995). There are various measurement techniques to determine soil respiration by in situ field conditions. The mostly used methods are chamber techniques which main principle lies at one basis: a definite area of the soil surface, is isolated from the air of the atmosphere by an isolation chamber. The CO_2 evolved from the soil into the chamber is determined quantitatively (SINGH andGUPTA, 1977). Emitted carbon-dioxide quantity of studied soil type and tillage operation can be calculated from measured changes of chamber CO_2 concentration, the covered soil surface, isolation chamber volume and incubation time.

Several research subjects are looking for the optimal chamber shape. Different chamber configurations are used to studysoil CO_2 emission. Research papers mention also large, ventilated chambers up to 3.25 m^3 volume(Reicosky, 1990), and smaller, portable chambers with cylindrical or rectangular shape (Zsembeli*et al.*, 2005; Parkin and Venterea, 2010). Some of these are shown on *figure 1.*

Our aim was to determine the intermediate-term effect on soil CO_2 emission of conventional and conservation tillage machines. Reducing soil CO_2 emission and keeping soil carbon has important benefits for the sustainability and productivity of the agro ecosystem.

2. Materials and Methods

Studies were executed on two sites with different soil base on wheat stubble.The first study was set on clay loam soil with high humus content in Enying (county Fejer) and the second on sandy clay soil with low humus content in Mesztegnyo (county Somogy),Hungary (*Table 1.*). Past years tillage practice was conventional tillage on every site.

The intermediate–term influence of tillage on soil CO_2 evolution was assessed by recording 3 series of successive measurements. Each series included a pre-tillage measurement to assess „reference" flux uniformity, followed by two different past-tillage measurement to compare fluxes along tilled and undisturbed plots. Tillage machines used to prepare measurement field were selected from field owner's equipment. These are shown on *figures 2-5* taken at site preparation.

Soil CO_2 fluxes were measured in situ using the calibrated TESTO 535 CO_2 tester (*Figure 6.*). By the earlier years experiences we used conical shaped, 8 liter and also rectangular shaped, 27 liter volume polyethylene sampling chambers. Chambers were installed by penetrating them into the soil to separate chamber air from the atmosphere. The sampling was made by every plot on minimum three random places. Measurements were made using the former validated ventilated method, where the chambers were aerated after each measurement cycle. Air CO_2 concentration and temperature was measured 1 meter height above the plots and also the soil temperature was measured and registered before every cycle.

Measurement cycle time was proposed to follow soil CO_2 emission intensity byobservationsof former studies to optimize representation of CO_2 flux. Smaller cycle times were used by higher CO_2 flux intensity expected in the first 3-5 hours after tillage and larger cycle times were defined in the rest of the measurement (*Table 2.*). Minimum measurement cycle time was limited by the number of the chambers, the net measurement duration (the infrared sensor needs 60-90 second time to conform to chamber climate) and the incubation time. Duration of emitted CO_2 accumulation was calculated to minimize measurement error and avoid alteration of soil microclimate by the isolation effect of the chamber.

Field heterogeneity was represented by moving the chamber to new sampling points after every measurement cycle. This method also eliminated measurements distortion by sampling points allocated on non-visible cultivation or other technological faults.

Measurement data was registered in [ppm] which specify gas concentration in [µmol/mol] unit. First step of data processing was the defining of CO_2 flux intensity by calculating [ppm] data forper unit surface and timeby using undermentioned equation (Meyer, Reicosky and Shell, 1987; Widén and Lindroth, 2003):

$$F_{CO_2} = \frac{dC}{dt}\frac{V * p * M}{R * (273{,}15 + T) * A} \qquad (1)$$

where$F_{CO_2}$is CO_2flux intensity$\left[\frac{g}{m^2 h}\right]$, $dt$is incubation time[h], $dC$is CO_2concentration change during incubation time$\left[\frac{mol}{mol}\right]$, V*is the chamber volume*$[m^3]$, p *is the atmospheric pressure*$[Pa]$, Mismolar mass of CO_2=44,01 $\left[\frac{g}{mol}\right]$, R is the universal gas coefficient = 8,314 $\left[\frac{J}{mol*K}\right]$, T is the temperature$[\,^oC]andA$ is the surface under the chamber$[m^2]$.

3. Results

Because of the varying measurement cycle times through the entire measurement periods the measurement points are not uniform distributed along time. Data processing was done after interpolating calculated flux intensity using shape-preserving piecewise cubic Hermite interpolation.Processed CO_2intensity curves and measured temperature data are shown on *figures 7-8.*in function of time. Marked points of the curves are the measured values.

Emission immediately after tillage shows the typical rapid increase with some fluctuation due to the impact of altering oxygen conditions followed by tillage. Intensity of CO_2 flux is continuously decreasing till the measured data of disturbed soil reaches similar values as measured by the untilled plots. According to visualized data the intensity of the CO_2 flux is depending not only on initial emission, but also on temperature. Intensity data curves of the untilled plots are obviously showing similarity with temperature curves.

Same flux intensity of tilled and untilled plots is well observable after 11-15 hours by the first measurement. The rapid decreasing of CO_2 emission intensity by the influence of lowering night temperature makes unable to notice the same effect by the second measurement.

Quantity of emitted CO_2 was determined using numerical integration of the interpolated data by low resolution trapezoidal principle. Calculated values of emitted carbon dioxide on all measurements and plots are summarized in *table 3*.

Tillage intensity, through the action of soil disturbance, changing soil aeration and the produced size of soil aggregates has a great influence on emitted amount of carbon dioxide. According to processed measurement data, moldboard ploughing expanded CO_2 emission mostly, because of the catalyzed microbial activity through the intensive oxygen incorporation. Resulted aggregate size and the uneven soil surface also contribute to large gas exchange (*Figure 9-10.*). The dominance of larger clods after tillage leads to fast continuously oxygen supply of microbiological processes through higher horizontal and vertical air penetration on the ploughed soil. The effect of missing packer equipment also reduces the accumulation of evolved CO_2.

The results of our research support the increased use of conservation tillage equipment with packer, to reduce the emission of soil $CO_2$to the emission of untilled field. The use of suitable packer for crushing clods and compact the soil surface layer has the same effect on CO_2 loss as on moisture conservation.

4. Conclusions

Based on the amount of carbon dioxide emitted by the studied tillage operations (ploughing, disk harrowing, cultivating) CO_2 emission of the plowed fields has the worst effects on climate change.

Investigated the results of the long term study has shown, that the quantity of emitted CO_2 by the moldboard ploughing was 36% and 61% higher by different soil conditions (clay loam and sandy clay), while disc harrowing produced only 18% and 5% higher CO_2 flux respectively as the reference plot.

From only the tillage operations point of view, the disc harrowing produced 13% and field cultivating 53% less emission than the ploughing. The amount of emitted carbon dioxidefrom theserelative differenceswere 12.18 kg/ha and 45.35kg/ha respectively during measurement time period. This difference came mostly from the intensity of tillage and the used packer equipment.

The technological sustainability criterion is spreading in the European Union's legal order, which foresees two important tasks in respect of soil tillage. First, there is a needto determine quantitatively the CO_2 emission of the various agricultural soil types after tillage. Gas emissions quantity strongly depends on type and organic material supply of soils. Conducting comprehensive series of measurements of different soil types using developed modeling methods, a "soil-emission databank" can be created which can give practical usability to soil emission measurements.

On the other hand, since the emissions after tillage is significantly dependent of the intensity of tillage, the tillage machine design, the established clod size and soil surface, thus creating the tillage equipment sustainability analysis by generalized method and model is indispensable. Development of new, low soil-emission tillage machines and tillage practices could be classified on this base, to promote climate-safe tillage procedures.

5. References

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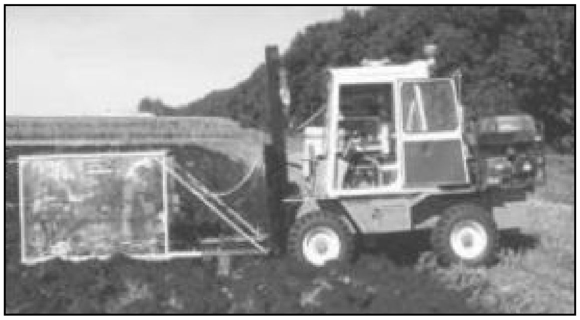
6. Figures and Tables



a.)

b.)

c.)

c.)

Figure 1: Soil CO_2 Emission Measurement Chambers with Different Shape and Size

a.) 3.25m^3 size rectangular shaped chamber. Source: (Reicosky, 1990)
b.) Small volume conical chamber. Source: (Kovács *et al.*, 2008)
c.) Small volume rectangular shaped chamber. Source: (Parkin and Venterea, 2010)
d.) Small volume cylindrical shaped chamber with temperature measurement. Source: (Parkin and Venterea, 2010)

Figure 2: Kverneland BB 115 moldboard plow

Figure 3: Kuhn Optimator compact disc harrow

Figure 4; Vogel&Noot ©plus XM reversible plow

Figure 5: ***PöttingerSynkro field cultivator with non-series packing equipment***

Figure 6: TESTO 535 CO_2 Tester and Portable Chambers

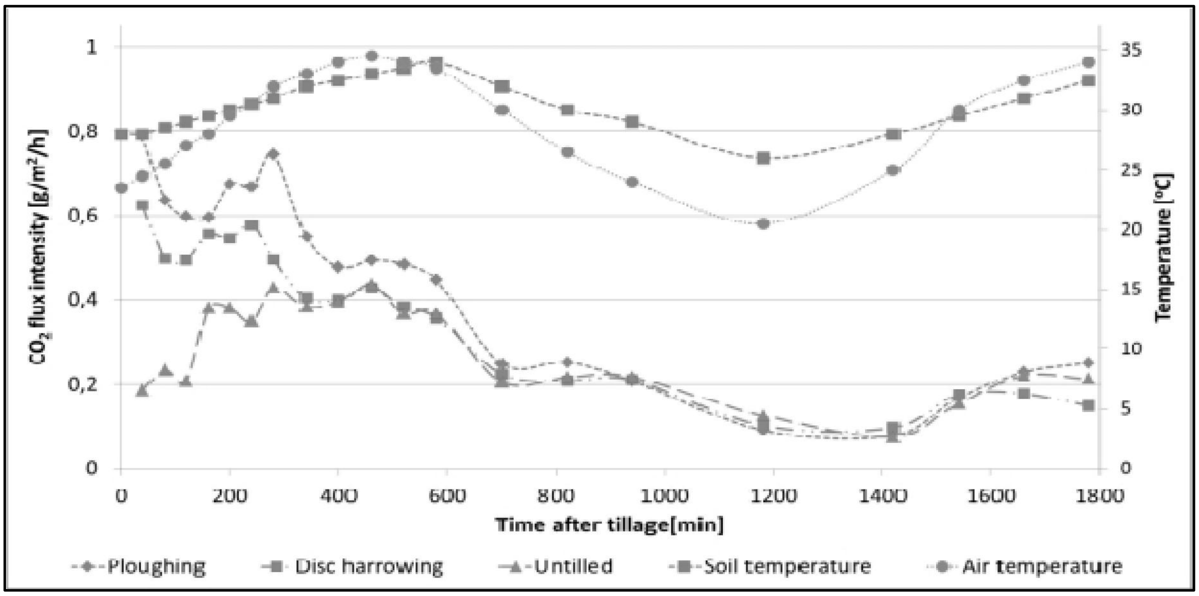


Figure 7: CO_2 Flux Intensity and Temperature Data in Function of Time (1. Measurement)

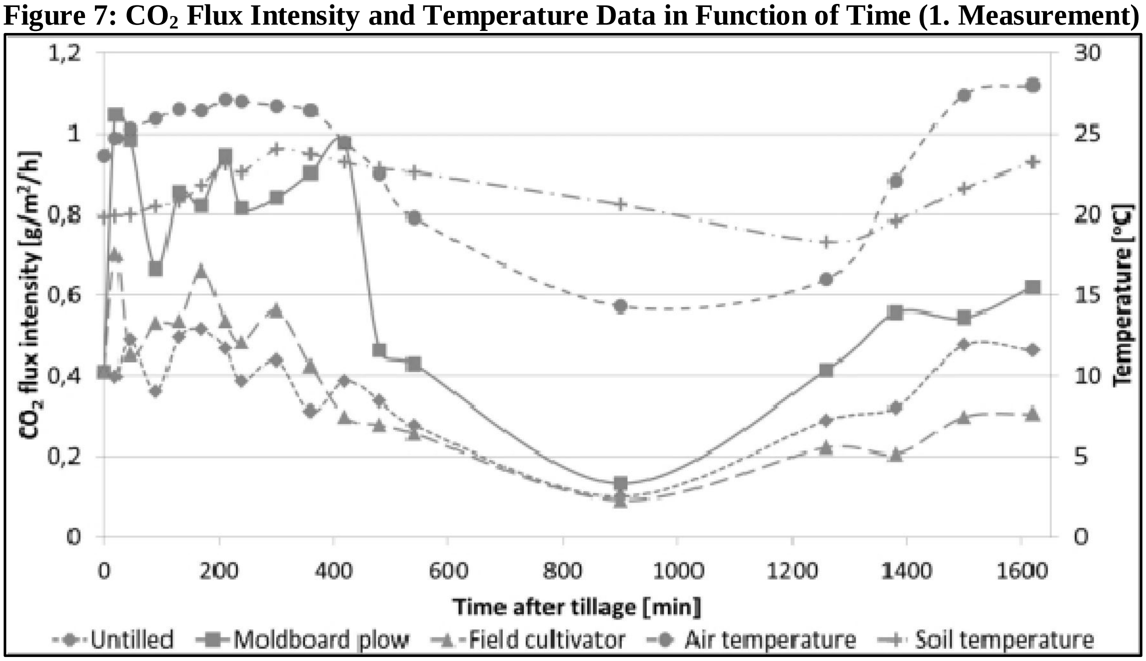


Figure 8: CO_2 Flux Intensity and Temperature Data in Function of Time (2. Measurement)

Figure 9. Surface aggregates after disc harrowing (1. measurement)

Figure 10. Surface aggregates after moldboard ploughing (2. measurement)

Table 1: Site Specification of Measurements

Meas. No.	Tillage operation / date	Site name	Weather condition	Tillage machines	Tillage depth, cm
1.	Stubble mulching on wheat stubble 15.07.2004.-16.07.2004.	Enying "S4"	dry, sunny, 30°C	Kuhn Optimator compact disc harrow	12-14
				Kverneland BB115 moldboard plow	24-26
2.	Stubble mulching on wheat stubble 20.07.2014.-30.07.2014.	Mesztegnyő "H1"	dry, sunny, 28°C	PöttingerSynkro field cultivator	20-22
				Vogel&Noot reversible plow	32-35

Table 2: Duration of Measurement Cycles

Measurement period after tillage	Measurement cycle
0-4 hours	45 minutes
4-9 hours	60 minutes
9-30 hours	120 minutes
night time	240-360 minutes

Table 3: Comparison of Emitted Carbon Dioxide Amount on Measured Plots

Measurement No.	Tillage operation	Amount of emitted CO_2 during measurement time [g/m^2]	Deviation of tilled plots from untilled surface	
			[g/m^2]	[%]
1.	**Untilled**	6.876	-	100
	Moldboard plowing	9.380	2.504	136
	Disc harrowing	8.162	1.286	118
2.	**Untilled**	8.074	-	100
	Moldboard plowing	13.044	4.970	161
	Field cultivating	8.509	0.435	105