

IMPACT OF DIFFERENT SOIL TILLAGE SYSTEMS AND NITROGEN FERTILIZATION ON SOIL CARBON DIOXIDE (CO₂) EMISSION FOR ORTHIC LUVISOL IN WESTERN SLOVAKIA

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Abstract

Agricultural management practices such as soil tillage may influence decay rates of dead biomass, leading to the changes of soil CO₂ emission. The aim of this study was to evaluate the effect of conventional tillage (CT) and reduced tillage (RT) combined with unamended control (N0) and addition of nitrogen fertilizers (N1) on soil CO₂ emission from cropland during the studied period (April-December in 2012). Weekly CO₂ flux, soil temperature, and soil water content were monitored during the studied period in western Slovakia. Soil CO₂ emission generally did not differ between conventional tillage compared with reduced tillage for both nitrogen treatments. Daily soil CO₂ emission averaged 87.2, 87.1, 98.2 and 102.9 kg CO₂ ha⁻¹ day⁻¹ for CTN0, RTN0, CTN1, and RTN1, respectively. A significant correlation ($p < 0.05$) between the CO₂ flux and soil temperature in conventionally and reduced tilled plots could lead to the easy conclusion that only the soil temperature (and not the soil moisture) was a controlling factor for fertilized and not fertilized plots, which wasn't our case.

Key words: soil CO₂ emission, conventional tillage, reduced tillage, agro-ecosystem

1. INTRODUCTION

A global climate change caused by anthropogenic emission of greenhouse gases (CO₂, CH₄, N₂O) is one of the most important environmental problems in the latest human history. The greenhouse gas exchange between croplands and atmosphere plays an important role in the global carbon cycle and carbon dioxide concentration in the atmosphere (CO₂). Increased atmospheric CO₂ has been considered a major contributor to global warming. Carbon loss from soil to the atmosphere as CO₂ has been enhanced due to inappropriate tillage practices (Reicosky et al. 1997). However, soil can function as a net sink for sequestering atmospheric CO₂ through appropriate soil and crop management (Lal et al. 1995; Paustian et al. 1995).

Reduced tillage is regarded as one of the most effective agricultural practices to reduce CO₂ emission and sequester atmospheric C in the soil (Kern & Johnson 1993; Curtin et al. 2000; Al-kaisi & Yin 2005). Studies showed that decreased tillage intensity reduces soil disturbance and microbial activities, thus reducing CO₂ emission (Lal & Kimble 1997; Curtin et al. 2000). On the other hand, increased tillage intensity showed increased CO₂ emission through increasing aeration due to increased soil disturbance (Roberts & Chan 1990) and to physical degassing of dissolved CO₂ from the soil solution (Reicosky & Lindstrom 1993). The effect of tillage on CO₂ emission, however, was short-lived (<24 hours). Studies on effect of tillage on soil CO₂ emission are mostly limited to the period between tillage and crop establishment (La Scala et al. 2001) or short-term CO₂ flux (Reicosky et al. 1999). Large number of studies on CO₂ emission during growing season is from grass or forest, but not from cropland (Marja Maljanen et al. 2001; Frank et al. 2002). The effect of different tillage practices during crop growing season is not well known. There are no such studies from the agricultural used soils of Slovakia at all.

The reduced tillage practices so far received great attention in America, Australia and South Africa, often in semi-arid areas. In Europe, no-tillage is less often practices than reduced tillage, which involves one or more stubble cultivations. The adoption of conservation tillage practices in Europe has been much slower, possibly due to the previously high production subsidies and smaller scale production in European agriculture, which has increased the financial risks associated with these practices. Implementation of conservation systems including reduced tillage and no-till systems is also an indirect measure resulting from ecological standards of the European Union for securing good agricultural and environmental conditions (GAEC) (ecological conditionality for direct payment obtaining also in condition of Slovak Republic). Measures of Slovak Republic for implementation of minimalization techniques came in force on 1. January 2009 (Cross-compliance 2007). Spreading of these techniques in condition of Slovak Republic is limited by large acreage of not suitable compacted soils or partly compacted soils. But there is also an absence of detailed regionalization of suitable

soils for this conservation systems as well as absence of long term field research in different ecological conditions (Kovac et al. 2003). Implementation of conservation systems on agricultural land involves quantification of these effects on biogeochemical cycles of nitrogen (N) and carbon (C) in different soil-climatic conditions and farming managements which differs in time and space.

The aim of this study was to evaluate the effect of conventional tillage (CT) and reduced tillage (RT) combined with unamended control (N0) and addition of nitrogen fertilizers (N1) on soil CO₂ emission from cropland during April-December period in 2012 on a long-term tillage field experiment initiated in 1994. Other factors such as soil water content and temperature were monitored to see their role (magnitude of influence) in soil CO₂ emission.

2. MATERIAL AND METHODS

2.1 Experimental site

This study was conducted at the Experimental site of the Department of Plant Production of SAU-Nitra, in Nitra region of Slovakia (lat. 48°19'00''; lon. 18°09'00'') during April-December 2012 (covering also crop growing season of spring barley) on a long-term tillage field experiment initiated in 1994. The soil type was classified as Orthic Luvisol (FAO 1998) containing 360.4 g kg⁻¹ of sand, 488.3 g kg⁻¹ of silt and 151.3 g kg⁻¹ of clay (Šimanský et al. 2008). The average annual air temperature was 11.4°C and annual precipitation was 492mm during the studied year (Tab.1). The N-fertilizers application rate and other information on farming practices for the crop including the timing for tillage, planting day, harvesting day, etc. were set according to the individual needs of crops recommended in terms of good agricultural practices (Fazekašová 2003; Fazekašová et al. 2013a; 2013b; Angelovičová & Fazekašová 2013, 2014; Bárek, Halaj & Takáč 2008; Bárek et al. 2013; Halaj et al. 2013a, 2013b).

The experiment compared two tillage methods (conventional tillage-CT and reduced tillage-RT) combined with unamended control (N0) and addition of nitrogen fertilizers (N1). Experiment was arranged in a split plot design with tillage as the main plots and the treatments N0 and N1 as the sub-plots with three replicates. CT consisted of tillage to 22 – 25 cm and RT consisted of disking to 10-12 cm depth both applied each fall, followed by harrow cultivator to 10 cm depth each spring before seeding. The spring barley (Kangoo variety) was seeded on 16 March 2012 at a rate of 4 500 000 seeds ha⁻¹. The doses of fertilizers were calculated by balance method and were applied to the soil twice throughout the season. First application (CT 50 kg N ha⁻¹ and RT 40 kg N ha⁻¹) was applied on 11 April and second (CT and RT 7 kg N ha⁻¹) on 23 July 2012. Both CT and RT plots were disked (10-12 cm) after harvest (12 July, 2012) on 24 July 2012 and crop residues were incorporated into the soil.

Table 1 30-year mean and actual (2012) monthly climate data for the nearby automatic weather station (300 m from the field site)

Month	30 - year mean (1961-1990)		2012	
	Precip. (mm)	Mean temp. (°C)	Precip. (mm)	Mean temp. (°C)
January	31.0	-1.7	51.0	1.3
February	32.0	0.7	17.4	-2.5
March	30.0	5.0	5.2	8.1
April	39.0	10.4	39.8	12.1
May	58.0	15.1	15.0	17.6
June	66.0	18.0	47.6	20.4
July	52.0	19.8	109.0	23.0
August	61.0	19.3	15.4	22.9
September	40.0	15.6	31.4	18.0
October	36.0	10.4	80.6	10.8
November	55.0	4.5	29.4	7.3

December	40.0	0.1	50.0	-1.6
Annual (total/average)	539.0	9.8	492.0	11.4

2.2 Measurement of soil CO₂ emissions, water content and temperature

The soil surface CO₂ flux was measured weekly in all treatments during and after the crop growing season from April-December 2012 using closed chamber technique. All gas samples were taken between 9 A.M and 12 A.M. of the day to reduce variability in CO₂ flux due to diurnal changes in temperature (Parkin & Kaspar 2003). The metal collar frame was inserted 10 cm deep into the soil in every plot and left undisturbed until harvest/disking occasion. On every gas sampling, the chamber (30 cm in diameter and 25 cm in height) were water sealed onto bottom collars and gas samples (20 mL) were collected through tube fittings (sealed with septum) at 0, 30 and 60 min after chamber deployment using an air-tight syringe (Hamilton) and transferred to pre-evacuated 12 mL glass vials (Labco Exetainer). Gas samples were analyzed for CO₂ using a gas chromatograph (GC-2010 Plus Shimadzu) equipped with a thermal conductivity detector. The GC was calibrated using 3 certified standard gas mixtures (CO₂, N₂O, and N₂) in the expected concentration ranges. CO₂ fluxes between soil/crop and atmosphere were calculated from the change of concentration during the chamber closure using a linear approach. Soil water content at 0-10 cm depth (gravimetric method) and soil temperature at 5 cm depth (Volcraft DET3R thermometer) was measured at each gas sampling event.

2.3 Statistical analyses

The statistical processing of the data included the determination of means, standard deviations, errors, Pearson coefficients of correlation at the confidence level of $p < 0.05$. The significance of the differences between the means was evaluated using one-way ANOVA at $p < 0.05$.

3. RESULTS AND DISCUSSION

3.1. Soil water content and temperature

There wasn't found significant difference ($p < 0.05$) in soil temperature between CT and RT for both fertilization levels (N0, N1) (Fig. 1). The average temperature was slightly lower in the conventional tillage as compared to reduced tillage for both fertilization levels. In the CTN0 and RTN0 system, the average temperatures were 19.0 and 19.1°C respectively, ranging between 3.1 and 29.0°C in CTN0 and 3.3 and 29.2 °C in RTN0. In the fertilized treatment CTN1 and RTN1, the average temperatures were 18.9 and 19.0°C respectively, ranging between 3.3 and 28.6°C in CTN1 and 3.1 and 28.3 °C in RTN1. Soil tillage and soil disturbance as a consequence may modify the relationship between the volume of air and the volume of soil particles inducing changes in the soil thermal conductivity and affecting the soil temperature. Soil tillage exhibits lower conductivity compared to soil non-tillage (Hillel 1998). Since we had almost the same temperatures for both tillage treatments and nitrogen levels, this wasn't our case.

The variability of the soil water content (SWC) was higher as compared to variability of temperature. The Figure 2 shows SWC trends for conventional tillage (CT) and reduced tillage (RT) combined with unamended control (N0) and addition of nitrogen fertilizers (N1) over the studied period. There wasn't found significant difference ($p < 0.05$) between both tillage treatments combined with fertilization levels also in the case of SWC. The average SWC was slightly lower in conventional tillage as compared to reduced tillage for both fertilization levels. In the CTN0 and RTN0 system, the average SWC were 13.8 and 14.0 (% by mass), ranging from 4.3 to 24.3 and from 3.6 to 23.5 for CTN0 and RTN0, respectively. In case of fertilized plots, the average SWC for CTN1 and RTN1 were 13.7 and 13.9 (% by mass), respectively and ranging from 3.8 to 23.3 and from 3.9 to 24.4 (% by mass) for CTN1 and RTN1, respectively. Slightly higher SWC in RT may indicate that tillage systems that involve less physical disturbance help to maintain soil water. The tillage activity influences the evaporative area and consequently a greater water loss. This effect depends on the depth, degree and frequency of soil tillage activities, the subsequent climatic conditions and the restructuring of the prepared layer (Salton & Mielniczuk 1995).

3.2. Soil CO₂ emission

Long-term CO₂ emission in the 2012 growing season from conventional (CT) and reduced tillage (RT) plots combined with and without N fertilizer application (N1, N0) followed similar patterns initially, increasing towards the spring barley filling stage in early summer and decreasing towards the autumn/winter season (Fig. 3). In general, the average CO₂ emissions were higher in both tillage treatments (CT and RT) by 19 and 18% in

case of fertilized plots (Tab. 2) as compared to unfertilized CT and RT plots. This suggests the fact that N fertilization increased CO₂ emission when soil water content is adequate. Limited or no increase in CO₂ emission with increased N fertilization rate had been reported by several researchers (Rochette & Gregorich 1998; Wagai et al. 1998).

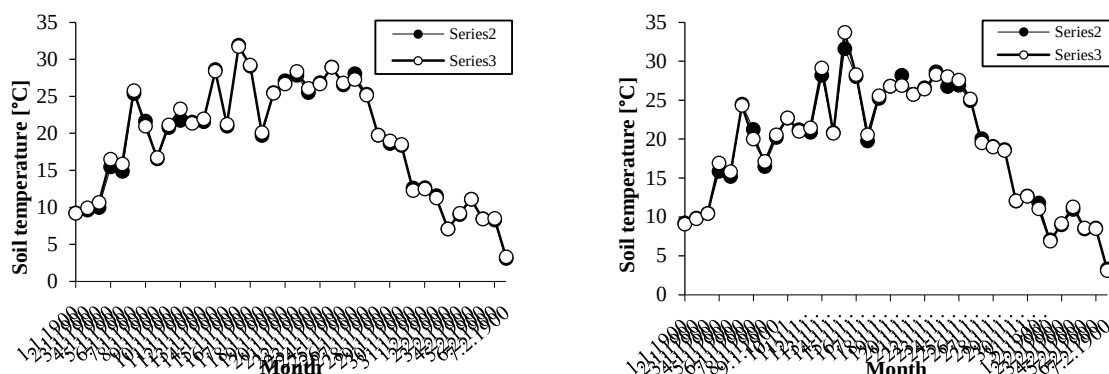


Fig. 1. Soil temperature under conventional (CT) and reduced tillage (RT) combined with (N1) and without (N0) N fertilizer application

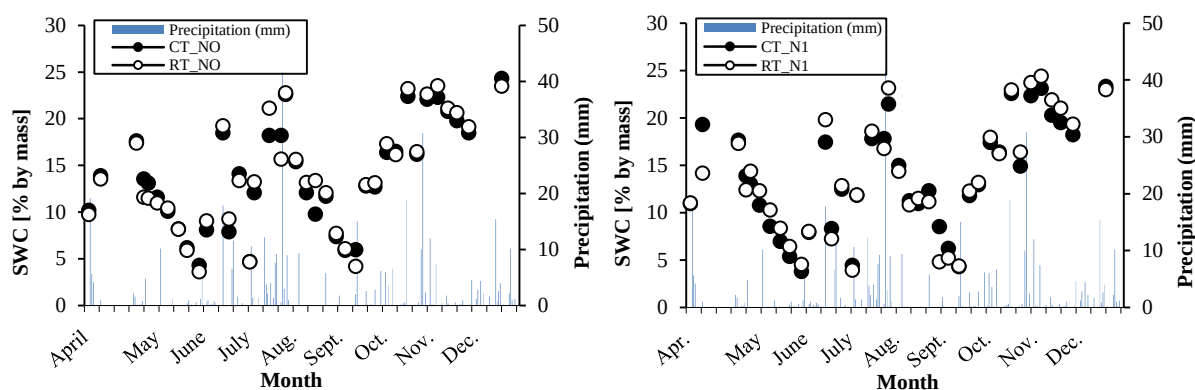


Fig. 2 Soil water content (SWC) and precipitation under conventional (CT) and reduced tillage (RT) combined with (N1) and without (N0) N fertilizer application

There wasn't significant difference ($p < 0.05$) in soil CO₂ between conventional tillage and reduced tillage for both, not fertilized and fertilized plots. The average CO₂ emissions from the soil were almost exactly the same in the CTN0 and RTN0, reaching values of 87.2 and 87.1 kg ha⁻¹ day⁻¹, respectively. The same was found in case of fertilized plots, when CO₂ emissions reached almost the same values of 103.5 and 102.9 kg ha⁻¹ day⁻¹ for CTN1 and RTN1, respectively. The highest CO₂ emissions were observed in mid-June (Fig. 3.) for both tillage treatments. Increase in soil moisture during this period due to precipitation events together with high soil temperature can be associated with the highest CO₂ emission. There is an exponential increase in soil CO₂ fluxes with respect to temperature increases observed for biological systems (O'Connell 1990). A rapid increase in soil CO₂ fluxes within minutes after precipitation and rewetting of dry soils has been observed in a variety of ecosystems (Jenette et al. 2008; Almagro et al. 2009; Morell et al. 2010). The rapid release of CO₂ is due to the infiltration of rainfall water into the soil pores, which replaces highly concentrated CO₂ air, resulting in degassing (Alvaro-Fuentes et al. 2008). Degassing is not considered to be soil respiration as it releases the stored CO₂ in soil from past microbial and root respiration. The CO₂ flux of as much as 300 kg ha⁻¹ day⁻¹ following heavy rain in dry soil in northern Great Plains had been known (Curtin et al. 2000). Seasonal variation in the CO₂ emissions under long term field measurements are attributed to changes in soil temperature under agricultural soils irrespective of the tillage systems (Aslam et al. 2000; Elder & Lal 2008; Almagro et al. 2009).

i.e. higher emissions measured in the summer season in comparison to the autumn/winter season due to higher C mineralization rates with increase in temperature (Kirschbaum 1995).

Our study also showed clear decline in CO₂ emissions just after barley harvest and then followed by second highest CO₂ peak just after incorporation of crop residues into the soil for both tillage treatments whether they were fertilized or not. Second emission peak patterns can be attributed to the combined effects of soil temperature, water availability and tillage. Finally, rainfall, high temperatures, and the crop residue available for decomposition embedded in the soil could result in a soil environment which enhanced high microbial activity, thereby increasing C mineralization and CO₂ flux during the summer on CTN0, RTN0, CTN1 and RTN1. Cumulative total CO₂ emissions were calculated by interpolating the emissions between each sampling day. On quantifying the total emissions during the studied period (April-December 2012) we found that they were 21.8 and 25.9 t ha⁻¹ in CTN0 and RTN0 and 21.5 and 25.7 t ha⁻¹ in CTN1 and RTN1, respectively (Tab. 2). Total emission didn't indicated an increase of soil CO₂ flux at the end of studied period when soils were tilled with conventional tillage as compared to reduced tillage for both nitrogen treatments (N0,N1).

Table.2 Mean, maximum, minimum and total cumulative CO₂ emissions during the studied period under conventional (CT) and reduced tillage (RT) combined with and without N fertilizer application (N0, N1)

Soil tillage and N level		CO ₂ emissions			
		Mean	Maximum	Minimum	Total
		kg ha ⁻¹ day ⁻¹			t ha ⁻¹
CTN0	not fertilized	87,2	275,4	-1,6	21,8
RTN0		87,1	276,9	-7,0	21,5
CTN1	fertilized	103,5	316,5	5,1	25,9
RTN1		102,9	394,9	5,0	25,7

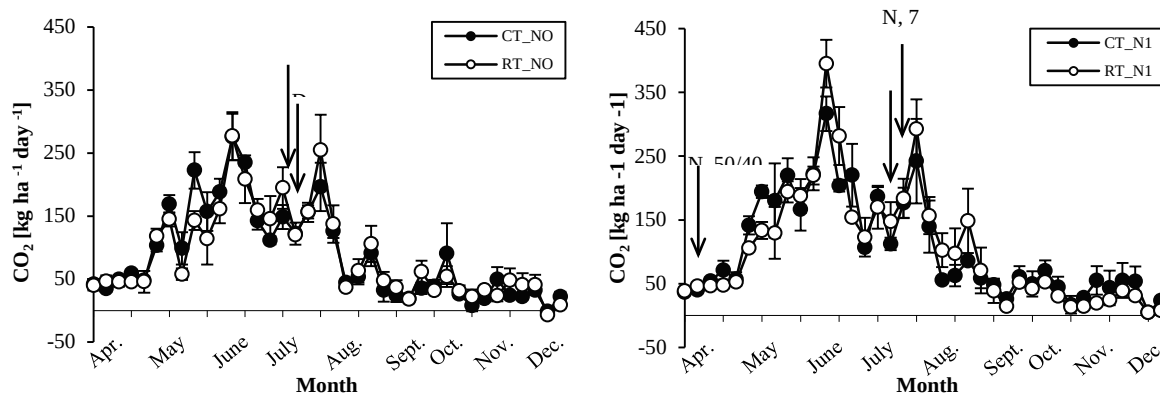


Fig. 3 Soil CO₂ emission under conventional (CT) and reduced tillage (RT) combined with and without N fertilizer application (N0, N1). Bars indicate S.E. (n=3) and arrows indicate time of harvest (H), disking with incorporation of crop residues (D) and fertilizer applications (N) with doses in kg ha⁻¹.

3.3 Relationship between CO₂ and soil temperature and soil water content

The results showed that CO₂ emissions for both tillage treatments combined with and without nitrogen fertilizers generally followed the trend of soil temperature. The Pearson correlation coefficient between the CO₂ flux and soil temperature during the studied period was significant ($p < 0.05$) for both conventional ($r = 0.52$ for CTN0; $r = 0.49$ for CTN1) and reduced tillage ($r = 0.60$ for RTN0; $r = 0.58$ for RTN1) whether the plots were fertilized or not. On the other hand, the correlation between the CO₂ flux and soil water content was not significant ($p < 0.05$) and showed weak relationship for both conventional ($r = 0.23$ for CTN0; $r = 0.27$ for CTN1) and reduced tillage ($r = 0.11$ for RTN0; $r = 0.19$ for RTN1) systems combined with and without N.

The significant relationship between CO₂ emission and soil temperature is well known (Follett 1997; Parkin & Kaspar 2003). High CO₂ flux usually occurs in the summer when soil temperature is higher and soil water content and substrate C availability is adequate, while low emission occurs in the winter when soil biological activity is minimal due to near-freezing soil temperature (Follett 1997; Bajracharya et al. 2000a, 2000b).

4. CONCLUSIONS

Results of this study showed that the average CO₂ emissions were higher in conventional tillage and reduced tillage when the plots were fertilized as compared to unfertilized plots. It can be also concluded that soil CO₂ emission didn't significantly differ between conventional tillage as compared to reduced tillage for both nitrogen treatments. A significant correlation ($p < 0.05$) between the CO₂ flux and soil temperature in conventionally and reduced tilled plots could lead to the easy conclusion that only the soil temperature (and not the soil moisture) was a controlling factor for fertilized and not fertilized plots, which wasn't our case. It can be concluded that increase in soil water content due to precipitation events together with high soil temperature were associated with the highest CO₂ emissions and smaller CO₂ fluxes but still high, when the soil was disturbed by crop residues incorporation after harvest.

ACKNOWLEDGEMENT

This study was supported by Slovak Grant Agency – VEGA, No. 1/0136/12; VEGA, No. 2/0040/12 and Slovak Research and Development Agency under the contract No. APVV-0512-12; APVV-0139-10.

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