ISSN 1392-3196 / e-ISSN 2335-8947
Zemdirbyste-Agriculture, vol. 101, No. 3 (2014), p. 227–234
DOI 10.13080/z-a.2014.101.029

The influence of tillage, fertilization and meteorological conditions on the CO_2 exchange rate in a loamy *Cambisol*

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Abstract

There is no consensus worldwide concerning the effects of soil management practices on soil net CO_2 exchange rate (NCER). The main goal of the study was to determine soil NCER in different agricultural management systems under contrasting meteorological conditions. The evaluation of moisture and temperature (determined by frequency domain reflectometry (FDR) method) impact on total soil NCER was performed. A closed chamber (CC) method using an infra-red gas analyzer (IRGA) was applied. A two-factorial field experiment was established on an *Endocalcari-Epihypogleyic Cambisol* (*CMg-p-w-can*) at the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry. A three-year (2009–2012) study revealed that rainy weather conditions suppressed NCER sharply: NCER was 15-fold lower under rainy meteorological conditions than under dry or normal conditions. Soil temperature in both unfertilized tillage systems (conventional tillage, no-tillage) was the main determinant for soil NCER, while this effect was suppressed by the total influence of soil water content, air temperature and amount of rainfall. Soil carbon dioxide flux was slightly (3%) higher under conventional tillage than under no-tillage during dry 2009 and normal 2012 years. In a wet year 2010, conventional tillage increased soil NCER by 70% compared to no-tillage. Fertilization with mineral NPK fertilizers increased soil NCER by on average 32% compared to unfertilized plots, but did not eliminate suppressive effects of meteorological conditions on soil NCER.

Key words: conventional tillage, no-tillage, NPK fertilization, rainfall, temperature, soil water content.

Introduction

Climate change and global warming have worldwide consequences. The most prominent factor driving these phenomena is the increased atmospheric concentrations of greenhouse gases (GHG). Anthropogenic activities have led to an increase in atmospheric concentration of CO_2 from 280 ppm in the pre-industrial era to almost 400 ppm at present (WMO, 2008; CDIAC, 2009), and it is increasing at the rate of about 2.2 ppm yr^{-1} (IPCC, 2007). Despite the vigorous debate on global warming (Kerr, 2009; Solomon et al., 2009; Lal, 2011), mean global temperature has increased by 0.8°C since 1880, and may increase by an additional 3–7°C by 2100 (IPCC, 2007; Allen et al., 2009; Lal, 2011).

Soil moisture and temperature are other important factors controlling soil CO_2 emissions (Wiseman, Seiler, 2004; Lopes de Gerenyu et al., 2005; Schaufler et al., 2010; Ni et al., 2012). In dry conditions soil CO_2 efflux is lower because root and micro-organism activity is typically low. Increasing the soil moisture normally increases the bio-activity in the soil; higher soil moisture content usually causes soil respiration increase. But if there is very high soil moisture, total soil CO_2 efflux is reduced, because of limited diffusion of oxygen and subsequent suppression of CO_2 emission.

Soil temperature is the best predictor of the dynamics of the soil CO_2 flux rate. The high positive correlation between CO_2 emissions and soil temperatures was found in natural and agricultural ecosystems of the Russian taiga zone (Kudeyarov, Kurganova, 1998). In a native Canadian grassland ecosystem the temperature declined in association with reductions in soil moisture. Schaufler et al. (2010) revealed a non-linear increase of CO_2 emissions with temperature increasing.

Tillage regime has been regarded as one of the important factors affecting CO_2 emissions from soils (Paustian et al., 2000; Oorts el al., 2007; Ponjičan et al., 2012; Li et al., 2013). Soil tillage management can affect factors controlling soil respiration, soil temperature and water content (Kladivko, 2001; Liu et al., 2006). Inappropriate agricultural practices can result in C losses from soils to the atmosphere (Smith et al., 2008; Li et al., 2013). The magnitude of CO_2 loss from the soil is highly related to frequency and intensity of soil disturbance caused by tillage (La Scala et al., 2006); however, there is no consensus in the literature on the differences in CO_2 emissions between no-tillage (NT) and conventional tillage (CT) systems. Application of mineral fertilizers also can increase soil CO_2 flux. The increase of CO_2 emissions with increasing nitrogen rates commonly is nonlinear (Sainju et al., 2008; Wilson, Al-Kaisi, 2008; Feiziene et al., 2012). According to Feiziene et al. (2012), soil water content directly affected NCER in both (NT and CT) tillage and fertilization treatments, whereas this effect was positive only under dry and normal weather conditions. Under wet weather conditions, the direct effect of soil water content on NCER was negative.

The main goal of our investigations was to determine soil CO_2 emission in different tillage-fertilization systems under contrasting meteorological conditions. Attention was focused on evaluation of moisture and temperature impact on total soil CO_2 efflux regime.

Materials and methods

Site and soil description and experimental design. The field trial was set up at the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry on *Endocalcari-Epihypogleyic Cambisol* (*CMg-p-w-can*) during 2009–2012 (55°23′50″ N, 23°51′40″ E). Two-factorial field experiment was established in 1999 having a split-plot design in four replications. Tillage systems – conventional tillage (CT) and no-tillage (NT) were the main plots, while fertilization – not fertilized (1) and moderate rates of mineral NPK fertilizers (2) were as sub-plots (Table 1).

Mineral NPK fertilizer rates were calculated according to soil properties and expected yield (Švedas, Tarakanovas, 2000). Expected yield for peas was 4.5 t ha^{-1} (NPK 0:0:31) in 2009, for winter wheat – 8.5 t ha^{-1} (NPK 150:0:42) in 2010, and for spring wheat – 6.0 t ha^{-1} (NPK 125:0:42) in 2012. CT involved stubble cultivation and deep ploughing. Pre-sowing tillage in CT was done one day before sowing. Direct drilling into untilled soil (NT) and tilled soil (CT) was performed with a flat disc seed drill. Fertilizers were spread on soil surface and slightly incorporated during pre-sowing tillage under CT or during direct drilling under NT.

Table 1. Field trial design

Tillage		
Treatment	Primary tillage	Presowing tillage
CT – conventional tillage	stubble cultivation (10–12 cm) + ploughing (23–25 cm)	spring tine cultivation (4–5 cm)
NT – no-tillage	Glyphosate (3 l ha^{-1})	direct drilling
Fertilization		
1	not fertilized	
2	moderate rates: NPK fertilizers according to soil properties and expected yield	

Soil analyses. A closed chamber (CC) method using an infra-red gas analyzer (IRGA) was used to quantify CO_2 fluxes between the soil and the atmosphere in the stands of agricultural crops during vegetation period (Feizienė, Povilaitis, 2013). Soon after sowing, soil surface net CO_2 exchange rate (NCER) was measured biweekly from May to July. Measurements were taken between 11 a.m. and 3 p.m. to reduce the variability in CO_2 flux. NCER was measured with a portable infrared gas analyzer (IRGA) attached to a data logger (LcSRS-1000; ADC BioScientific Ltd, UK). The collar was inserted into the soil to a depth of 10 cm in each treatment. Each NCER measurement was done in four replications. Soil temperature (T-soil) and volumetric water content (VWC) were recorded at the 10 cm soil depth by a portable soil sensor, type WET-2 with HH2 probe, using frequency domain reflectometry (FDR) method. Soil NCER, temperature and water content were measured biweekly for up to six times in all treatments from May to July until ripeness of crops.

Statistical analysis. Data were analyzed using the software *ANOVA* and *STAT-ENG*. Treatment means were separated by using the least significant difference (LSD) and evaluated at the 5% probability level ($P = 0.05$). The path analysis (Williams et al., 1990) was implemented for a deeper evaluation of the interdependence among the net CO_2 exchange rate (NCER), soil temperature (T-soil), soil water content, rainfall and air temperature (T-air) and for the presentation of the correlation matrix.

Results and discussion

Effect of meteorological conditions. Soil NCER, T-soil and VWC significantly responded to meteorological conditions of individual year and soil management practices (Table 2, Figs 1–3). The influence of the year character and management practices and their interaction was significant ($P \leq 0.01$) for NCER, T-soil and VWC. Cold winter and long spring thaw caused excess of soil moisture during crop growing period in 2010. Consequently, mean VWC in 2010 was 50% higher than in 2009 and 2012. In 2010, the NCER was 10.7-fold lower than in 2009 and 20.3-fold lower than in 2012. This circumstance was the reason for particularly low soil vitality. Nevertheless, averaged data across the years did not reveal an impartial influence of agricultural management on VWC, T-soil and NCER. The decision was made that the effect of agricultural management on soil NCER should be considered in close relation with the peculiarities of individual years.

Interaction of soil management practices with meteorological conditions. The year 2009 exhibited dry spring, very wet end of June and normal July. In 2009, the mean T-air of the test period was 19.6°C, the total amount of rainfall 257.1 mm, the mean air humidity 66.3%, mean wind speed 6.8 m s^{-1} and the sum of sunny hours did not exceed 795.3. Much higher than normal amount of rainfall was registered on June 7, 14 and 23 in 2009. An extreme rainfall event was registered on July 23 during which the monthly average was exceeded by 19% and the total amount of rainfall for June increased by 3.56-fold compared to the long-term mean. The mean VWC in CT was significantly lower than in NT ($P < 0.05$), while fertilization influencing better crop stand density caused markedly higher VWC ($P < 0.01$) compared to unfertilized plots. We suppose that denser plant cover acted like an umbrella and suppressed soil evaporation intensity (Feiziene et al., 2011). In contrast, T-soil in CT

Table 2. Effects of year and management practices on mean data of soil net CO_2 exchange rate (NCER), soil temperature (T-soil) and volumetric water content (VWC) at the 0–10 cm depth averaged across dates of measurement

Year (factor A)	Management practices (factor B)	NCER µmol m^{-2} s^{-1}	T-soil °C	VWC %
2009		0.815 b	20.0 a	13.0 b
2010		0.076 c	18.0 b	19.5 a
2012		1.547 a	17.9 b	13.0 b
	CT-1 (1)	0.707 c	18.8 a	14.9 b
	CT-2 (2)	0.948 a	18.6 a	15.3 a
	NT-1 (3)	0.725 c	18.7 a	15.0 a
	NT-2 (4)	0.871 b	18.5 b	15.4 a
Contrasts				
CT (1 + 2) *vs* NT (3 + 4)		0.029 ns	0.1 ns	−0.1 ns
Fertilization (2 + 4) *vs* no fertilization (1 + 3)		0.194**	−0.2 ns	0.4*

Notes. NCER, T-soil and VWC data followed by the same letters are not significantly different at $P < 0.05$; *, ** – the least significant difference at $P < 0.05$ and $P < 0.01$, respectively, ns – not significant. CT-1 – convention tillage without fertilizers, CT-2 – convention tillage with fertilizers, NT-1 – no-tillage without fertilizers, NT-2 – no-tillage with fertilizers.

system was significantly higher than in NT, but fertilized soil was significantly cooler than unfertilized ($P < 0.05$) one. This is a consistent pattern, i.e. the higher was VWC, and the lower T-soil was registered. NCER depended on soil management practices also. The higher tillage intensity and plant nutrition level was applied, the higher the CO_2 flux was registered (Table 3, Figs 1 and 4).

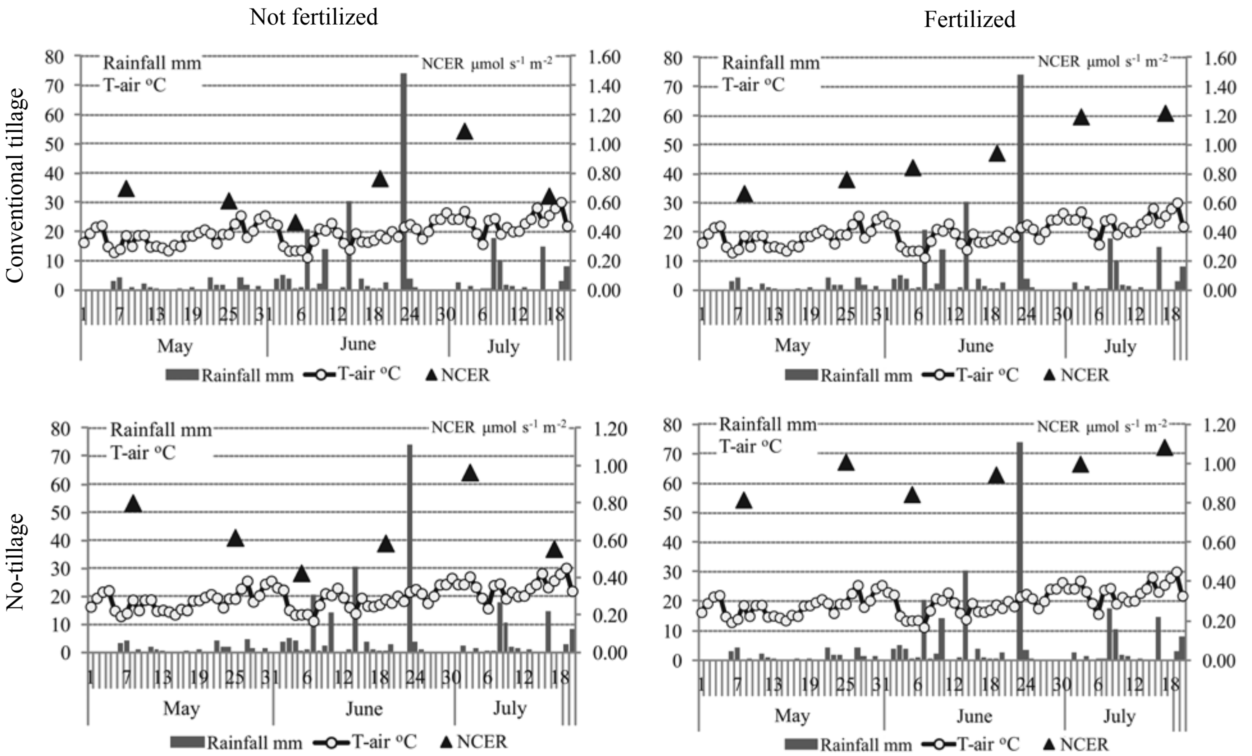


Figure 1. Meteorological conditions (rainfall and air temperature (T-air)) and soil net CO_2 exchange rate (NCER) in 2009

It should be noted that NCER significantly depended on the weather conditions. However, only dynamic NCER measurements and data analysis could provide objective answers about NCER responses to weather changes. The highest NCER during an exceptionally dry spring in 2009 was registered in NT-2 system. An extreme rainfall at the end of June sharply changed VWC and T-soil. Consequently, soil respiration demonstrated a different pattern. The highest NCER manifested in CT-2 system. In this system NCER increased by 26% as compared to NCER value obtained before extreme rainfall, whereas NCER increase in NT-2 system amounted to 6% only. The opposite response to that was demonstrated by unfertilized soil. In CT-1 system NCER increased by 42%, in NT-1 system by 64%, compared to value obtained before extreme rainfall. Nevertheless, NCER in unfertilized soil sharply decreased in two weeks.

In 2010, the mean midday T-air of the test period was 21.5°C, the total amount of rainfall 177.7 mm, the mean air humidity 76.0%, mean wind speed 7.6 m s^{-1} and the sum of sunny hours amounted to 645.9. The spring of 2010 was late, rainy and windy, with contrasting day and night temperatures. The amount of precipitation during the spring period amounted to 136% as compared to the long-term mean. At the end of March, the large amount of water from melting snow stayed in the fields due to deep (80 cm) soil freeze. Soils became warmer only in the second half of the May. June was the rainiest month (94.2 mm, while the long-term mean is 52.3 mm) of the crop vegetation period. The weather during June was contrasting: the first ten-day period and the beginning of the second ten-day period were warm, while the rest of the month was rainy and rather cool. The amount of rainfall during June amounted to 116% as compared to the long-term mean. Very warm weather with heat waves was registered in July. Soil VWC exceeded the optimal moisture content (18 volume percent) from early spring to the end of June. Excess of soil water caused an increase in anaerobic processes. Soil respiration almost stopped. Tillage and fertilization influence on NCER was insignificant. The mean VWC in CT was significantly lower than in NT ($P < 0.05$). Fertilization influencing better stand density caused markedly higher VWC and lower T-soil ($P < 0.01$) compared to unfertilized plots (Table 3, Figs 2 and 4).

Table 3. Effect of management practices on soil net CO_2 exchange rate (NCER), soil temperature (T-soil) and volumetric water content (VWC) at the 0–10 cm depth averaged across dates of measurement

Management practices	NCER µmol m^{-2} s^{-1}			T-soil °C			VWC %		
	2009	2010	2012	2009	2010	2012	2009	2010	2012
CT-1 (1)	0.713 b	0.068 b	1.339 d	20.3 a	18.1 a	17.9 b	12.5 b	18.9 c	13.3 a
CT-2 (2)	0.939 a	0.097 a	1.808 a	20.2 a	17.9 b	17.7 c	13.3 a	19.7 b	12.9 a
NT-1 (3)	0.658 c	0.071 a	1.448 c	20.1 a	18.1 a	18.0 a	12.7 b	19.2 c	13.1 a
NT-2 (4)	0.950 a	0.069 b	1.593 b	19.6 b	17.8 b	18.0 a	13.4 a	20.2 a	12.5 b
Contrasts									
CT (1 + 2) *vs* NT (3 +4)	0.022*	0.013 ns	0.053*	0.4*	0.0 ns	−0.2**	−0.2*	−0.4*	0.3*
Fertilization (2 + 4) *vs* no fertilization (1 + 3)	0.259**	0.014 ns	0.307**	−0.3*	−0.3**	−0.1*	0.8**	0.9**	−0.5*

Notes. NCER, T-soil and VWC data followed by the same letters are not significantly different at $P < 0.05$; *, ** – the least significant difference at $P < 0.05$ and $P < 0.01$, respectively, ns – not significant. CT-1 – conventional tillage without fertilizers, CT-2 – conventional tillage with fertilizers, NT-1 – no-tillage without fertilizers, NT-2 – no-tillage with fertilizers.

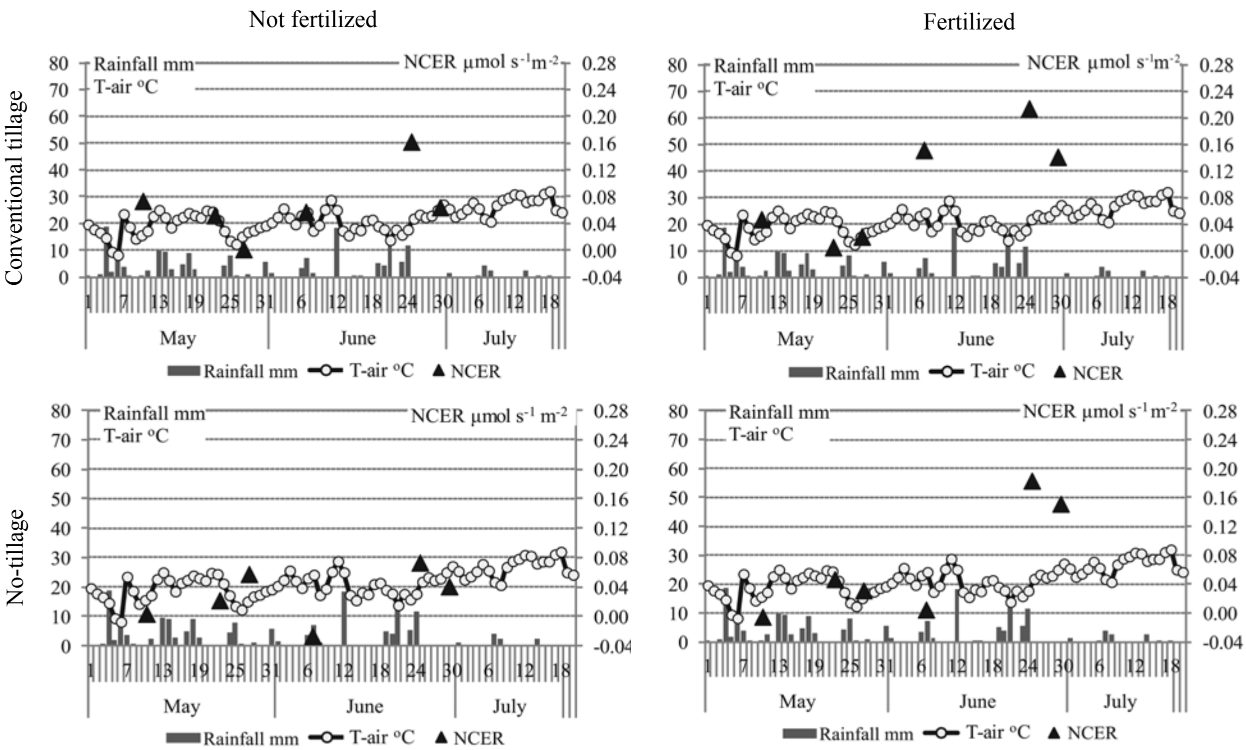


Figure 2. Meteorological conditions (rainfall and air temperature (T-air)) and soil net CO_2 exchange rate (NCER) in 2010

The year 2012 was characterized by contrasting temperature fluxes during the year, by windy and dry spring and also by windy and rather cool and rainy summer. The mean T-air of the test period was 20.1°C, the total amount of rainfall was 233.0 mm, the mean air humidity averaged 73.4%, the mean wind speed was 8.9 m s^{-1} and the sum of sunny hours did not exceed 7822.0. The mean VWC in CT was significantly higher than in NT ($P < 0.05$). Fertilization caused markedly lower VWC ($P < 0.05$) compared to unfertilized plots. In contrast to 2009 and 2010 data, T-soil in CT system was significantly lower than in NT, but fertilized soil also was significantly cooler than unfertilized ($P < 0.05$). NCER also depended on soil management practices. The higher tillage intensity in CT and the higher plant nutrition level was applied, the higher the CO_2 flux was registered (Table 3 and Figs 1–3).

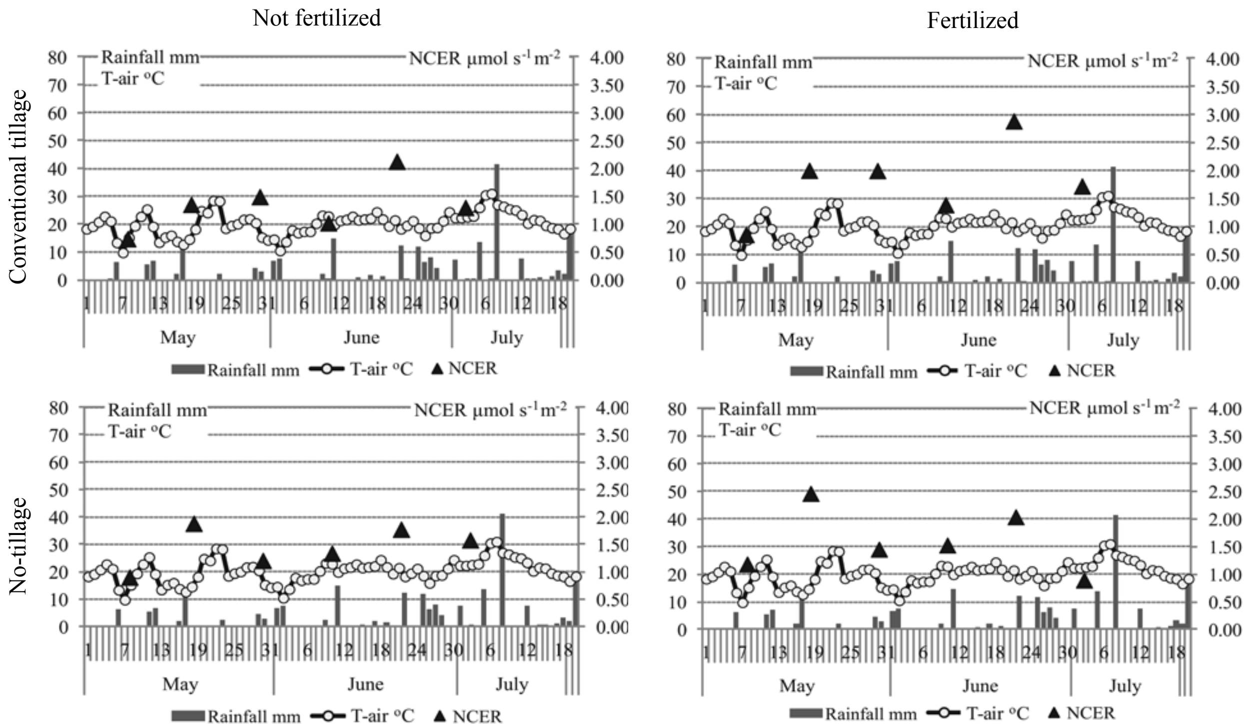
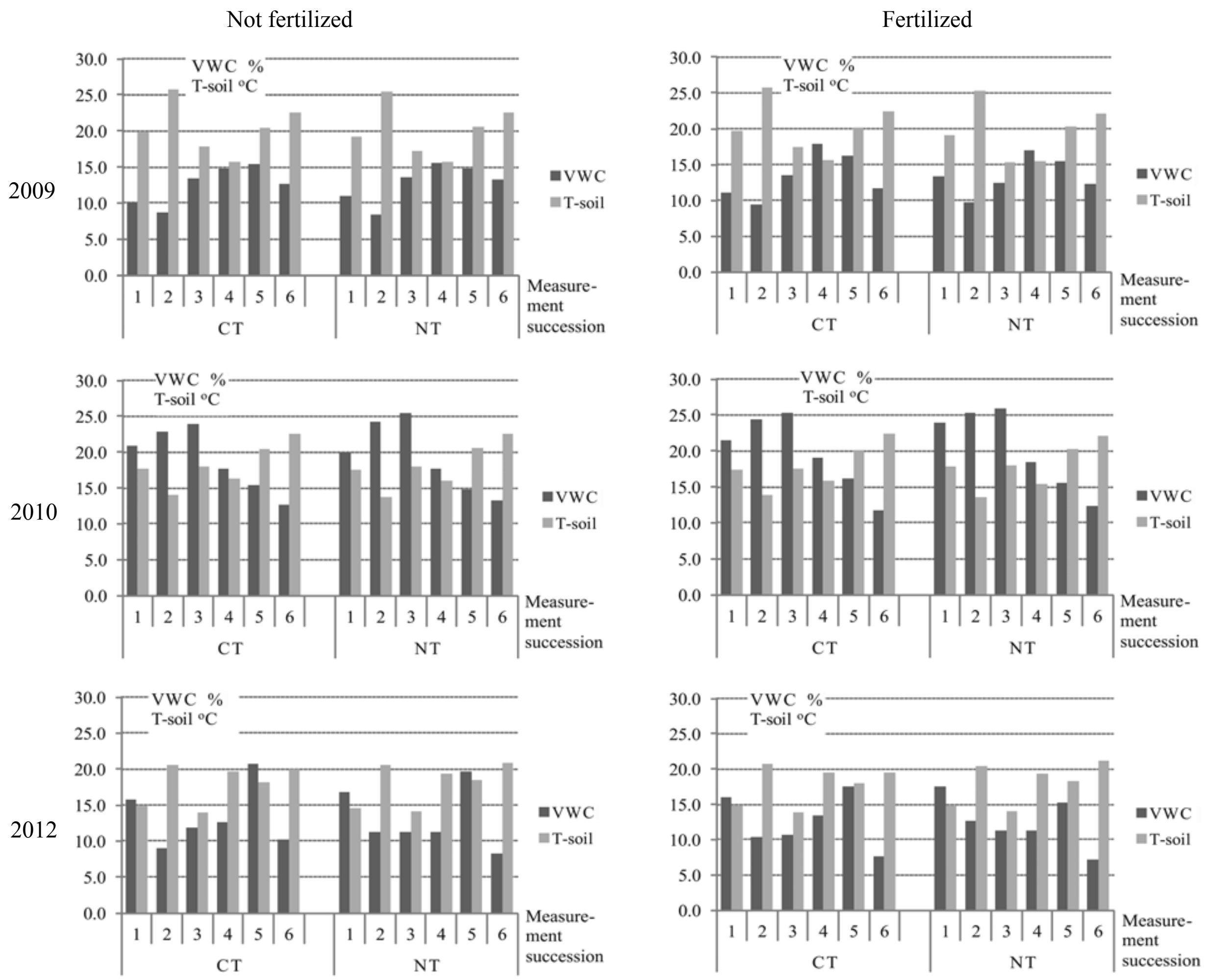


Figure 3. Meteorological conditions (rainfall and air temperature (T-air)) and soil net CO_2 exchange rate (NCER) in 2012



CT – convention tillage, NT – no-tillage

Figure 4. Changes in soil temperature (T-soil) and volumetric water content (VWC) under different management practices during the study period

Correlation between NCER, T-air, T-soil, VWC and rainfall. All processes taking part in soil are in close interdependence. Changes in weather patterns caused by the climate change, including droughts and extreme events, have significant influence on greenhouse gases flux. According to literature, soil NCER peaked at intermediate soil moisture and decreased under increasingly dry conditions, but also decreased when soils became water saturated (van Straaten et al., 2009). Our data are in line with the above mentioned findings. The correlation matrix between the investigated indices and NCER is presented in Table 4. In 2009, significant correlation between the NCER and T-air was registered in all soil management systems. In 2012, such relationship was established only in NT systems with fertilizer application. Significant correlations between the NCER and VWC were observed in CT-1 treatment in 2009 and 2010, and in both fertilized treatments (CT-2, NT-2) in 2009 only.

Significant correlations ($P < 0.05$) in all treatments were observed between VWC and T-soil (2009 and 2010), T-air and VWC (2010), T-air and T-soil (2010, 2012 and in NT-2 treatment in 2009). Rainfall significantly influenced VWC (2009) and T-soil (2009, 2010), while paired correlation between rainfall and NCER was clearly expressed only in treatment NT-1 (2009), in NT-2 (2010) and in all treatments in 2012 (except NT-2).

Path analyses using NCER as the dependent variable. The direct effect of VWC on NCER depended on year peculiarities and tillage. It was positive in CT system, but only in the year which could be characterize as dry (2009 with dry spring and wet summer) or normal (2012). In all other cases the direct effect of VWC on NCER was negative (Table 4). The correlation (r(Y) = the sum of the entire path connecting the two variables) between NCER and VWC in many cases was higher in CT than in NT. In 2009, the indirect effects of all key drivers suppressed the direct effect of VWC on NCER in both CT and NT systems. However, the VWC was a dominant factor enhancing NCER in dry and normal year, but suppressing NCER in wet year.

Table 4. Soil net CO_2 exchange rate (NCER), soil temperature (T-soil), and volumetric water content (VWC) at the 0–10 cm depth and rainfall and air temperature (T-air) correlation matrix

Year	Tillage	Indices	Correlation matrix							
			not fertilized				fertilized			
			2	3	4	5	2	3	4	5
2009	CT	1(Y) – NCER	0.75**	0.51*	−0.08	−0.23	0.79**	0.44	0.00	0.05
		2 – T-air	1.00	0.30	0.33	−0.28	1.00	0.15	0.34	−0.28
		3 – VWC		1.00	−0.68*	0.36		1.00	−0.79**	0.54*
		4 – T-soil			1.00	−0.61*			1.00	−0.59*
		5 – rainfall				1.00				1.00
	NT	1(Y) – NCER	0.63*	0.04	0.14	−0.55*	0.74**	−0.12	0.63*	0.02
		2 – T-air	1.00	0.22	0.41	−0.28	1.00	0.23	0.49*	−0.28
		3 – VWC		1.00	−0.73*	0.50*		1.00	−0.65*	0.49*
		4 – T-soil			1.00	−0.58*			1.00	−0.54*
		5 – rainfall				1.00				1.00
2010	CT	1(Y) – NCER	0.05	−0.59*	0.37	−0.28	0.32	−0.80**	0.60*	−0.25
		2 – T-air	1.00	−0.63*	0.92**	−0.57*	1.00	−0.70*	0.92**	−0.57*
		3 – VWC		1.00	−0.77**	0.33		1.00	−0.82**	0.37
		4 – T-soil			1.00	−0.70*			1.00	−0.72*
		5 – rainfall				1.00				1.00
	NT	1(Y) – NCER	−0.48	0.46	−0.47	−0.17	0.48	−0.75**	0.72*	−0.82**
		2 – T-air	1.00	−0.58*	0.92**	−0.57*	1.00	−0.61*	0.92**	−0.57*
		3 – VWC		1.00	−0.74**	0.25		1.00	−0.71*	0.37
		4 – T-soil			1.00	−0.71*			1.00	−0.73*
		5 – rainfall				1.00				1.00
2012	CT	1(Y) – NCER	0.16	0.44	0.13	0.90**	0.27	0.10	0.21	0.89**
		2 – T-air	1.00	−0.13	0.67*	0.07	1.00	0.08	0.72*	0.07
		3 – VWC		1.00	−0.32	0.33		1.00	−0.29	0.09
		4 – T-soil			1.00	−0.17			1.00	−0.17
		5 - rainfall				1.00				1.00
	NT	1(Y) – NCER	0.70*	−0.08	0.78**	0.49*	0.86**	0.32	0.22	0.45
		2 – T-air	1.00	0.10	0.59*	0.07	1.00	0.18	0.57*	0.07
		3 – VWC		1.00	−0.37	0.33		1.00	−0.54*	0.08
		4 – T-soil			1.00	−0.11			1.00	−0.15
		5 – rainfall				1.00				1.00

*, ** – the least significant difference at $P < 0.05$ and $P < 0.01$, respectively; CT – convention tillage, NT – no-tillage

T-soil in both unfertilized tillage systems was the main determinant for NCER, while this effect was suppressed by the total influence of other investigated factors (Table 5). Consequently, the correlation between NCER and T-soil in many cases was insignificant. In other words, an increase in rainfall content influenced higher VWC, while an increase in T-air at the same time caused higher T-soil and more intensive evaporation with higher CO_2 flux in dry and normal year. NCER was suppressed by wet weather conditions while T-air was high (2010). Fertilization mitigated suppressive effects of the weather conditions on NCER but did not eliminate it. Management practices and weather conditions, soil water content variation, T-soil and T-air fluctuation range affected soil NCER. Under dry weather and soil conditions the NCER responded weakly to negligible variation in soil water content changes. Rainy weather conditions prolonged soil water saturation and sharply suppressed NCER. The higher soil water content fluctuation ranges, the more significant soil NCER response to water changes was registered.

Table 5. Pathway of soil net CO_2 exchange rate (NCER) response to soil temperature (T-soil), volumetric water content (VWC) at the 0–10 cm depth and rainfall and air temperature (T-air) during the study period

Year	Tillage	Indices	Path coefficients									
			not fertilized					fertilized				
			2	3	4	5	NCER 1(rY)	2	3	4	5	NCER 1(rY)
2009	CT	1(Y) – NCER										
		2 – T-air	0.875	−0.017	−0.206	0.094	0.75**	0.770	0.042	0.013	−0.037	0.79**
		3 – VWC	0.264	−0.056	0.423	−0.125	0.51*	0.114	0.283	−0.030	0.072	0.44
		4 – T-soil	0.292	0.038	−0.618	0.209	−0.08	0.264	−0.224	0.038	−0.080	0.00
		5 – rainfall	−0.241	−0.020	0.377	−0.342	−0.23	−0.212	0.152	−0.023	0.135	0.05
	NT	1(Y) – NCER										
		2 – T-air	1.375	−0.256	−0.626	0.133	0.63*	1.017	−0.139	0.042	−0.177	0.74*
		3 – VWC	0.309	−1.140	1.111	−0.241	0.04	0.231	−0.610	−0.056	0.313	−0.12
		4 – T-soil	0.563	0.829	−1.529	0.279	0.14	0.497	0.399	0.085	−0.349	0.63*
		5 – rainfall	−0.379	−0.571	0.886	−0.482	−0.55*	−0.280	−0.297	−0.046	0.643	0.02
2010	CT	1(Y) – NCER										
		2 – T-air	−1.786	0.210	1.674	−0.049	0.05	−1.913	0.138	2.468	−0.371	0.32
		3 – VWC	1.120	−0.334	−1.405	0.029	−0.59*	1.341	−0.197	−2.188	0.239	−0.80**
		4 – T-soil	−1.647	0.259	1.814	−0.060	0.37	−1.767	0.161	2.672	−0.470	0.60*
		5 – rainfall	1.016	−0.112	−1.269	0.086	−0.28	1.089	−0.072	−1.924	0.653	−0.25
	NT	1(Y) – NCER										
		2 – T-air	1.444	0.715	−3.757	1.115	−0.48*	−0.393	0.418	0.015	0.445	0.48*
		3 – VWC	−0.843	−1.225	3.025	−0.495	0.46	0.239	−0.687	−0.012	−0.288	−0.75**
		4 – T-soil	1.325	0.905	−4.097	1.397	−0.47*	−0.361	0.490	0.017	0.573	0.72*
		5 – rainfall	−0.822	−0.310	2.922	−1.959	−0.17	0.224	−0.253	−0.012	−0.781	−0.82**
2012	CT	1(Y) – NCER										
		2 – T-air	−0.203	−0.035	0.338	0.062	0.16	−0.295	0.018	0.481	0.068	0.27
		3 – VWC	0.026	0.271	−0.162	0.304	0.44	−0.023	0.231	−0.191	0.086	0.10
		4 – T-soil	−0.135	−0.086	0.508	−0.156	0.13	−0.214	−0.066	0.665	−0.169	0.21
		5 – rainfall	−0.014	0.090	−0.087	0.909	0.90**	−0.020	0.020	−0.113	0.998	0.89**
	NT	1(Y) – NCER										
		2 – T-air	0.268	−0.005	0.396	0.038	0.70*	1.119	−0.028	−0.256	0.022	0.86**
		3 – VWC	0.026	−0.051	−0.248	0.189	−0.08	0.205	−0.152	0.242	0.025	0.32
		4 – T-soil	0.158	0.019	0.671	−0.064	0.78**	0.636	0.082	−0.450	−0.047	0.22
		5 – rainfall	0.018	−0.017	−0.075	0.568	0.49*	0.076	−0.012	0.066	0.321	0.45

*, ** – the least significant difference at $P < 0.05$ and $P < 0.01$, respectively; number in bold – direct effect, underlined number – dominant effect; CT – convention tillage, NT – no-tillage

It could be summarized that CO_2 fluxes during the study period were: 1.308 and 1.274, 0.131 and 0.077, 1.097 and 1.060 kg ha^{-1} hr^{-1} in CT and NT respectively in 2009, 2010 and 2012. Mineral NPK fertilization increased CO_2 flux by on average 32% compared to unfertilized plots in 2009–2012.

Conclusions

1. Rainy weather conditions prolonged soil water saturation and sharply suppressed net CO_2 exchange rate (NCER). Soil volumetric water content (VWC) was a dominant factor enhancing NCER in dry and normal year, but suppressing CO_2 flux in wet year. Soil temperature (T-soil) in both unfertilized tillage systems was the main determinant for CO_2 flux while this effect was suppressed by the total influence of soil water content, soil temperature and rainfall. The correlation between CO_2 flux and soil temperature in many cases was insignificant.

2. Soil carbon dioxide flux was slightly (3%) higher under conventional tillage (CT) than under no-tillage (NT) during dry 2009 and normal 2012 years. In a wet year 2010, conventional tillage increased soil NCER by 70% compared to no-tillage.

3. Mineral NPK fertilization increased CO_2 flux by on average 32% compared to unfertilized plots, but did not eliminate the suppressive effects of the weather conditions on NCER.

Received 08 11 2013
Accepted 01 04 2014

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ISSN 1392-3196 / e-ISSN 2335-8947
Zemdirbyste-Agriculture, vol. 101, No. 3 (2014), p. 227–234
DOI 10.13080/z-a.2014.101.029

Žemės dirbimo, tręšimo ir meteorologinių sąlygų įtaka CO_2 apykaitai priemolingame rudžemyje

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Santrauka

Pasaulyje nesutariama dėl įvairios agrarinės veiklos įtakos dirvožemio CO_2 srautų intensyvumui. Tyrimo tikslas – nustatyti CO_2 srautų apykaitos intensyvumą taikant skirtingas žemės dirbimo ir tręšimo sistemas kontrastingomis meteorologinėmis sąlygomis. Įvertinta drėgmės ir temperatūros (nustatyta FDR metodu) įtaka dirvožemio CO_2 srautų apykaitos intensyvumui (nustatytas IRGA metodu). Dviejų veiksnių lauko eksperimentas atliktas Lietuvos agrarinių ir miškų mokslo centro Žemdirbystės institute giliau karbonatingame sekliai glėjiškame rudžemyje (RDg8-k2). Drėgnais metais CO_2 srautų apykaitos intensyvumas buvo vidutiniškai 15 kartų mažesnis nei sausringais ir normalios drėgmės metais. Dirvožemio temperatūra abiejuose netręštuose žemės dirbimo (tradicinio žemės dirbimo ir tiesioginės sėjos) variantuose buvo pagrindinis veiksnys, lėmęs CO_2 srautų apykaitos intensyvumą; šio veiksnio įtaką sustiprino dirvožemio drėgmės kiekis, oro temperatūra ir kritulių kiekis. Dirvožemio CO_2 apykaitos intensyvumas taikant tradicinę žemės dirbimo sistemą sausringais 2009 ir normalaus drėgnio 2012 metais buvo 3 % didesnis nei taikant tiesioginę sėją. 2010 m., esant dirvos pertekliniam drėgniui, tradicinio žemės dirbimo taikymas CO_2 srautų apykaitos intensyvumą padidino net 70 %, palyginus su tiesiogine sėja. Patręšus mineralinėmis NPK trąšomis CO_2 srautų apykaitos intensyvumas buvo vidutiniškai 32 % didesnis nei netręšus, tačiau tręšimas neigiamos meteorologinių sąlygų įtakos CO_2 srautų apykaitos intensyvumui esmingai nesumažino.

Reikšminiai žodžiai: dirvožemio drėgnis, krituliai, temperatūra, tiesioginė sėja, tradicinis žemės dirbimas, tręšimas NPK.