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Influence of tillage systems on short-term soil CO_2 emissions

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Abstract

Agricultural ecosystems can play a significant role in greenhouse gas emissions, specifically, carbon dioxide. 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. Our objectives were (1) to determine short-term, tillage-induced soil CO_2 emissions; (2) to determine the effect of different tillage systems and time after tillage operation on soil CO_2 emissions and soil microclimate and (3) to examine the relations between short-term soil CO_2 emissions and microclimate (soil temperature, soil water content; air temperature and relative air humidity). Soil CO_2 concentrations were measured on Stagnic Luvisols, in a temperate continental climate of the central lowland Croatia in October 2013 before, zero and three hours after tillage operations with *in situ* closed static chamber method. The four tillage systems were no-tillage (NT), ploughing to 25 cm (P_{25}), very deep ploughing to 50 cm (P_{50}) and subsoiling to 50 cm (PS_{50}). The study showed that tillage has impact on soil CO_2 emissions and soil microclimate. Tillage has accelerated the transfer of soil CO_2 to the atmosphere but soil CO_2 emissions declined sharply within three hours after tillage operations. Soil temperature has decreased after tillage operation and afterwards continued to rise while soil water content has been decreasing during whole study period. Correlations between soil CO_2 emissions and microclimatic factors were mostly weak or modest while best type of studied correlations between soil CO_2 emissions and microclimate showed to be the second order polynomial correlation.

Keywords: short-term soil CO_2 emissions, tillage, soil water content, soil and air temperature, relative air humidity

Introduction

Agricultural sector has contributed by 9.4 per cent to total Croatian greenhouse gas emissions in 2014 (NIR 2016). Agricultural soils can act both as a source or a sink of greenhouse gases. Tillage often accelerates and increases soil CO_2 emissions by speeding organic carbon decomposition i.e. decreasing soil organic matter, changing soil microclimate (temperature and water content), disrupting soil aggregates, increasing aeration and increasing contact between soil and crop residues (Gebhart, D.L. *et al.* 1994; Reicosky, D.C. *et al.* 1995, 1997; Gregorich, E.G. *et al.* 2005; Bilen, S. *et al.* 2010; Bilandžija, D. *et al.* 2016). Tillage may have long-term influence on soil CO_2 emissions but also it often increases short-term soil CO_2 emissions due to a rapid physical release of CO_2 trapped in the soil air pores (Bilandžija, D. *et al.* 2013). Tillage management can increase atmospheric CO_2 concentrations but it is uncertain to which extent tillage enhances the transfer of soil CO_2 to the atmosphere.

The objectives of our research were (1) to determine the effects of ploughing (30 cm depth), very deep ploughing (50 cm depth) and ploughing (30 cm depth) with subsoiling (50 cm depth) on short-term soil CO_2 emissions relative to no-tillage (NT); (2) to determine the effect of four different tillage systems and time after tillage operation on soil CO_2 emissions and soil microclimate; (3) to determine best function of correlation between soil CO_2 emissions and microclimatic conditions.

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Materials and methods

Experimental site and tillage systems

Field experiment with four different tillage systems usually implemented in Croatia was set up in Blagorodovac near Daruvar (elevation: 133 m a.s.l.; N 45°33′54′′, E 17°02′56′′) in central lowland of Croatia. Field experiment was established in 1994 with the aim of research 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 2014). Size of each tillage plot is 22.1 m × 1.87 m. Tillage systems differed in tools that were used, depth and direction of tillage and planting.

Tillage was conducted in October 2013 and tillage systems were:

a) no-tillage (NT) – planting directly into the mulch along the slope;

b) ploughing to 30 cm (P_{30}) – tillage and planting across the slope;

c) very deep ploughing to 50 cm (P_{50}) – tillage and planting across the slope;

d) ploughing to 30 cm + subsoiling to 50 cm (PS_{50}) – tillage and planting across the slope.

Measurement of CO_2 concentrations and calculation of soil CO_2 emissions

Soil CO_2 concentrations were measured before, zero and three hours after tillage implementation in three repetitions at each plot. For the measurement of soil carbon dioxide concentrations, *in situ* closed static chamber method was used. The chambers were made of lightproof metal material and they consist of two parts: frames (25 cm in diameter) and caps (25 cm in diameter and 9 cm high) fitted with a gas sampling port. The circular frames were inserted about 10 cm into the soil at the beginning of measurements. Before the chambers closure, near the soil surface, the initial CO_2 concentrations inside the frames were measured. Afterwards, the chambers were closed with caps and the incubation period was 30 minutes after which accumulated CO_2 in the chamber was measured *(Photos 1–4).* Measurements of CO_2 concentrations (ppm) were conducted with portable infrared carbon dioxide detector (GasAlertMicro5 IR, 2011). Measurements were conducted on bare soil and when necessary (at no-tillage system), vegetation was removed before the beginning of measurement.

The soil CO_2 emissions (efflux) were afterwards calculated according to Widen, B. and Lindroth , A. (2003), and Tóth, T. *et al.* (2005) as:

$$FCO_2 = \frac{M \times P \times V\,(c_2 - c_1)}{R \times T \times A\,(t_2 - t_1)},$$

where FCO_2 = soil CO_2 efflux (kg/ha per day); M = molar mass of the CO_2 (kg/mol); 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); R = gas constant (J/mol/K); T = air temperature (K); A = chamber surface (m^2); $t_2 - t_1$ = incubation period (day).

Photos 1–4. Measurement of short-term soil CO_2 emissions (from left to right): tillage implementation (1); inserted circular frames into the soil (2); incubation period (3); measurement of accumulated CO_2 in the chamber (4).

Determination of microclimate

Soil temperature, soil water content, air temperature and *relative air humidity* were measured in order to determine their influence on tillage-induced CO_2 emissions. Soil temperature (°C) and soil water content (%) were determined with IMKO HD2 - probe Trime, Pico64 (2011) at 10 cm depth in the vicinity of each chamber along with measurement of soil CO_2 concentrations. The air temperature (°C) and relative air humidity (%) were determined with Testo 610 (2011) and air pressure was determined with Testo 511 (2011) at the height about 1 m above the soil surface.

Data analysis

Soil CO_2 emissions were analyzed using statistical Software SAS (SAS 2002–2004). Variability between tillage systems were evaluated with analysis of variance (ANOVA) and tested, if it were necessary, with adequate *post-hoc* (Bonferroni) t-tests. In all statistical tests significance level was p≤0.05.

A linear, exponential, logarithmic and second order polynomial regression procedure was used to determine the dependence of each climatological factor on soil surface CO_2 emissions. The value of the correlation coefficient was ranked by Roemerk-Orphal scale (0.0–0.10: no correlation; 0.10–0.25: very weak; 0.25–0.40: weak; 0.40–0.50: modest; 0.50–0.75: strong; 0.75–0.90: very strong; 0.90–1.00: full correlation) (Vasilj, Đ. 2000).

Results

Microclimate and short-term tillage-induced soil CO_2 emissions

During the studied period on October 28, 2013 (between 8.00 and 17.00 hours) it was mostly sunny and warm, air temperature ranged from 23.2 to 28.2 °C and relative air humidity varied from 50.9 to 60.4 per cent *(Table 1).* Soil temperature before the tillage operations varied from 26.9 to 33.0 °C, immediately after the tillage operations it declined sharply up to 10.9 °C and afterwards it mostly continued to

Table 1. Soil CO_2 emissions and climatologic factors (means ± SD) before, zero and three hours after tillage operation (n = 3)

Parameter	Tillage system	Before tillage operation	Zero hours after tillage operation	Three hours after tillage operation
Air temperature, °C	NT	23.2 ± 0.7	25.7 ± 0.5	28.1 ± 0.7
	P_{30}	23.2 ± 0.9	25.7 ± 0.3	28.1 ± 0.4
	P_{50}	23.4 ± 1.2	25.8 ± 0.3	28.2 ± 1.1
	PS_{50}	23.4 ± 0.8	25.8 ± 0.2	28.2± 0.9
Relative air humidity, %	NT	60.4 ± 2.2	55.6 ± 0.8	50.7 ± 1.1
	P_{30}	60.4 ± 1.9	55.6 ± 0.7	50.7 ± 0.9
	P_{50}	56.7 ± 2.2	53.7 ± 0.9	50.9 ± 1.3
	PS_{50}	56.7 ± 2.1	53.7 ± 0.9	50.9 ± 1.1
Soil temperature, °C	NT	33.0 ± 1.7	33.4 ± 2.2	33.0 ± 2.0
	P_{30}	31.5 ± 1.3	10.9 ± 0.7	11.5 ± 2.7
	P_{50}	26.9 ± 1.3	12.8 ± 2.1	16.2 ± 2.5
	PS_{50}	31.0 ± 3.2	11.6 ± 1.5	10.7 ± 1.5
Soil water content, %	NT	23.4 ± 0.1	22.7 ± 0.1	16.2 ± 0.0
	P_{30}	23.9 ± 0.3	23.0 ± 0.0	16.2 ± 0.1
	P_{50}	25.7 ± 0.1	23.8 ± 0.1	18.7 ± 0.0
	PS_{50}	25.7 ± 0.1	23.7 ± 0.1	18.6 ± 0.1
Soil CO_2 emissions, kg CO_2/ha per day^{-1}	NT	114.1 ± 13.3	100.5 ± 20.1	122.8 ± 16.3
	P_{30}	85.9 ± 4.7	126.0 ± 10.2	45.6 ± 6.3
	P_{50}	76.5 ± 4.5	116.6 ± 18.8	49.6 ± 6.4
	PS_{50}	85.9± 6.3	123.3± 15.3	34.9± 7.6

rise while on no-till system, soil temperature was mostly steady. Soil water content ranged from 23.4 to 25.7 per cent before the tillage operations, and after the tillage operations it was continuously declining during the study period up to 16.2 per cent *(Table 1).*

The soil CO_2 emissions measured on tilled systems before tillage ranged from 76.5 to 85.9 kg CO_2 /ha per day. Immediately after tillage soil CO_2 emissions ranged from 116.6 to 126.0 kg CO_2 /ha per day and were on average 47.4 per cent greater than the average emission before tillage operations, while three hours after tillage it was on average 48.6 per cent lower compared to average emission before tillage operation. The exception was no till system where soil CO_2 emissions were high and ranged from 100.5 to 122.8 kg CO_2 /ha per day during the whole study period *(Table 1).*

Influence of tillage systems and time on soil CO_2 emissions and soil microclimate

Different tillage systems didn't have any significant impact on average soil CO_2 emissions and soil water content while average soil temperature determined at no-till was significantly higher compared to other tilled systems *(Table 2).*

Average soil CO_2 emission of the experimental plot measured before tillage operation was not significantly different from soil CO_2 emissions after tillage but emissions measured immediately after and three hours after tillage operation were significantly different. Soil temperature measured before tillage was significantly higher compared to those measured after tillage. Soil water content was significantly declining within hours after tillage operation

Correlation between short-term soil CO_2 emissions and microclimate

Between soil CO_2 emissions and soil temperature, very weak positive logarithmic (r = +0.23), modest positive second order polynomial (r = +0.41), weak positive linear (r = +0.25) and exponential (r = +0.35) correlation was determined. The values of correlation coefficients indicate the presence of positive modest linear (r = +0.40), exponential (r = +0.48) and logarithmic (r = +0.40) correlation between soil CO_2 emissions and soil water content. An exception is the correlation in the second order polynomial type which is negatively modest and amounts r = -0.41. Between soil CO_2 emissions and air temperature, negative weak linear (r = -0.36), negative modest exponential (r = -0.47), negative weak logarithmic (r = -0.35) and negative strong second order polynomial (r = -0.70) correlation was determined. Positive weak linear (r = +0.37) and logarithmic (r = +0.38), positive modest exponential (r = +0.46) and negative strong second order polynomial (r = -0.52) correlation was determined between soil CO_2 emissions and relative air humidity.

Table 2. Influence of different tillage systems and time on soil CO_2 emissions and soil microclimate

Tillage	Soil CO_2 emission, kg CO_2/ha per day	Soil temperature, °C	Soil water content, % vol.
NT	112.5 a	33.2 a	20.8 a
P_{30}	85.9 a	18.0 b	21.0 a
P_{50}	80.9 a	18.6 b	22.7 a
PS_{50}	81.4 a	17.8 b	22.7 a
Time	**Soil CO_2 emission, kg CO_2/ha per day**	**Soil temperature, °C**	**Soil water content, % vol.**
Before tillage	90.6 ab	30.6 a	24.7 a
Zero hours after tillage	116.6 a	17.2 b	23.3 b
Three hours after tillage	63.2 b	17.9 b	17.4 c

Averages followed by same letter are not significantly different.

Discussion

Air temperature was rising and relative air humidity was declining during the measurement period. Soil temperature was high and steady at no till during the whole study period while on tilled systems soil temperature declined sharply after tillage operation due to the disruption of soil aggregates and increasing aeration by which the soil climate was changed; after which soil temperature continued to rise. Soil water content was continuously declining, partly due to the tillage operation but also due to the increase of air temperature and an increase in soil water evaporation. Decreased soil water content in tilled treatments just after tillage and the greatest soil water content in NT was observed by Alvaro-Fuentes, J. *et al*. (2007). Lampurlanes, J. *et al.* (2001) also observed greater water contents in NT and suggested that better infiltration rates in NT promoted greater soil water content as compared to tilled treatments.

At no till system, soil CO_2 emission was not significantly higher compared to tilled systems and was high and steady during the whole study period. Soil CO_2 emissions increased rapidly immediately after tillage operation due to physical release of CO_2 from soil pores and solutions at all tilled treatments. A significant increase of CO_2 emission immediately after tillage operations in tillage treatments, except NT, was also observed by Alvaro-Fuentes, J. *et al*. (2007). Already three hours after tillage operation, soil CO_2 emissions declined sharply and were lower compared to emissions measured before tillage operation. Reicosky, D.C. (1997), observed a decrease within 2 hours after a pass with plough.

Many authors (Reicosky, D.C. and Lindstrom, M.J. 1993; Reicosky, D.C. *et al.* 1997; Ellert, B.H. and Janzen, H.H. 1999; Al-Kaisi, M.M. and Yin, X. 2005) also obtained in their research that the effect of tillage on soil CO_2 emission was short-lived. Reicosky, D.C. and Lindstrom, M.J. (1993), and Prior, S.A. *et al*. (2000) suggested that initial CO_2 emission after tillage was also related to the depth and degree of soil disturbance. In our experiment, similar results were not determined. Within tilled treatments, P_{30} was the tillage operation with greatest CO_2 flux after tillage compared to other tilled treatments although the differences were not significant.

In our study, no significant relationships between CO_2 emissions and microclimate conditions were found. Microclimatic conditions had mostly weak or modest impact on soil CO_2 emission. Similar results were reported by Kessavalou, A. *et al*. (1998); Al-Kaisi, M.M. and Yin, X. (2005); Omonode, R.A. *et al*. (2007); Jabro, J.D. *et al*. (2008); Li, C. *et al*. (2010); Bilandžija, D. *et al*. (2014) and Bilandžija, D. (2015). Of all tested functions, best type of correlation between soil CO_2 emissions and microclimatic factors, showed to be the second order polynomial correlation, except for soil water content.

According to its determination coefficient, 17 per cent of soil CO_2 emissions depended on soil temperature, 17 per cent of soil CO_2 emissions depended on soil water content, 27 per cent of soil CO_2 emissions depended on relative air humidity and 49 per cent of soil CO_2 emissions depended on air temperature. A possible explanation for this lack of relationship with CO_2 flux may be related to the fact that soil microclimate conditions were only measured to 10 cm depth and soil tillage was implemented to 30 and 50 cm soil depth. Therefore, a large proportion of the CO_2 emission could come from deeper than 10 cm soil layer.

Conclusions

At no till system soil CO_2 emissions were steady and high during whole study period. Tillage did not have significant, on 3 hours average, short term impact on soil CO_2 emissions. However, tillage accelerated the transfer of soil CO_2 to the atmosphere and caused an immediate sharp increase in soil CO_2 emissions which were on average 40–50 per cent higher compared to those before tillage. This was a relatively short lived process, lasting less than 3 hours from tillage operation after which the soil CO_2 emissions were on average 40–50 per cent lower compared to those measured before tillage.

At tilled systems, soil temperature rapidly declined after tillage operation and afterwards continued to rise while at no-till system it was steady during whole study period. Soil water content was declining with time of measurement during whole study period. The tillage-induced soil CO_2 emissions appeared to be independent of changes in microclimate as correlations between soil CO_2 emissions and microclimatic factors were mostly weak or modest. The obtained data suggested that correlations were independent from the function type used. Further long term research is needed to better assess also the impact of other agroecological factors such as soil physical and chemical parameters, especially changes of soil organic matter content in the topsoil on CO_2 emissions.

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