Original scientific paper

Tillage induced CO_2 emissions in relation to soil parameters

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Abstract

Carbon dioxide (CO_2) emissions from soil play an important role in the global carbon cycle. Tillage management can increase atmospheric CO_2 concentrations and contribute to global warming but it is uncertain to which extent tillage enhances the transfer of soil CO_2 to the atmosphere. The objectives of our research were to assess, on six different tillage treatments that have been managed since 1994 as: black fallow - BF, ploughing up and down the slope to 30 cm - PUDS, no-tillage – planting direction up and down the slope – NT, ploughing across the slope to 30 cm – PAS, very deep ploughing across the slope to 50 cm - VDPAS and subsoiling across the slope to 50 cm – SSPAS, the effects of primary tillage (ploughing to 30 cm depth) and secondary tillage (disking and harrowing) on short-term soil CO_2 efflux relative to no-tillage (NT) treatment and to determine correlation between soil CO_2 efflux and soil parameters (soil temperature, soil moisture and electrical conductivity) on Stagnic Luvisols in Croatia. Soil CO_2 concentrations were measured 0, 3 and 6 hours after primary tillage and 1 and 4 hours after secondary tillage by closed static chamber method in September 2012. CO_2 effluxes immediately after primary tillage were higher on PAS, VDPAS and SSPAS while lower on BF and PUDS treatments compared to NT treatment. Already 3 and 6 hours after primary tillage, the soil CO_2 effluxes were lower on all tilled treatments compared to NT treatment. After secondary tillage, CO_2 effluxes were lower on all tilled treatments compared to NT treatment. The highest average soil CO_2 efflux after primary tillage was determined at PAS treatment (62.30 kg $ha^{-1}day^{-1}$), followed by respectively: SSPAS (61.35 kg $ha^{-1}day^{-1}$), VDPAS (48.98 kg $ha^{-1}day^{-1}$), PUDS (35.19 kg $ha^{-1}day^{-1}$) and BF(16.65 kg $ha^{-1}day^{-1}$) treatment while average soil CO_2 efflux at NT treatment, amounted 68.48 kg $ha^{-1}day^{-1}$. The highest average soil CO_2 efflux after secondary tillage was determined at VDPAS treatment (26.39 kg $ha^{-1}day^{-1}$), followed by respectively: SSPAS (24.97 kg $ha^{-1}day^{-1}$), PAS (15.69 kg $ha^{-1}day^{-1}$), PUDS (9.99 kg $ha^{-1}day^{-1}$) and BF (8.56 kg $ha^{-1}day^{-1}$) treatment while average soil CO_2 efflux at NT treatment amounted 59.21 kg $ha^{-1}day^{-1}$. CO_2 effluxes were very weak negatively correlated with soil temperature (r=0.12) and soil moisture (r=0.16) while moderate negatively correlated with electrical conductivity (r=0.40). Electrical conductivity was weak positively correlated with soil temperature (r=0.28) and strong positively correlated with soil moisture (r=0.52) while non correlation was determined between soil temperature and soil moisture (r=0.01). Our study suggests that tillage had impact on soil CO_2 efflux and accelerates the transfer of soil CO_2 to the atmosphere but it declined sharply within hours after tillage operations.

Key words: CO_2 efflux, tillage, soil temperature, soil moisture, electrical conductivity

Introduction

Agriculture plays an important role in the global flux of greenhouse gases. In 2010, agricultural sector contributed by 11.4% to total greenhouse gas emission in Croatia (National Inventory Report, 2012). Agricultural soils can act both as a source or a sink of greenhouse gases. The CO_2 flux from soil to the atmosphere (soil respiration) determines the extent to which plant carbon added to the soil is retained or released to the atmosphere. Soil CO_2 fluxes are strongly dependent on plant and soil microbial growth as influenced by temperature and moisture and are also sensitive to agricultural management, including selection of crop species, tillage and addition of fertilizers and manure (Ellert and Janzen, 1999). Tillage accelerates soil CO_2 emissions by changing soil climate, disrupting soil aggregates, increasing aeration, increasing contact between soil and crop residue and speeding organic carbon decomposition (Gregorich et al., 2005; Bilen et al., 2010). Tillage may have long-term influence on soil CO_2 flux but also it often increases short-term soil CO_2 flux due to a rapid physical release of CO_2 trapped in the soil air pores. It can be said that tillage management can increase atmospheric CO_2 concentrations and contribute to global warming but it is uncertain to which extent tillage enhances the transfer of soil CO_2 to the atmosphere. Due to mentioned above, the objectives of our research were to assess the effects of primary tillage (ploughing to 30 cm depth) and secondary tillage (disking and harrowing) on short-term soil CO_2 effluxes relative to no-tillage (NT) and to determine correlation between soil CO_2 effluxes and soil parameters (soil temperature, soil moisture and electrical conductivity).

Materials and Methods

Experimental site and tillage treatments

Field experiment with six different tillage treatments usually implemented in Croatia was set up in Blagorodovac near Daruvar (elevation: 133 m asl; N 45º33´937´´, E 17º02´056´´) in central, lowland Croatia. Field experiment was established in 1994 with the aim of investigation on determination of soil degradation by water erosion and later, in 2011, expanded to the research on soil CO_2 concentration measurements. Soil type at the experimental site is determined as Stagnic Luvisols (IUSS Working group World reference base for soil resources, 2006). Tillage treatments differed in tools that were used, depth and direction of tillage and planting. Size of each tillage treatment is 22.1 m x 1.87 m. Tillage treatments are:

BF: black fallow, control treatment – ploughing direction is up and down the slope, disked and harrowed (without cover crop);

PUDS: ploughing to 30 cm – ploughing and planting direction is up and down the slope, disked and harrowed;

NT: no-tillage – planting in conducted directly into the mulch with planting direction up and down the slope;

PAS: ploughing to 30 cm – ploughing and planting direction is across the slope, disked and harrowed;

VDPAS: very deep ploughing to 50 cm – ploughing and planting direction is across the slope, disked and harrowed;

SSPAS: ploughing to 30 cm plus subsoiling to 50 cm – ploughing, subsoiling and planting direction is across the slope, disked and harrowed.

Very deep ploughing to 50 cm on VDPAS treatment and subsoiling to 50 cm on SSPAS treatment are implemented every 3 to 4 years since the experimental site was established (due to their prolonged effect) and they were last implemented in 2011. In 2012, primary tillage (ploughing to 30 cm depth) was implemented on 28 September and secondary tillage (disking and harrowing) on 29 September on all tillage treatments except the NT treatment.

Measurement of CO_2 concentrations

Soil CO_2 concentrations were measured 0, 3 and 6 hours after primary tillage implementation and 1 and 4 hours after secondary tillage implementation. For the measurement of soil carbon dioxide concentrations, the closed static chamber method was used. The chambers are made of lightproof metal material to avoid the sunlight effect on the measurements, and they consist of two parts: frames and caps. The circular frames (25 cm in diameter) are inserted between the growing plants about 5 cm into the soil at the beginning of measurements. The caps are 25 cm in diameter and 9 cm high, fitted with a gas sampling port. Before the chambers closure, the initial CO_2 concentrations inside the frames near soil surface were measured. Afterwards, the chambers were closed with caps and the incubation period was 30 minutes after which the CO_2 concentrations in closed static chambers were measured. In situ measurements of carbon dioxide concentrations (ppm) in the chambers were conducted with portable infrared carbon dioxide detector (GasAlertMicro5 IR, 2011). Measurements were conducted on bare soil and when necessary (at the no-tillage treatment), vegetation was removed from frames inside before the beginning of measurement.

Measurements of carbon dioxide concentrations were conducted in three repetitions at each treatment. The soil carbon dioxide efflux (expressed as kg CO_2 per ha per day) was afterwards calculated according to Widen and Lindroth (2003) and Toth et al. (2005) as:

$$F_{CO2} = [M * P * V * (c_2 - c_1)] / [R * T * A * (t_2 - t_1)]$$

Where:

F_{CO2} – soil CO_2 efflux (kg $ha^{-1}day^{-1}$)
M – molar mass of the CO_2 (kg mol^{-1})
P – air pressure (Pa)
V – chamber volume (m^3)
$c_2 – c_1$ - CO_2 concentration increase rate in the chamber during incubation period (µmol mol^{-1})
R – gas constant (J $mol^{-1}K^{-1}$)
T – air temperature (K)
A – chamber surface (m^2)
$t_2 – t_1$ – incubation period (day)

Measurement of soil parameters

The aim of the research requires reliable data on soil temperature, soil moisture and electrical conductivity in the soil surface layer (at 10 cm depth). Soil temperature (°C), soil moisture (%) and electrical conductivity (dS/m) were determined with adequate instrument (IMKO HD2 - probe Trime, Pico64, 2011) at 10 cm depth in the vicinity of the chamber along with each measurement of soil CO_2 concentration.

Results and Discussion

On the day when primary tillage was conducted, sky was cloudy in the morning and by the afternoon it becomes sunny. Air temperature ranged from 12.8 to 22.5°C and relative air humidity ranged from 39 to 75%. On the day when secondary tillage was conducted, the weather was cloudy and windy during day. Air temperature ranged from 14.0 to 16.7°C and relative air humidity ranged from 64 to 81%.

Soil CO_2 effluxes and soil parameters after primary and secondary tillage

In general, tillage induced soil CO_2 effluxes varied widely with treatment and time of measurement (Figure 1). Emissions were greater immediately after tillage but declined sharply within hours after tillage operations. CO_2 effluxes immediately after primary tillage (at 0 h) were higher on PAS, VDPAS and SSPAS treatments while lower on BF and PUDS treatments compared to NT treatment. Already 3 (and 6) hours after primary tillage, the CO_2

effluxes were lower on tilled treatments compared to NT treatment. Reicosky and Lindstrom (1993), Ellert and Janzen (1999) and Al - Kaisi and Yin (2005) also obtained in their research that the effect of tillage on soil CO_2 emission was short-lived. The highest average soil CO_2 efflux after primary tillage was determined at PAS treatment (62.30 kg $ha^{-1}day^{-1}$), followed by respectively SSPAS (61.35 kg $ha^{-1}day^{-1}$), VDPAS (48.98 kg $ha^{-1}day^{-1}$), PUDS (35.19 kg $ha^{-1}day^{-1}$) and BF(16.65 kg $ha^{-1}day^{-1}$) treatment while average soil CO_2 efflux at NT treatment amounted 68.48 kg $ha^{-1}day^{-1}$. After secondary tillage, CO_2 effluxes were lower on all tilled treatments compared to NT treatment. The highest average soil CO_2 efflux after secondary tillage was determined at VDPAS treatment (26.39 kg $ha^{-1}day^{-1}$), followed by respectively SSPAS (24.97 kg $ha^{-1}day^{-1}$), PAS (15.69 kg $ha^{-1}day^{-1}$), PUDS (9.99 kg $ha^{-1}day^{-1}$) and BF (8.56 kg $ha^{-1}day^{-1}$) treatment while average soil CO_2 efflux at NT treatment amounted 59.21 kg $ha^{-1}day^{-1}$. Amount of CO_2 released into the atmosphere differed with different tillage systems and the amount of emitted CO_2 was related to the degree of soil disturbance.

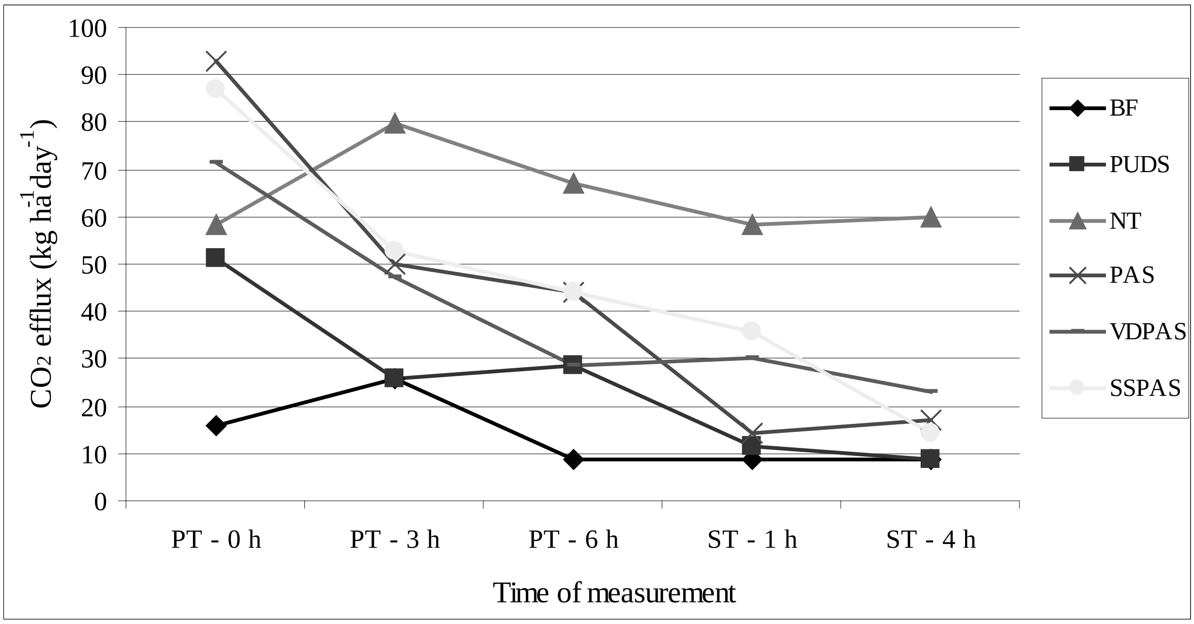

Figure 1. Short-term CO_2 effluxes after primary (PT) and secondary (ST) tillage

<u>*Correlation between soil CO_2 effluxes, soil temperature, soil moisture and electrical conductivity*</u>

CO_2 effluxes were very weak negatively correlated with soil temperatures (r=0.12) and soil moisture (r=0.16) while moderate negatively correlated with electrical conductivity (r=0.40). The weak correlation of CO_2 efflux with soil temperature and soil moisture reported in this study was in accordance with other reports from tillage experiments (Al- Kaisi and Yin, 2005; Kessavalou et al., 1998). Also, other researches (Pathak and Rao, 1998; Setia et al., 2010; Setia et al. 2011) have found a negative impact of salinity on soil CO_2 emissions. Electrical conductivity was weak positively correlated with soil temperature (r=0.28) and strong positively correlated with soil moisture (r=0.52) while non correlation was determined between soil temperature and soil moisture (r=0.01). Correlations between soil CO_2 efflux, soil temperature, soil moisture and electrical conductivity are presented at Figures 2-7.

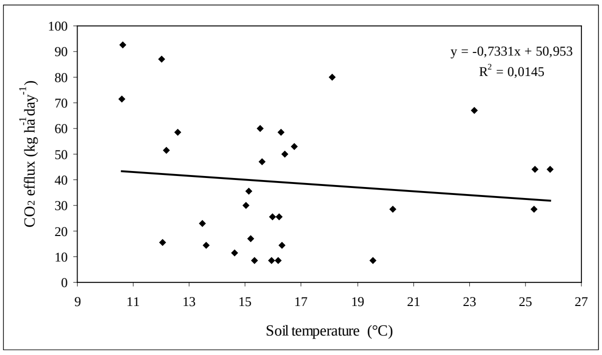

Figure 2. Correlation between soil CO_2 effluxes and soil temperature

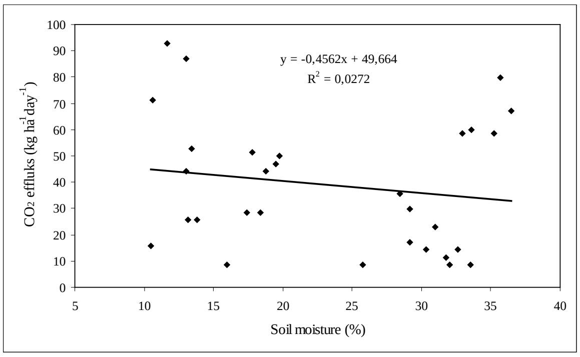

Figure 3. Correlation between soil CO_2 effluxes and soil moisture

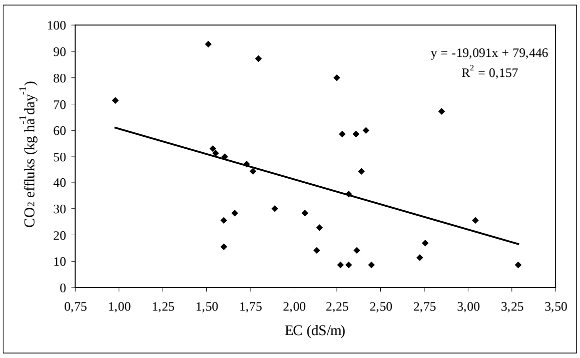

Figure 4. Correlation between soil CO_2 effluxes and electrical conductivity

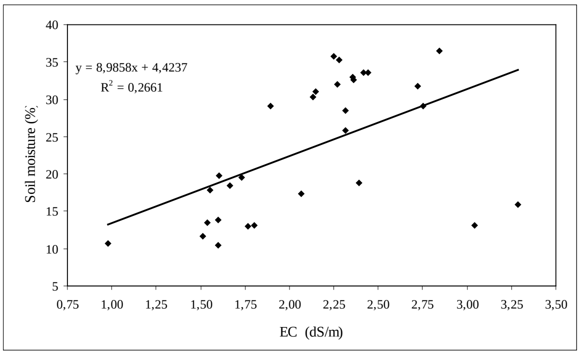

Figure 5. Correlation between soil electrical conductivity and soil moisture

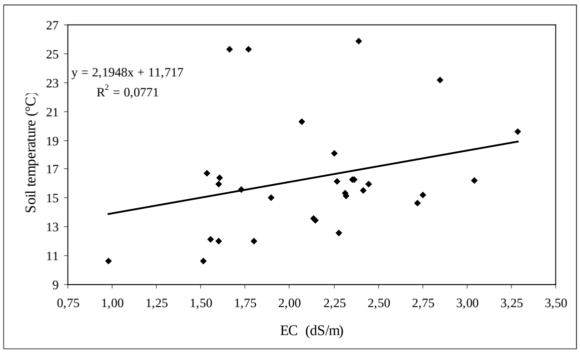

Figure 6. Correlation between soil electrical conductivity and soil temperature

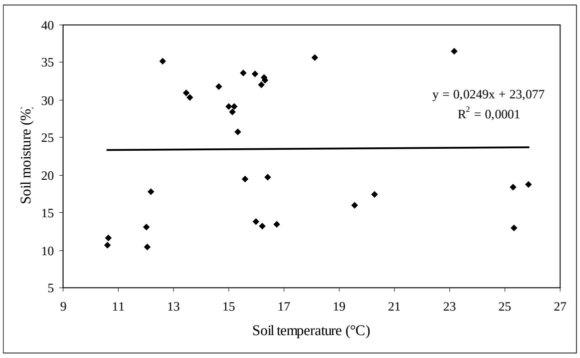

Figure 7. Correlation between soil moisture and soil temperature

Conclusions

Our study suggests that tillage had impact on soil CO_2 efflux and accelerated the transfer of soil CO_2 to the atmosphere but they were relatively short - lived. CO_2 effluxes were greater immediately after tillage but declined sharply within hours after tillage operations. CO_2 effluxes immediately after primary tillage were higher on PAS, VDPAS and SSPAS treatments while lower on BF and PUDS treatments compared to NT treatment. Already 3 (and 6) hours after primary tillage, the CO_2 effluxes were lower on tilled treatments compared to NT treatment. The highest average soil CO_2 efflux after primary tillage was determined at PAS treatment, followed by respectively SSPAS, VDPAS, PUDS and BF treatment. After secondary tillage, CO_2 effluxes were lower on all tilled treatments compared to NT treatment. The highest average soil CO_2 efflux after secondary tillage was determined at VDPAS treatment, followed by respectively SSPAS, PAS, PUDS and BF treatment. CO_2 effluxes were very weak negatively correlated with soil temperatures and soil moisture while moderate negatively correlated with electrical conductivity. Electrical conductivity was weak positively correlated with soil temperature and strong positively correlated with soil moisture while non correlation was determined between soil temperature and soil moisture. The amount of CO_2 emitted into the atmosphere differed with different tillage systems and was related to the degree of soil disturbance.

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