Soil Carbon Loss by Soil Respiration under Different Tillage Treatments

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Summary

Soil carbon stocks are highly vulnerable to human activities (such as tillage), which can decrease carbon stocks significantly. These activities break down soil's organic matter and some carbon is converted to carbon dioxide (CO_2). A part of CO_2 (a greenhouse gas that is one of the main contributor to global warming) is lost from the soil by soil respiration (soil CO_2 efflux). The aim of our study is to determine the soil carbon loss by soil CO_2 efflux under different tillage treatments. The experimental site is characterized by continental climate. Field experiment with six different tillage treatments usually used in this area was set up on Stagnic Luvisols in Daruvar, central lowland Croatia in 1994 with investigation aim on determination of soil degradation by water erosion and later, in 2011, expanded to the research on soil CO_2 efflux. Tillage treatments differed in tools that were used, depth and direction of tillage. Tillage treatments were: black fallow (BF), ploughing up/down the slope to 30 cm (PUDS), no-tillage (NT), ploughing across the slope to 30 cm (PAS), very deep ploughing across the slope to 50 cm (VDPAS) and subsoiling (50 cm) plus ploughing (30 cm) across the slope (SSPAS). Field measurements of soil CO_2 concentrations were conducted during one year (n = 14) from November 2011 till November 2012, when cover crop was corn (*Zea mays L.*). Preliminary soil sampling for determination of soil total carbon content was conducted in April 2011. This paper presents results of soil total carbon content in the soil surface layer (0-30 cm), the variations of CO_2-C efflux during the year, soil carbon loss by CO_2-C efflux and correlation between soil total carbon content and CO_2-C efflux. The range of soil surface total carbon content varied from 19083.7 kg/ha at BF treatment up to 31073.6 kg/ha at SSPAS treatment. The treatment with the lowest average measured CO_2-C efflux was BF. The average CO_2-C efflux at BF treatment was 7.9 kg CO_2-C/ha/day where CO_2-C efflux varied from 2.3 kg CO_2-C/ha/day up to 22.6 kg CO_2-C/ha/day. The treatment with the highest average measured CO_2-C efflux was NT. Range of CO_2-C efflux at NT treatment varied from 7.8 kg CO_2-C/ha/day up to 65.8 kg CO_2-C/ha/day and the average CO_2-C efflux was 24.4 kg CO_2-C/ha/day. Daily soil total carbon loss by soil respiration ranged from 0.04% at BF treatment up to 0.09% at NT treatment. Soil CO_2-C efflux was fully positively correlated with soil total carbon content (r=0.91). After all mentioned, it can be stated that in these agro-ecological conditions, best tillage practice in sustainable plant production in terms of the lowest daily soil total carbon loss (0.06%) by soil respiration is ploughing to 30 cm (PUDS and PAS). Still, it is necessary to conduct the total soil carbon balance in the future research for better understanding of soil carbon gains and losses.

Key words

soil carbon loss, soil respiration, CO_2 - C efflux, Croatia

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Received: May 23, 2013 | Accepted: February 19, 2014

Introduction

It is presumed that global warming is caused by the increased atmospheric greenhouse gas (GHG) concentrations originated from the fossil fuel combustion, land use change, soil cultivation and other human activities. Depletion of soil carbon pool contributes to the CO_2 emissions to the atmosphere. Soil carbon stocks are highly vulnerable to human activities which can decrease carbon stocks significantly. These activities break down soil's organic matter and some carbon is converted to carbon dioxide (CO_2). A part of CO_2 (a greenhouse gas that is one of the main contributor to global warming) is lost from the soil by soil respiration. Soil respiration or soil CO_2 efflux is one of the most important components of the ecosystem carbon budget, which consists of organic matter decomposition and mineralization, root respiration and rhizosphere or faunal respiration (Carlisle et al., 2006). Rates of soil respiration are controlled by several factors including soil temperature, soil moisture, soil physical and chemical properties (Raich and Tufekcioglu, 2000; Jarecki and Lal, 2006) and are also influenced by agricultural practices such as tillage (Mielnick and Dugas, 2000). Tillage strongly affect CO_2 emission by creating soil conditions favourable for oxidation and mineralization of organic carbon in the soil by improving soil aeration, soil disaggregation and increasing the contact between soil and crop residue what leads to a rapid decomposition. Some cultivated soils have lost one-half to two-thirds of the original soil organic carbon pool (Lal, 2004). Monitoring of CO_2 emissions and changes in soil carbon content for different tillage treatments is important to determine the best tillage practice that maintain soil productivity, increase carbon storage and contribute to climate change mitigation (Ussiri and Lal, 2009). Therefore, the objective of our study was to determine the soil carbon loss by soil CO_2 efflux under different tillage treatments.

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 45°33´937´´, E 17°02´056´´) in central, lowland Croatia. Field experiment was establish 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 (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 were:

1. BF: black fallow, control treatment – ploughing direction is up and down the slope;
2. PUDS: ploughing to 30 cm – ploughing and planting direction is up and down the slope, disked and harrowed;
3. NT: no tillage – planting in conducted directly into the mulch with planting direction up and down the slope;
4. PAS: ploughing to 30 cm – ploughing and planting direction is across the slope, disked and harrowed;
5. VDPAS: very deep ploughing to 50 cm – ploughing and planting direction is across the slope, disked and harrowed;
6. SSPAS: ploughing to 30 cm plus subsoiling to 50 cm – ploughing, subsoiling and planting direction is across the slope, disked and harrowed.

Climate conditions and cover crop at the experimental site

For the interpretation of climate conditions at the experimental site in the climatological period 1961-1990 and studied period November 2011 – November 2012, the official meteorological data from the main meteorological station of Meteorological and Hydrological Service of Croatia located in Daruvar were used. The climate conditions at the experimental site are described by Lang's rain factor and Walter climate diagram. The climate classification for the interpretation of Lang's rain factor is conducted according to Gračanin's climate classification (Butorac, 1988).

Cover crop at the experimental field was corn (*Zea mays L.* - hybrid Zlatko), the main arable crop in Croatia - 34.2 % of total arable land and gardens area (Statistical Yearbook of the Republic of Croatia, 2012). At the experimental field, corn was seeded on 30 April 2012 and harvest was conducted on 1 October 2012. Depth of sowing was 3 - 4 cm, distance between rows was 70 cm and inter-row distance was 22 cm, what makes the total number of 65 000 plants per hectare.

Soil sampling for determination of soil total carbon content

Preliminary soil sampling for determination of soil total carbon content in the surface layer (0 – 30 cm) was conducted in April 2011. Samples were sampled with the soil probe (Eijkelkamp, 2005). The soil total carbon content was determined in the composite soil sample which were composed of 10 individual soil samples on each treatment. Soil samples were transported on the same sampling day in plastic bags for chemical analysis. Preparation of soil samples and sample analysis were conducted in the Analytical Laboratory of the Department of General Agronomy, Faculty of Agriculture. Preparation of soil samples for analysis of soil total carbon content (drying, milling, sieving, dividing for analysis and for archive) was conducted in compliance with the Standard ISO 11464:2006 and soil total carbon content was determined using the CHNS analyzer according to the Standard ISO 10694:1995.

Measurement of soil CO_2 concentrations

Soil CO_2 concentrations were measured during 13 months (n = 14) from November 2011 till November 2012. For the measurement of soil CO_2 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 two parts: frame and cap. The circular frames (25 cm in diameter) are inserted between the growing plants about 5 cm into the soil at the beginning of measurement. 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 CO_2 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 frame inside before the beginning of measurement. Measurements of CO_2 concentrations were conducted in three replications at each treatment what makes the total number of 252 measurements (14 measurement dates x 3 repetitions x 6 treatments).

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 - t1 – incubation period (day)

Results and discussion

Climate conditions at the experimental site

The experimental field is characterised by continental climate. Mean annual amount of precipitation in Daruvar during referent, climatological 30 - year period (1961-1990) was 878 mm and mean annual temperature was 10.6 °C. According to the Lang's rain factor (L_f), the 30 – year period (1961-1990) was characterised by the humid climate (L_f =83). The studied period November 2011 - November 2012 was dryer and warmer compared to the referent climatological period with mean annual precipitation amount of 763 mm and mean annual temperature of 11.2 °C. According to the Lang's rain factor, the studied period November 2011 - November 2012 was characterised by semihumid climate (L_f =68).

Average climate conditions are without dry period during the 30 – year period (1961-1990) according to Walter climate diagram (Figure 1) while in the studied period November 2011 - November 2012 there was determined a water deficit during periods February – March and June - August (Figure 2).

Soil total carbon content in the surface layer (0-30 cm)

Soil total carbon content differed by maximal of 11989.9 kg/ha between the tillage treatments in the soil surface layer (0 - 30 cm). The lowest soil total carbon content was determined at the BF treatment (control treatment) where it amounted 19083.7 kg/ha. If we compare the treatments with the cover crop, the lowest soil total carbon content was determined at the PUDS treatment where soil total carbon content amounted 23746.8 kg/ha. The highest soil total carbon content was determined at the SSPAS treatment where it amounted 31073.6 kg/ha, followed by NT, PAS and VDPAS treatment respectively. On all conventional tilled treatments, except the SSPAS treatment, soil total carbon content was lower compared to NT treatment. The soil total carbon content in the surface layer (0 - 30 cm) is presented at Figure 3.

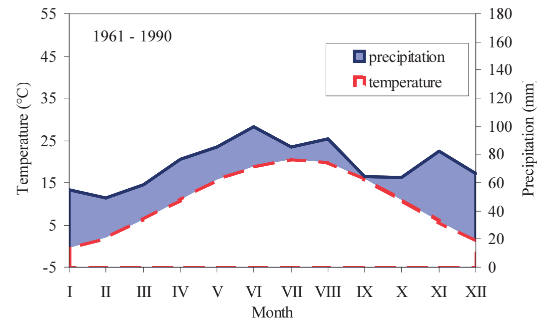

Figure 1. Walter climate diagram for the period 1961 - 1990

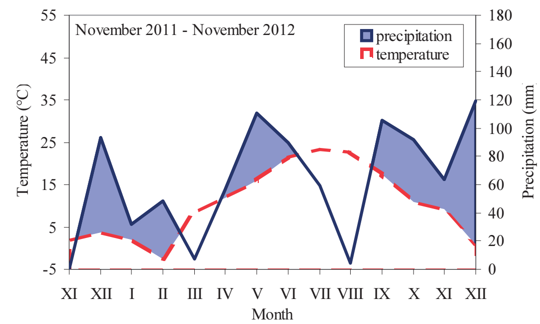

Figure 2. Walter climate diagram for the period November 2011 – November 2012

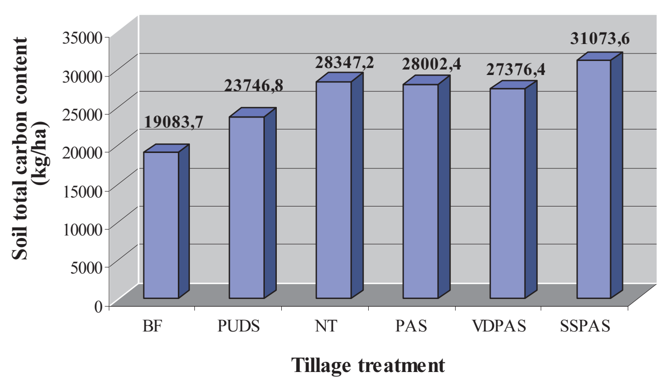

Figure 3. Soil total carbon content in the surface layer (0-30 cm)

Conceicao et al. (2013) determined that the soil carbon stock in 0–20 cm was higher in no tillage than in conventional tillage treatment in a subtropical Acrisol after 18 years of tillage. Andruschkewitsch et al. (2013) carried out study on loess soils in Germany with different tillage treatments: conventional tillage and no-tillage. They determined a significantly increased organic carbon contents in the top 5 cm of no tillage treatment compared to conventional tilled treatment. However, the differences between tillage treatments became smaller with increasing soil depth and in 25 - 40 cm soil depth, the conventional tillage treatment even showed a significantly higher organic carbon con-

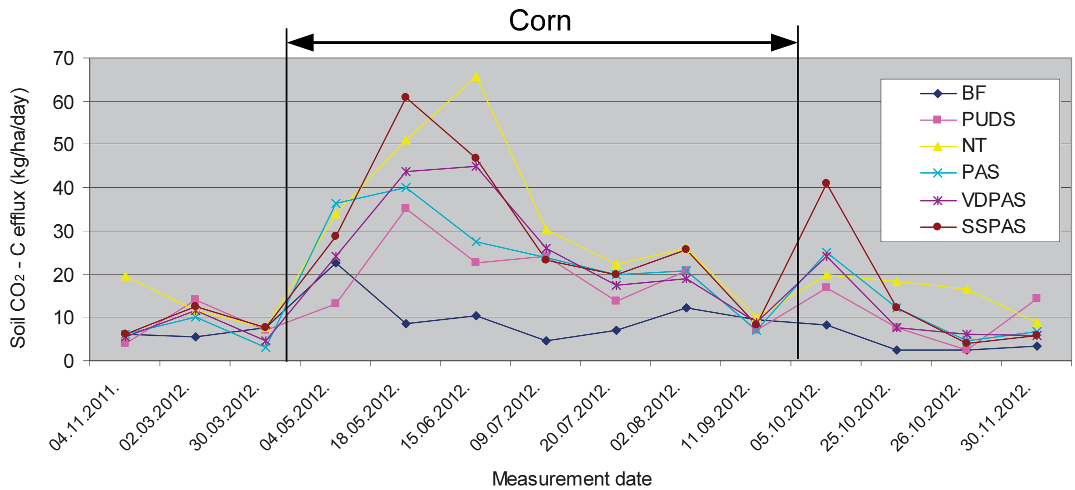

Figure 4. Variations of CO_2 – C efflux in investigated period

tent. Similarly, Hermle et al. (2008) found in an Orthic Luvisol after 19 years of different tillage treatments increased organic carbon contents in 0 - 10 cm of no tillage compared to conventional soils and also in 20–30 cm soil depth increased organic carbon contents under conventional tillage. On the other hand, Alvarez et al. (1998) determined that total C in the 0 to 20 cm layer was not different in no-tilled and ploughed soils.

Variations of CO_2 – C efflux during the studied period

Rates of soil respiration were dependent upon soil temperature and soil moisture content thus CO_2 – C effluxes were lower in colder period of the year and higher in the warmer period (Figure 4). Also, CO_2 – C effluxes were influenced by the presence of crop on the experimental field and its growth. CO_2 – C effluxes were lower during the period without cover crop and higher during the vegetation period what was likely a result of considerable contributions from root and microbial respiration. During the vegetation period, CO_2 – C effluxes were higher in first half of corn growing season and lower in the second half of corn growing season. Higher effluxes determined shortly after the harvest were most likely related to crop root and residue decomposition.

Differences in CO_2 – C effluxes have been determined between the tillage treatments (Table 1). The lowest average CO_2 – C efflux was determined at the BF treatment with the average CO_2 – C efflux of 7.9 kg ha^{-1}day^{-1} what is in accordance with the Rastogi et al. (2002) who reported that the presence of crops have influence on CO_2 emissions and that emission from cropped soil is approximately 2 to 3 times higher compared to bare soil while other authors reported ~20% higher rates of soil respiration on cropped field than fallow fields (Raich and Tufekcioglu, 2000). Comparing the treatments with the cover crop, the lowest average CO_2 – C efflux was determined at the PUDS treatment, followed by PAS, VDPAS, SSPAS and NT treatment, respectively: 14.5 kg ha^{-1}day^{-1}, 17.4 kg ha^{-1}day^{-1}, 17.9 kg ha^{-1}day^{-1}, 21.6 kg ha^{-1} day^{-1} and 24.4 kg ha^{-1}day^{-1}. The highest CO_2 emission under NT could be attributed to maintenance of higher soil moisture at the soil surface and higher biological activity. Similar results were obtained by Hendrix et al. (1988) and Franzluebbers et al. (1995) while, in contrast, lower CO_2 emissions were observed under no tillage compared to conventional tillage by Curtin et al. (2000), Al-Kaisi et al. (2005), Bauer et al. (2006) and Ussiri and Lal (2009). The treatment with the highest average CO_2 – C efflux range during the investigated period was NT, followed by SSPAS, VDPAS, PAS, PUDS and BF respectively (Table 1).

Table 1. Minimal, maximal and average CO_2 – C efflux (kg ha^{-1}day^{-1}) in investigated period

Tillage treatment	Minimal CO_2 – C efflux (kg ha^{-1}day^{-1})	Maximal CO_2 – C efflux (kg ha^{-1}day^{-1})	Range (kg ha^{-1}day^{-1})	Average CO_2 – C efflux (kg ha^{-1}day^{-1})
BF	2.3	22.6	20.3	7.9
PUDS	2.3	35.1	32.7	14.5
NT	7.8	65.8	58.0	24.4
PAS	3.1	40.1	37.0	17.4
VDPAS	4.7	44.8	40.1	17.9
SSPAS	3.9	60.8	56.9	21.6

Correlation between total soil carbon and CO_2 – C efflux and soil carbon loss

Correlation between total soil carbon content and CO_2 – C efflux is presented at Figure 5. Soil CO_2 - C efflux was fully positively correlated with soil total carbon content (r = 0.91). Similar results were obtained in non-salt affected soils (La Scala et al., 2000) and in the salt-affected landscapes (Setia et al., 2011) where cumulative CO_2 release was correlated with soil carbon content.

Daily total soil carbon loss by soil respiration differed by tillage treatments by maximal of 0.05 %. The lowest daily soil total carbon loss is determined at BF treatment where it amounted 0.04 %. Comparing the treatments with the cover crop, the lowest losses are determined at the treatments PUDS and PAS where carbon losses amounted 0.06 %. The soil total carbon loss of 0.07 % is determined at the VDPAS treatment and SSPAS treatment. The highest daily soil total carbon loss by soil respiration is determined at NT treatment and it amounted 0.09 %. Similar results were obtained by Alvarez et al. (1998). They reported the negative annual carbon budget under conventional and no tillage

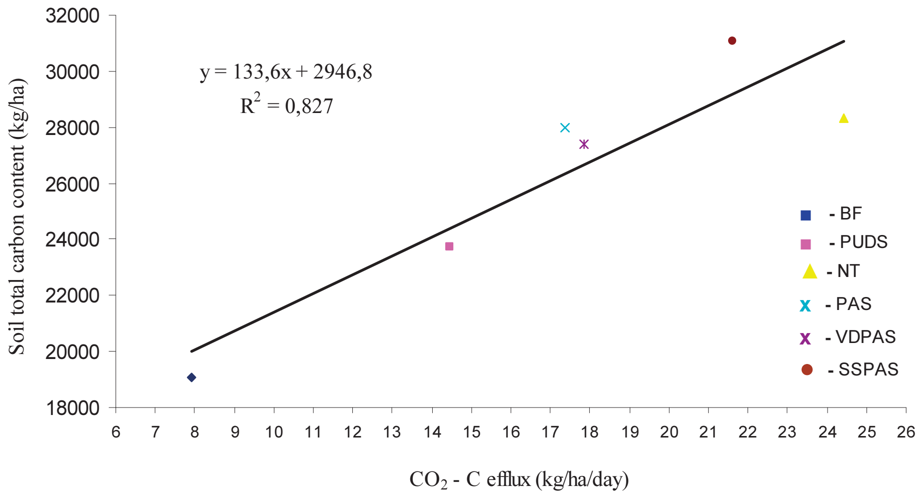

Figure 5.
Correlation between soil total carbon content and CO_2 – C efflux

systems, but no-tillage system lost more carbon than the conventional tillage did. Dao (1998) concluded that the proportion of soil organic carbon respired in the 60-day period was twice as great under conventional tillage as no tillage. Baker and Griffis (2005) have examined the impact of conventional and strip tillage on the net ecosystem exchange in the Midwestern United States and they determined a greater C loss from the conventional field than from the strip-tilled field but carbon removed in yield in the conventional field was larger too, so change in soil organic carbon was nearly identical.

Conclusions

This research was initiated to assess the impact of different tillage treatments on CO_2 efflux, to determine the daily soil total carbon loss by soil respiration and to determine correlation of soil total carbon content and CO_2 – C efflux. The experimental field was set up on Stagnic Luvisols that has been managed using BF, PUDS, NT, PAS, VDPAS and SSPAS treatments for 16 years.

The experimental field is characterised by continental climate. The studied period November 2011 - November 2012 was dryer and warmer compared to the referent climatological period with mean annual precipitation amount of 763 mm and mean annual temperature of 11.2 °C. According to Walter climate diagram, in the studied period November 2011 - November 2012 there was determined a water deficit during periods February – March and June – August.

Soil total carbon content differed by maximal of 11989.9 kg/ha between the tillage treatments in the soil surface layer (0 - 30 cm). The lowest soil total carbon content was determined at BF treatment. Comparing the treatments with the cover crop, the highest soil total carbon content was determined at SSPAS treatment followed by respectively: NT, PAS, VDPAS and PUDS treatment.

Lower CO_2 – C effluxes were determined in colder period of the year and in the period without cover crop while higher CO_2 – C effluxes were determined in the warmer period of the year and during the corn vegetation period. During the vegetation period, CO_2 – C effluxes were higher in first half of corn growing season and lower in the second half of corn growing season.

The lowest average CO_2 – C efflux was determined at the BF treatment with the average of 7.9 kg ha^{-1}day^{-1}. Comparing the treatments with the cover crop, the lowest average CO_2 – C efflux was determined at the PUDS treatment followed by PAS, VDPAS, SSPAS and NT treatment respectively: 14.5 kg ha^{-1}day^{-1}, 17.4 kg ha^{-1}day^{-1}, 17.9 kg ha^{-1}day^{-1}, 21.6 kg ha^{-1}day^{-1} and 24.4 kg ha^{-1}day^{-1}. The treatment with the highest average CO_2 – C efflux variation during the investigated period was NT, followed by SSPAS, VDPAS, PAS, PUDS and BF respectively.

Daily soil total carbon loss by soil respiration differed by maximal of 0.05 % between tillage treatments and it ranged from 0.04 % at BF treatment up to 0.09 % at NT treatment. Soil CO_2-C efflux was fully positively correlated with soil total carbon content (r = 0.91).

After all mentioned, it can be stated that in these agro-ecological conditions, best tillage practice in sustainable plant production in terms of the lowest average CO_2 – C efflux is ploughing up and down the slope to 30 cm (PUDS) and in terms of the lowest daily soil total carbon loss by soil respiration is ploughing to 30 cm (0.06 % at PUDS and PAS). Still, it is necessary to conduct the total soil carbon balance in the future research for better understanding of soil carbon gains and losses.

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