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Soil surface carbon dioxide exchange rate as affected by soil texture, different long-term tillage application and weather

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Abstract

The current study was carried out at the Lithuanian Institute of Agriculture in Dotnuva on an *Endocalcari-Epihypogleyic Cambisol* (*CMg-p-w-can*). It was aimed to investigate the effect of air and soil temperature, air humidity and gravimetric water content (GWC) on soil CO_2 exchange rate (NCER) under conventional (CT), reduced (RT) and no-tillage (NT) management on loam and sandy clay loam soils.

Application of NT on both loam and sandy loam soils increased soil GWC and decreased soil air temperature compared to CT and RT both under dry and wet weather conditions. NCER under dry weather conditions, on loam soil under NT was higher by 0.024–0.033 g CO_2-C m^{-2} h^{-1} than under RT or CT, while on sandy loam soil NCER was lower by 0.011 g CO_2-C m^{-2} h^{-1} than under CT application. No significant differences were registered when comparing NT with RT management. NCER under wet weather conditions, on the loam soil under NT was lower by 0.043 g CO_2-C m^{-2} h^{-1} compared to CT, and insignificantly differed from RT; whereas on sandy loam NCER under wet weather conditions was lower by 0.069–0.087 g CO_2-C m^{-2} h^{-1} than under RT and CT. Relatively hot air waves during summer resulted in sharp soil temperatures increase and soil GWC reduction. Dry and hot weather situation under moderate climatic conditions of the Baltic region could be attributed to NCER potential limiting condition either on loam or sandy loam soil and affecting all three tillage management practices investigated. Even small rainfall (to 13.5 mm event) essentially enhanced CO_2 flux under dry weather conditions. It was noticed that warm weather conditions and higher than normal rainfall inhibited soil CO_2 exchange rate. Soil NCER responded to changes of weather and soil state more sensitively in NT than in RT and CT application both under dry and wet environmental conditions.

Key words: *Cambisol*, loam, sandy loam, soil CO_2 exchange rate, tillage, climatic conditions.

Introduction

The influence of agricultural production systems on greenhouse gas generation and emission is of interest as it may affect potential balance between terrestrial systems and atmosphere. Agricultural ecosystems can play a significant role in production and consumption of greenhouse gases, specifically, carbon dioxide. Soil temperature and soil moisture are considered the most influential environmental factors controlling soil surface carbon dioxide exchange rate. These factors interact to affect the productivity of terrestrial ecosystems and the decomposition rate of soil organic matter, thereby driving the temporal variation of soil respiration (Wiseman, Seiler, 2004).

Soil texture effects on soil respiration and soil organic matter (SOM) content are documented rather controversially in literature. Some authors revealed that soil texture and type have a strong effect on soil respiration. Fine-textured soils have high water-holding capacity, potentially prolonging the availability of water in surface layers. Conversely, high infiltration rates on coarse-textured soils shift available water to deeper soil layers. Thus, the interaction of soil texture, SOM and plant cover may result in significant spatial and temporal variation in soil respiration responses to precipitation pulse variability (Cable et al., 2008). Some results revealed that in conservation tillage, no significant correlations occurred between soil CO_2 flux and soil bulk density, sand fraction, or clay fraction of the surface 7.5 cm. In CT, sand fraction was positively correlated, while bulk density and clay fraction were negatively correlated with soil CO_2 flux rate, but only when the soil was moist. Long-term conservation tillage management resulted in more uniform within and across-season soil CO_2 flux rates that were less affected by precipitation events (Bauer et al., 2006).

Soil moisture is another important factor influencing soil respiration. In dry conditions, root and micro-organism activity is typically low, resulting in low soil CO_2 efflux. Increasing the soil moisture normally increases the bio-activity in the soil. 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 emissions. Furthermore, it was evidenced that the effect of precipitation on soil respiration stretched beyond its direct effect via soil moisture (Raich et al., 2002). Thus, it is important to understand which climatic factors control soil respiration and, moreover, how these factors affect CO_2 emissions from soils (Reichstein, Beer, 2008).

The temperature is the best predictor of the annual and seasonal dynamics of the soil respiration 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). Chamber measurements of total ecosystem respiration (TER) in a native Canadian grassland ecosystem were made during two study years with different precipitation. The temperature sensitivity coefficient for ecosystem respiration declined in association with reductions in soil moisture. Soil moisture was the dominant environmental factor that controlled seasonal and interannual variation in TER (Flanagan, Johnson, 2005).

The amount and distribution of precipitation has also been shown to be an important controlling factor of soil respiration (Lee et al., 2002). Rain exerts control during dry periods either by controlling soil water fluctuations in surface layers where most of the biological activity occurs (Lee et al., 2002) or by strongly stimulating soil CO_2 emissions in what is called the 'Birch effect' or 'drying and rewetting effect' (Birch, 1958; Lee et al., 2002). Some results revealed that, in addition to temperature and soil water content, rain plays a role in determining the total amount of carbon released from soils (Yuste et al., 2003), while other results state that water content of the surface soil layer (6.5 cm) was almost always higher with conservation tillage, but soil CO_2 flux was highly correlated with soil water content only in conventional tillage (Bauer et al., 2006). Furthermore, in temperate ecosystems, where precipitation is evenly distributed over the year, may be sensitive reaction to the amount and distribution of rainfall during drought (Lee et al., 2002).

Depending on the management practices being used, agricultural soils can be either a net source or a net sink for C (Paustian et al., 2000; La Scala et al., 2008). Tillage practice can influence the exchange of CO_2 between soil and the atmosphere. Much of the blame for loss of C has been assigned to the practice of ploughing the soil (Reicosky, Archer, 2007), and tilled soils are viewed by many as a depleted C reservoir that can be refilled.

The magnitude of CO_2 loss from the soil due to tillage practices is highly related to frequency and intensity of soil disturbance caused by tillage (Prior et al., 2004). Reicosky et al. (2005) and Al-Kaisi and Yin (2005) found a relatively higher CO_2 emission for soils under mouldboard ploughing than NT in corn and corn-soybean rotation systems. In contrast, La Scala et al. (2006) found that CO_2 emission was highest under chisel relative to mouldboard ploughing and NT shortly after tillage. Relatively fewer studies have been conducted to evaluate long-term effects of tillage on GHGs emissions. Some research data revealed that CO_2 emission with NT was significantly less than for CT (Curtin et al., 2000). However, while some information is available for short-term CO_2 emission, there is a complete lack of data to assess effects of long-term tillage on long-term CO_2 emission (Al-Kaisi, Yin, 2005). Others observed that growing season CO_2 emissions were significantly affected by rotation but not by tillage treatments (Omonode et al., 2007) or stated that CO_2 emissions were not significantly different among mouldboard ploughing, no-tillage and bare fallow (Elder, Lal, 2008).

Hendrix et al. (1998) measured higher CO_2 emissions from 5- and 6-yr-old no-till soils than from conventionally tilled soils. They found a strong relationship between CO_2 emissions and soil temperature in both treatments but no relationship could be found with soil water. Within a crop growing season, CO_2 fluxes from croplands can be minimized by adopting no-tilled compared with other tillage practices (Sainju et al., 2008). Fortin et al. (1996) indicated that CT and NT produced similar CO_2 emissions in a wet year. However, in a dry year, CT produced lower CO_2 emissions than NT. Within a crop growing season, CO_2 fluxes from croplands can be minimized by adopting no-tilled continuous crops with reduced N fertilization rate compared with other management practices.

To better understand this critical issue, we continuously observed CO_2 exchange rate in a controlled experiment in agricultural cultivated soil. We specifically addressed the following questions concerning the soil texture, air and soil temperature, air humidity and gravimetric water content sensitivity of soil respiration. (1) Is the CO_2 exchange rate dependent on soil (temperature, water content) and weather conditions (air temperature, humidity, precipitation) directly or indirectly? (2) How much do meteorological conditions contribute to CO_2 exchange rate on soils with different texture? (3) How much does tillage practice influence CO_2 exchange rate on soils with different texture under different weather and soil conditions?

Materials and methods

Site and soil description and experimental design. The present study was conducted on an *Endocalcari-Epihypogleyic Cambisol* (*CMg-p-w-can*) in two long-term tillage experiments situated in cultivated fields of the Lithuanian Institute of Agriculture in Dotnuva, Central Lithuania (55º23′50″ N and 23º51′40″ E). Since the time of establishment in 1999, conventional tillage (CT), reduced tillage (RT), and no-tillage (NT) systems have been compared in plots with different soil properties under continuous 5-course crop rotation (winter wheat → oil-seed rape → spring wheat → spring barley → pea) application (Table 1). Tillage system depths and fertilisation practices have been consistent since the trial establishment. NPK fertiliser rates were calculated and broadcast before presowing tillage according to soil properties and expected crop yield. This study included CT, RT and NT comparison and their influence on soil surface carbon dioxide exchange rate (NCER) under different weather and soil conditions in the 10th and 11th successive years of the experiment.

Table 1. Field trial design

Abbreviation	Primary tillage	Presowing tillage
CT – conventional tillage	Deep ploughing (22–25 cm)	Spring tine cultivation (4–5 cm)
RT – reduced tillage	Stubble cultivation (12–15 cm)	Spring tine cultivation (4–5 cm)
NT – direct drilling	No-tillage	Direct drilling

The experimental layout had randomized treatments with four replications. Each replicate consisted of plots 9 m wide, 20 m long (180 m^2). Primary tillage treatments involving mouldboard ploughing and shallow stubble cultivation were applied after harvesting in each autumn and presowing tillage operations were carried out each spring just before sowing. The mouldboard ploughing treatment was applied using a reversible 4-body plough. Mouldboard ploughing inverted the soil to a 22–25 cm depth without extensive breaking of soil aggregates. The stubble cultivation (12–15 cm depth) was done with a cultivator consisting of disc coulters in combination with a heavy spiked roller, and with intensive breaking action on soil aggregates. Presowing soil loosening (4–5 cm) was applied with a combined spring tine cultivator, and cereals were sown by a universal seed drill. In direct drilling treatment the soil was rototilled at the 4–5 cm depth by a combined soil tillage-sowing unit with a vertical rototiller and sown at the same time.

Long-term application of NT resulted in obvious differences in soil chemical properties in 0–10 cm soil surface layer in the 10th–11th year of the experiment (Table 2). NT system conditioned obvious stratification of N, P, K and organic carbon. Higher content of these elements was accumulated on soil surface. In loamy soil, pH also became higher under NT than under RT and CT. However, on sandy loam this index in NT treatment was lesser by 14–21% compared to RT and CT treatments. Soil bulk density during overall crop growing season was higher in NT than in RT and CT.

Description of weather conditions. Daily air temperature and precipitation conditions for the study periods (May 8–July 9) are shown in Fig. 1.

Table 2. Soil properties and texture in the 10th year (2008) of tillage experiments

Tillage	Soil indicators								
	Texture composition (soil particles %)			Organic C %	Total N %	Available P (A-L) mg kg^{-1}	Available K (A-L) mg kg^{-1}	pH_{KCl}	Bulk density Mg m^{-3}
	sand (2.0–0.05 mm)	silt (0.05–0.002 mm)	clay (<0.002 mm)						
Loam									
CT	51.76* / 47.53**	28.96* / 40.87**	19.28* / 11.60**	1.17	0.140	135	187	6.77	1.26
RT				1.34	0.156	147	198	6.73	1.29
NT				1.38	0.162	165	245	6.88	1.35
Sandy loam									
CT	53.71* / 53.66**	32.58* / 33.91**	13.71* / 12.43**	1.01	0.108	80	132	6.38	1.24
RT				0.97	0.109	80	142	5.87	1.27
NT				1.15	0.123	85	182	5.04	1.39

Note. * – 0–20 cm, ** – 20–40 cm.

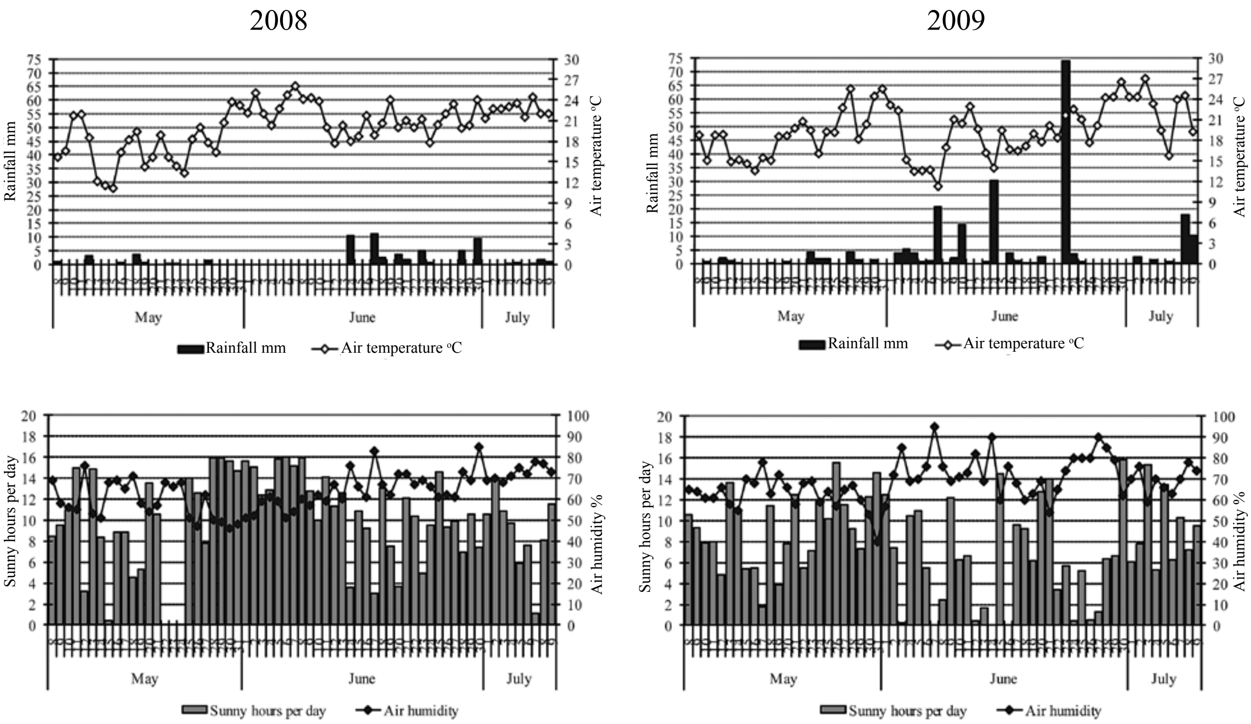


Figure 1. Daily rainfall, air humidity, sunny hours and actual air temperature at the time of CO_2 measurement in 2008 and 2009

In 2008, more rainfall was recorded during the 14th–30th of June, however without extreme events. Mean air temperature was 20.1ºC, total precipitation was 64.4 mm, mean air humidity 63.4%, and sum of sunny hours amounted to 624.6. In contrast, in 2009, mean air temperature of the measurements period was 19.3ºC, total annual precipitation 220.7 mm, mean air humidity 68.8%, and sum of sunny hours did not exceed 488.0. Much more than normal precipitation occurred on the 7th, 14th and 23rd of June in 2009. Extreme phenomenon was observed when rainfall on the 23rd of July exceeded monthly average by 19%, and the total precipitation of June was 3.56 fold higher than normal.

Carbon dioxide flux and soil gravimetric water content and temperature measurements. Classical chamber methods with measurement of CO_2 either by, infrared gas analyzer or trapping in alkali, remain useful tools, because chamber methods allow CO_2 fluxes to be measured directly from the soil. Micrometeorological techniques are only able to obtain the total CO_2 efflux and cannot partition total efflux into its individual sources (Kuzyakov, 2006).

We used a dynamic closed chamber to measure in situ CO_2 fluxes with a portable CO_2 analyser. Its purpose is to measure the gas exchange associated with soil biomass respiration. The highly accurate miniaturised CO_2 infrared gas analyser is placed directly adjacent to the soil chamber, ensuring the fastest possible response to gas exchanges in the soil. The closed chamber method is often applied to quantify the net CO_2 exchange between the atmosphere and low-stature canopies typical for agricultural crop stands (Steduto et al., 2002). CO_2 fluxes from the soil surface were measured at weekly intervals for up to 10 weeks in the barley growing season of 2008 and in the peas growing season of 2009.

Soil net CO_2 exchange rate (soil respiration per unit area, μmol m^{-2} s^{-1}):

$N_{CER} = u_s \times (-\Delta c)$, (1),

here: u_s – molar flow of air per square meter of soil, mol m^{-2} s^{-1}, Δc – difference in CO_2 concentration through soil hood, dilution corrected, μmol mol^{-1}:

$\Delta c = C_{ref} - C_{an}$, (2),

here: $C_{ref.}$ – CO_2 flowing into soil chamber, μmol mol^{-1}; C_{an} – CO_2 flowing out from soil chamber, μmol mol^{-1}.

The data of CO_2 exchange rate presented in this paper were converted from μmol s^{-1} m^{-2} to C g m^{-2} h^{-1} as it is more common for data presentation.

Each CO_2 flux measurement was done in 4 replications in each trial treatment. The chamber was placed on the soil surface and slightly pressed down by hand. CO_2 flux was recorded in data logger in about 2 min when no noticeable changes in CO_2 respiration were registered. To avoid the effects of the time of the respiration measurement on soil temperature, it is recommended to analyse the whole time series in order to infer the temperature dependence of respiration, or at least to standardise the time at which soil respiration is measured (Steduto et al., 2002). Our measurements were carried out weekly starting from May 8 between 12.00 and 16.00 pm.

Soil temperature was determined by a portable soil WET-sensor at the same time of CO_2 measurement near the chamber at the 10 cm depth. Similarly, gravimetric soil water content was measured near the chamber by collecting soil samples from the 0–10 cm depth with a probe (1.5 cm diameter) every time CO_2 flux was measured. The moist soil was oven-dried at 105ºC for 48 h and water content was determined. Soil texture was identified according to pipette method (Gee, Bauder, 1986).

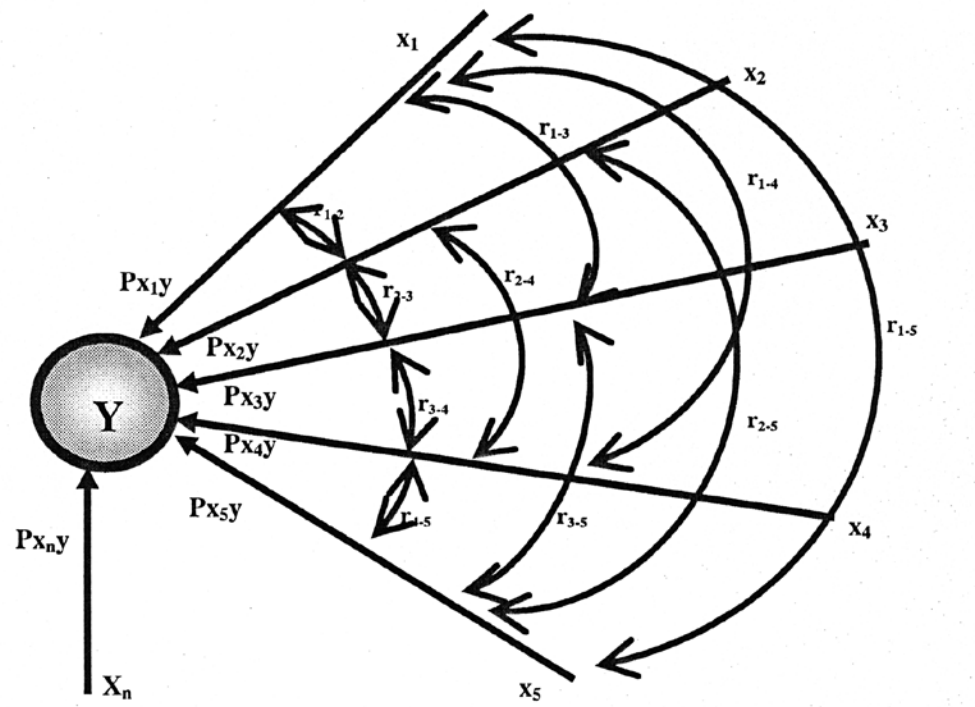
Statistical analysis. Data analysis was performed using the software *Statistica*. Since the underlying objective of the study was to assess the possibly interacting effects of tillage and soil conditions on greenhouse gas emissions, statistical analyses were done in stages for the gas emission data. First the data were verified to substantiate differences between years. With that data analyzed to determine CO_2 exchange rate, we also calculated responses of soil temperature and soil gravimetric water content to variation of weather conditions during crop growing season. Further, the data were separated and analyzed separately for tillage and soil texture effects by date of individual year's growing season. Treatment means were separated using least significant difference (LSD) and the effects of tillage on gas fluxes, soil water content and soil temperature were evaluated at the 5% level of probability (P = 0.05). Furthermore, Path analysis was used for deeper evaluation of relationships between CO_2 exchange rate and individual environmental (soil and weather) factors and among all other indices investigated (Fig. 2).

This method showed after-effect of individual factors on soil NCER, made clearer causality of these after-effects and also revealed the degree of influence of all factors investigated on NCER. Reciprocity of different factors and after-effect of one factor to other gave final result, i.e. view of substantial influence of weather and soil conditions on NCER. Correlation coefficient (total sum of effects) showed the strength of this influence.

Results and discussion

Soil features response to weather conditions and soil texture interaction. Because of contrasting meteorological conditions, the experimental data significantly differed between the years 2008 and 2009 (Fig. 3, Table 3).

Our statistical analysis revealed that daily rainfall data was not significant for the parameters investigated. The best relationship was revealed when total rainfall amount of 3 last days was used. Mean soil CO_2 exchange rate (NCER) on both soils with different texture in wet year 2009 was

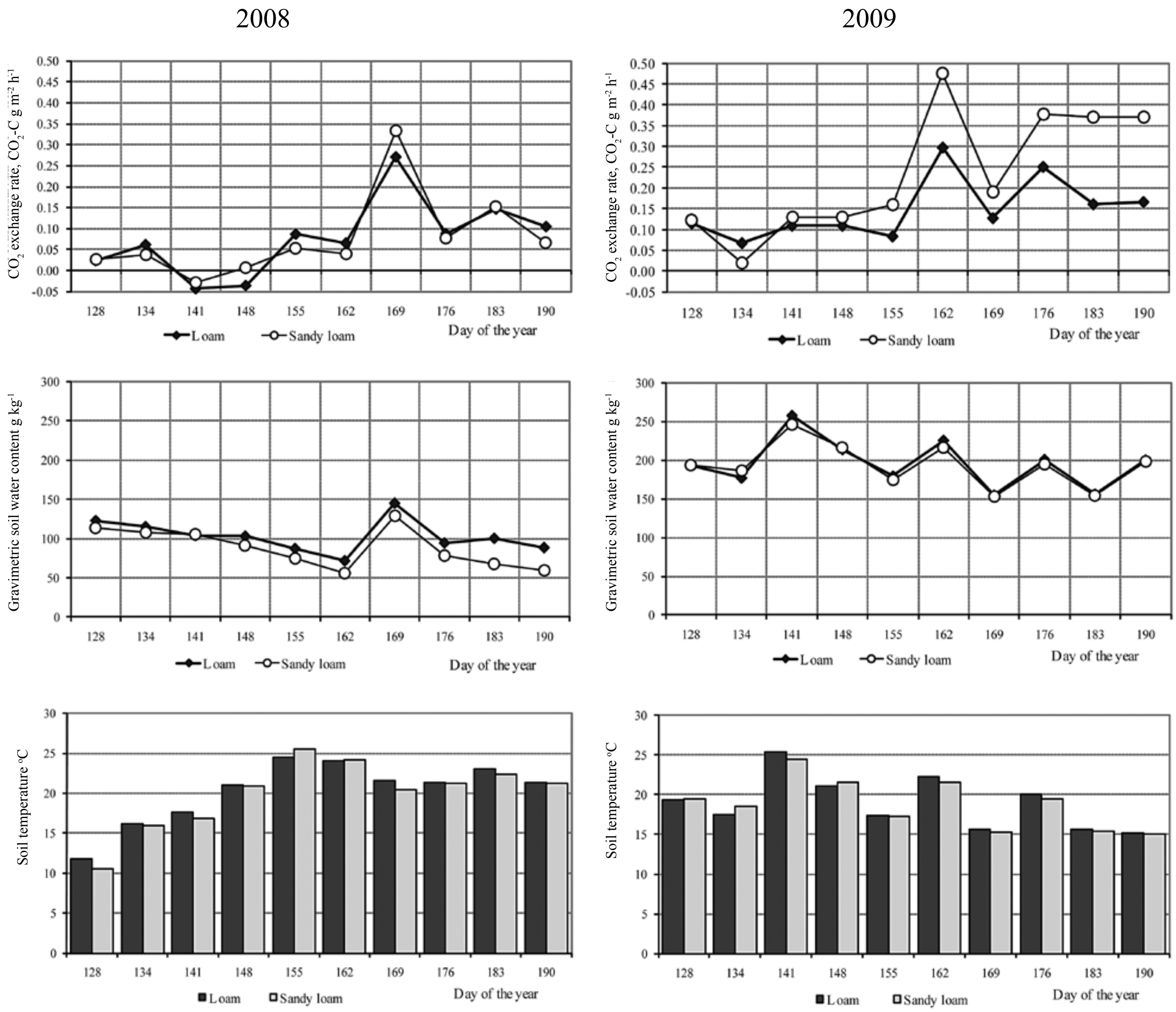


Note. x_1, x_2, x_3, x_4, x_5 – indices, which influenced main index y; $r_{1\text{-}2}$, $r_{2\text{-}3}$ etc. – correlation between indices.

Figure 2. Scheme of Path relationships (P) and paired (r) correlations

by 0.115 g CO_2-C m^{-2} h^{-1} higher than that in dry year 2008. Gravimetric water content (GWC) under rainy 2009 conditions was higher by 98.85 g kg^{-1} than in dry 2008. Cloudy, cool and humid conditions in 2009 resulted in 1.08ºC lesser soil surface temperature compared to 2008. Some researchers observed that CO_2 evolution from fine-textured soil could be approximately twice as high as that from course-textured soil (Rastogi et al., 2002). Our investigated soils are referred to as medium-textured soils, consequently great differences in CO_2 fluxes were not established. Mean NCER during the two-year experimental period on loamy soil was lesser by 0.043 g CO_2-C m^{-2} h^{-1} compared to that on sandy loam. Meanwhile soil temperature and GWC on the loam was higher by 0.18ºC and 8.62 g kg^{-1}, respectively, than on sandy loam. Many early trials were sufficiently successful with limited data sets to suggest that there were significant underlying relationships between soil water characteristics and soil texture (Gijsman et al., 2002). More recent studies have evaluated additional variables and relationships (De Gryze et al., 2006; Saxton, Rawls, 2006).

Interactions of the year with soil texture were significant for NCER ($P \leq 0.001$), GWC ($P \leq 0.01$) and soil temperature ($P \leq 0.05$). Soils with different textures had diverse soil moisture behaviours. Lighter textured soil responded more sensitively to changes of meteorological conditions. On the loam difference of mean NCER between 2008 and 2009 amounted to 0.072 g CO_2-C m^{-2} h^{-1}, certainly this index was higher under humid conditions in 2009. However, on the sandy loam the difference in NCER was greater than on the loam and amounted to 0.158 g CO_2-C m^{-2} h^{-1}. It is obvious that soil GWC influenced CO_2 flux intensity. GWC on the loam in 2008 was lesser by 98.85 g kg^{-1} and on the sandy loam by 105.28 g kg^{-1}, compared to GWC in 2009. Sullivan (2002) noted that moisture holding capacity on loam textured soils can be greater by 1.7 fold compared to that on sandy loam. However, during our two-year experimental period soil GWC on the loam was greater only on average by 6%, compared to GWC on the sandy loam. Borken et al. (1999) observed that drought reduced soil respiration, while rewetting increased it by 48–144%. We found much greater differences. Our data suggest that rewetting of dry soil resulted in a large increase in CO_2 efflux only at high temperatures. A heavy rain on day 169 of the year 2008 and on day 162 of the year 2009 increased CO_2 flux by 5.3 and 3.8 fold, respectively.



Analysis of factors variance:

	Soil surface net CO_2 exchange rate (NCER) g CO_2-C m^{-2} h^{-1}		Soil temperature ºC		Gravimetric soil water content g kg^{-1}	
	F-act.	LSD_{05}	F-act.	LSD_{05}	F-act.	LSD_{05}
Year (factor A)	259.71**	0.007	248.44**	0.07	7246.6**	0.76
Soil texture (factor B)	36.43**	0.007	6.60*	0.07	131.04**	0.76
Tillage (factor C)	4.11*	0.010	13.00**	0.10	41.97**	1.07
A x B	36.41**	0.012	0	0.11	72.86**	1.24
A x C	9.18**	0.013	2.35	0.12	19.12**	0.31
B x C	4.01*	0.013	1.01	0.12	4.82*	1.31
A x B x C	1.64	0.022	1.16	0.21	5.56**	2.28

Notes. F-act. – actual variance ratio (F-test), LSD_{05} (least significant difference), * $P \leq 0.05$ and ** $P \leq 0.01$.

Figure 3. Effect of soil texture on soil surface CO_2 exchange rate and soil gravimetric water content and temperature under different meteorological conditions averaged across tillage practices

Table 3. Effect of soil texture and meteorological conditions on CO_2 exchange rate, soil temperature and water content averaged across tillage practices

Year	Soil texture	Soil surface net CO_2 exchange rate (NCER) g CO_2-C m^{-2} h^{-1}	Soil temperature ºC	Gravimetric soil water content g kg^{-1}
Dry 2008		0.077[c]	20.0[a]	95.9[c]
Wet 2009		0.192[a]	18.9[c]	194.8[a]
	Loam	0.113[c]	19.5[a]	149.7[a]
	Sandy loam	0.156[a]	19.3[c]	141.1[c]
Contrasts:				
Loam (2008 + 2009) *vs*. sandy loam (2008 + 2009)		−0.043***	0.18*	8.62**
2008 (loam + sandy loam) *vs*. 2009 (loam + sandy loam)		−0.115***	1.08**	−98.85***
Loam (2008) *vs*. loam (2009)		−0.072**	1.08**	−92.43**
Sandy loam (2008) *vs*. sandy loam (2009)		−0.158**	1.08**	−105.28**
Loam (2008) *vs*. sandy loam (2008)		0.000[ns]	0.18[ns]	15.04**
Loam (2009) *vs*. sandy loam (2009)		−0.086**	0.17[ns]	2.19*

Notes. NCER, soil temperature and GWC data followed by the same letters are not significantly different at $P < 0.05$. *, ** and *** – least significant difference at $P < 0.05$, $P < 0.01$ and $P < 0.001$ respectively, ns – not significant.

Soil features response to texture and tillage interaction. Soil texture and its interaction with tillage, texture x date of measurement interaction and tillage x date of measurement interaction was significant ($P \leq 0.001$) for soil CO_2 flux in both 2008 and 2009. Meteorological conditions of the year corrected interactions for soil GWC and temperature. In 2008, significant interactions were designated between texture and tillage, and between texture and date of measurement for soil GWC and temperature indications, but tillage x date of measurement interaction was not significant for soil temperature. In 2009, significant interactions were identified between texture and date of measurement for soil GWC and temperature, but interaction tillage x date of measurement was significant only for GWC. Soil GWC averaged between soil textures. GWC at 0–10 cm depth, on the loam was higher on average by 1.9 fold and on the sandy loam by 2.2 fold in 2009 than in 2008 (Fig. 4, Table 4). It was higher in NT than in RT and CT on a day of the dry 2008 year (DOY) 134, 141, 148, 155, 162, 169, 176, 183 and 190. Soil water storage on the loam was greater on average by 15.04 g kg^{-1} than on the sandy loam.

Application of NT on both loam and sandy loam increased soil GWC on average by 13.50 g kg^{-1} and 10.38 g kg^{-1} compared to RT and CT respectively, however it was also observed that GWC on the loam in NT treatment was higher by 14.60–15.92 g kg^{-1} than in RT and CT, while, in comparison GWC on the sandy loam this distinction amounted only to 4.83–12.40 g kg^{-1}. In rainy 2009, soil GWC averaged between soil textures and was higher in NT than in RT and CT on DOY 134, 141, 148, 155, 162, 169, 183 and 190, while GWC differences were marginal. Water storage on the loam was greater on average by 2.19 g kg^{-1} than on the sandy loam. Application of NT on both loamy soil and sandy loam increased GWC on average by 2.43 g kg^{-1} and 2.46 g kg^{-1} compared to RT and CT respectively, meanwhile GWC on the loam in NT treatment was higher by 1.54–1.97 g kg^{-1} than in RT and CT (the difference was not significant), while on the sandy loam this distinction amounted only to 2.95–3.32 g kg^{-1}.

In contrast to distribution of GWC in soil across measurement date, soil surface temperature on the loam was lower than on the sandy loam in 2008 on DOY 148, 155, 162, 169 and 176 and in 2009 on DOY 128, 134 and 148. It was not surprising to observe a lower soil temperature and a higher GWC on soils with different texture and at different meteorological conditions.

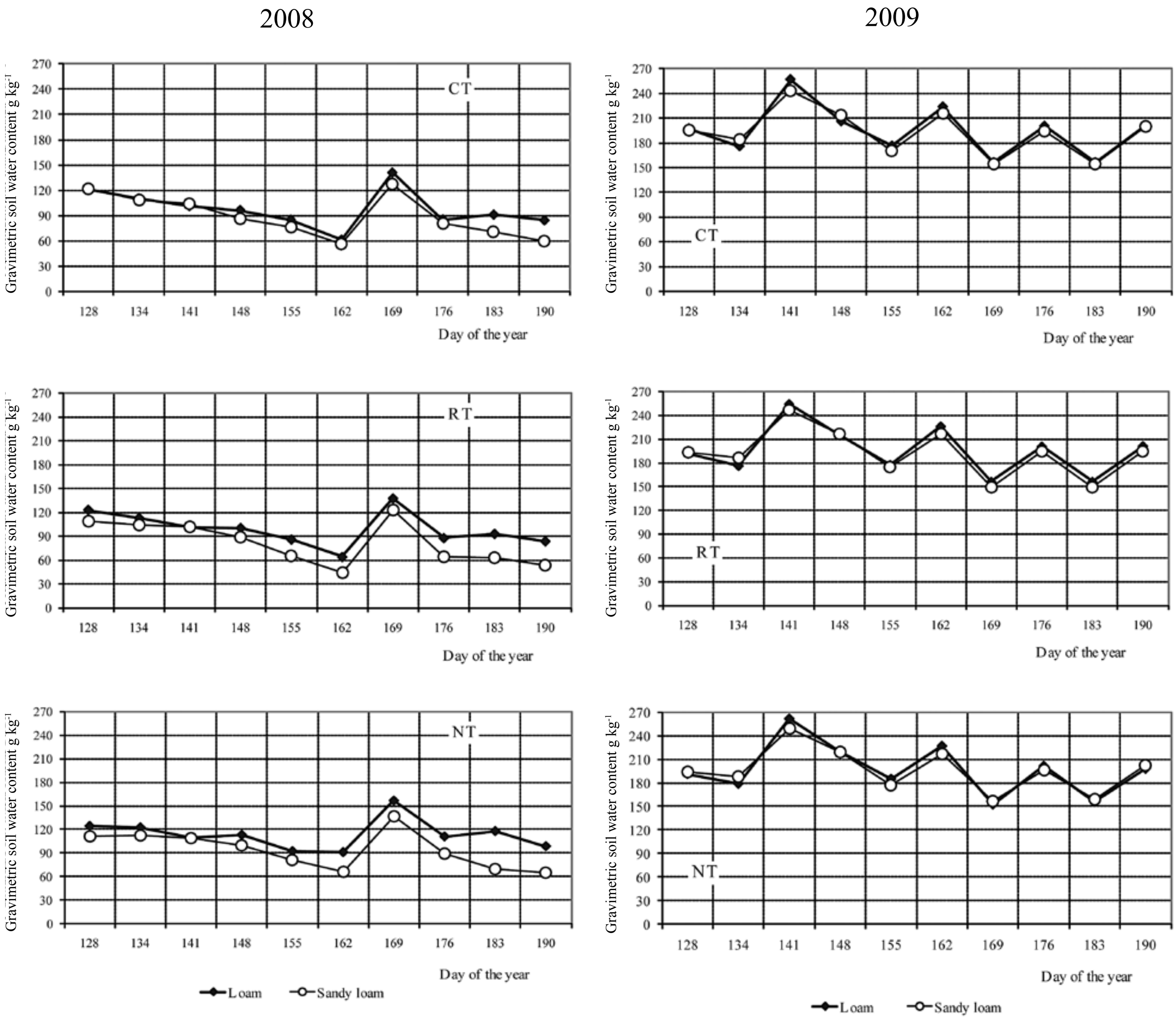


Figure 4. Effect of soil texture and tillage practices (CT – conventional, RT – reduced, NT – no-tillage) on soil surface gravimetric water content under different meteorological conditions

Table 4. Effect of soil texture and tillage on CO_2 exchange rate and soil temperature and water content averaged across dates of measurement

Soil texture	Tillage	Soil surface net CO_2 exchange rate g CO_2-C m^{-2} h^{-1}		Soil temperature °C		Gravimetric soil water content g kg^{-1}	
		2008	2009	2008	2009	2008	2009
1	2	3	4	5	6	7	8
Loam		0.077^{b}	0.149^{c}	20.0^{a}	19.0^{a}	103.45^{a}	195.88^{a}
Sandy loam		0.077^{b}	0.235^{a}	20.0^{c}	18.8^{c}	88.41^{c}	193.69^{c}
	CT	0.073^{b}	0.212^{a}	20.1^{a}	18.9^{b}	93.51^{c}	193.95^{b}
	RT	0.073^{b}	0.208^{a}	20.1^{a}	19.0^{a}	90.39^{c}	193.98^{b}
	NT	0.084^{a}	0.156^{c}	19.6^{c}	18.7^{c}	103.89^{a}	196.41^{a}
Contrasts:							
CT *vs.* RT		0.000 ^{ns}	0.052***	0.04 ^{ns}	−0.04^{ns}	3.12***	−0.03^{ns}
CT *vs.* NT		−0.011**	0.056***	0.54**	0.20**	−10.38***	−2.46***

Table 4 continued

1	2	3	4	5	6	7	8
RT *vs.* NT		-0.011^{**}	0.004^{ns}	-0.50^{**}	0.24^{**}	-13.50^{***}	-2.43^{***}
$\text{Loam}_{(CT + RT + NT)}$ *vs.* $\text{sandy loam}_{(CT + RT + NT)}$		0.000^{ns}	-0.086^{***}	0.18^{*}	0.17^{**}	15.04^{***}	2.19^{***}
Loam (CT) *vs.* sandy loam (CT)		-0.021^{**}	-0.080^{**}	0.40^{**}	0.20^{ns}	8.38^{***}	2.25^{*}
Loam (RT) *vs.* sandy loam (RT)		-0.003^{ns}	-0.124^{**}	-0.08^{ns}	0.20^{ns}	17.27^{***}	3.05^{**}
Loam (NT) *vs.* sandy loam (NT)		0.024^{**}	-0.055^{**}	0.22^{ns}	0.12^{ns}	19.47^{***}	1.27^{ns}
Loam (CT) *vs.* loam (RT)		-0.009^{ns}	0.026^{ns}	0.28^{*}	-0.04^{ns}	-1.33^{ns}	-0.43^{ns}
Loam (CT) *vs.* loam (NT)		-0.033^{**}	0.043^{*}	0.63^{**}	0.24^{*}	-15.92^{***}	-1.97^{ns}
Loam (RT) *vs.* loam (NT)		-0.024^{**}	0.017^{ns}	0.35^{**}	0.28^{*}	-14.60^{***}	-1.54^{ns}
Sandy loam (CT) *vs.* sandy loam (RT)		0.009^{ns}	-0.018^{ns}	0.20^{ns}	-0.04^{ns}	7.56^{***}	0.38^{ns}
Sandy loam (CT) *vs.* sandy loam (NT)		0.011^{*}	0.069^{**}	0.45^{**}	0.16^{ns}	-4.83^{***}	-2.95^{**}
Sandy loam (RT) *vs.* sandy loam (NT)		0.002^{ns}	0.087^{**}	0.65^{**}	0.20^{ns}	-12.40^{***}	-3.32^{**}

Notes. NCER, soil temperature and GWC data followed by the same letters are not significantly different at $P < 0.05$. *, ** and *** – least significant difference at $P < 0.05$, $P < 0.01$ and $P < 0.001$ respectively, ns – not significant.

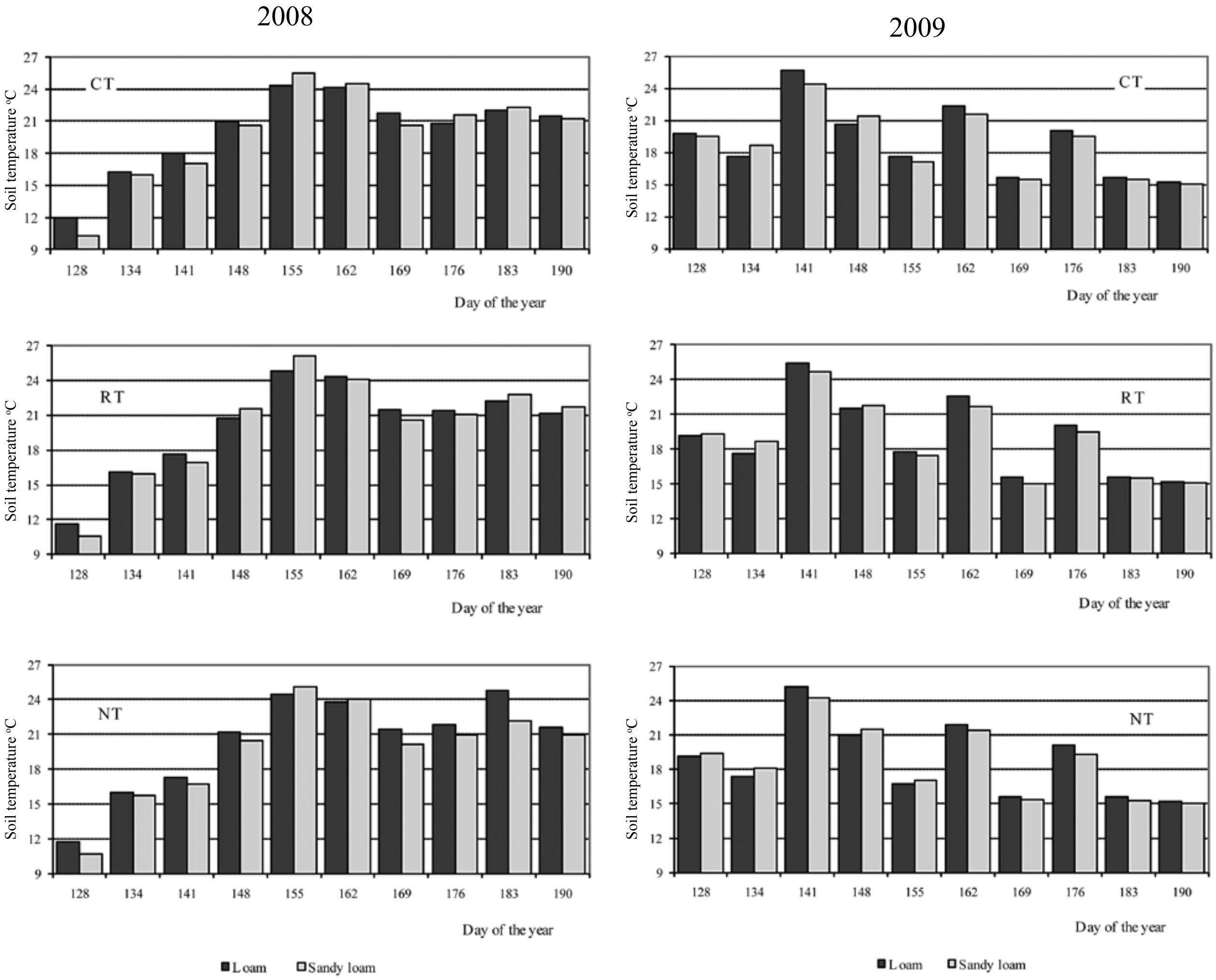


Figure 5. Effect of soil texture and tillage practices (CT – conventional, RT – reduced, NT – no-tillage) on soil surface temperature under different meteorological conditions

Increased GWC and evaporation from the soil surface reduces soil temperature, as wet soil is slower to change in temperature than dry soil (Parkin, Kaspar, 2003; Feizienė et al., 2009). In 2008, soil temperature averaged across tillage systems and was higher on the loam on average by 0.18ºC than on the sandy loam (Table 4, Fig. 5).

Admittedly the soil temperature on the loam in NT treatment was lower by 0.35–0.63ºC than in RT and CT, while on the sandy loam this distinction ranged from 0.45 to 0.65ºC. In humid and cloudy 2009, the soil temperature averaged across tillage systems and was higher on the loam on average by 0.17ºC than on the sandy loam. Significant influence of tillage on soil temperature was registered solely on the loam. Soil temperature under NT impact was 0.24 and 0.28ºC lesser compared to RT and CT, respectively.

Soil NCER varied between different meteorological conditions of the year, soil texture classes and among tillage practices (Table 4, Fig. 6). It was observed that average soil CO_2 flux, on the loam was higher on average by 1.9 fold and on the sandy loam by 3.1 fold in 2009 than in 2008. In dry 2008, the NCER, averaged across soil texture and tillage practices, increased from 0.025 g CO_2-C m^{-2} h^{-1} (on DOY 128) to 0.303 g CO_2-C m^{-2} h^{-1} (on DOY 169), after which it declined. In humid and cloudy 2009, it ranged from 0.118 g CO_2-C m^{-2} h^{-1} (on DOY 128) to 0.387 g CO_2-C m^{-2} h^{-1} (on DOY 162), after which it also decreased.

In 2008 the NCER was higher on the loam than on the sandy loam on DOY 128, 134, 155, 162, 176 and 190, while average values of the measurements per year on loam and on sandy loam did not differ statistically. Soil NCER averaged between soil textures and was highest in NT treatment (0.084 g CO_2-C m^{-2} h^{-1}). However, CO_2 flux on the loam in NT treatment was higher by 0.024–0.033 g CO_2-C m^{-2} h^{-1} than in RT and CT, while on the sandy loam this distinction was reverse, i.e. CO_2 flux in NT treatment was lesser by 0.011 g CO_2-C m^{-2} h^{-1} than in CT, but did not differ significantly from RT. In 2009, NCER was higher on the loam than on the sandy loam only on DOY 134. Soil NCER averaged between soil textures and contrary to our expectations was the highest in CT treatment (0.212 g CO_2-C m^{-2} h^{-1}). CO_2 flux on the loam in NT treatment was lesser by 0.043 g CO_2-C m^{-2} h^{-1} than in CT, but did not differ significantly from RT. On the sandy loam, CO_2 flux in NT treatment was lesser by 0.069–0.087 g CO_2-C m^{-2} h^{-1} than in RT and CT.

Soil CO_2 exchange rate in relation to selected conditions. Path analysis of relationships among basic environmental features revealed that soil NCER directly and indirectly (through interaction of other environmental factors) responded to weather conditions, soil GWC and temperature (Tables 5 and 6).

Summarised evaluation of integrated research data (2008 + 2009) did not show any pronounced differences between the influence of tillage and soil texture on soil CO_2 exchange rate. Examination of individual year data and different soil texture disclosed more correct and accurate outcomes.

It is clear that atmospheric circumstances significantly influenced soil NCER. Notwithstanding, soils with different texture responded inconsistently to the same conditions. Direct influence of **relative air humidity** on soil NCER was identified as a common trait in 2008 and 2009, i.e. increment of air humidity apparently increased CO_2 flux (Path coefficient ranged from 0.382 to 1.119 in 2008 and from 0.382 to 0.663 in 2009). However, it was observed, that in 2008 the increase of air temperature indirectly mitigated (Path coefficient ranged from −0.091 to −0.733; correlation coefficient between air temperature and humidity $r = 0.65^*$) and higher rainfall content enhanced (Path coefficient ranged from 0.054 to 0.377; correlation coefficient between rainfall and humidity $r = 0.44^*$) the influence of air humidity on CO_2 flux. Total effect (that represents $r(Y)$ in Tables 5 and 6) of air humidity and its interactions with other environmental factors on NCER in 2008 averaged among tillage systems and was more substantial on the loamy soil ($r(Y)$ varied from 0.49* to 0.59*) than on the sandy loam ($r(Y)$ varied from 0.43* to 0.49*). Meanwhile, in 2009 both air temperature (Path coefficient ranged from −0.008 to +0.516; correlation coefficient between air temperature and humidity $r = 0.55^*$) and rainfall content (Path coefficient ranged from 0.082 to 0.243; correlation coefficient between rainfall and humidity was $r = 0.33$) indirectly enhanced the influence of air humidity on CO_2 flux. Total effect of air humidity and its interactions with other environmental factors on NCER in 2009 was more substantial on the sandy loam ($r(Y)$ varied from 0.66* to 0.84**) than on the loam ($r(Y)$ varied from 0.58* to 0.78**). Admittedly, total effect of air humidity on NCER in 2008 on the loam was more definite in NT system ($r(Y) = 0.59^*$) than in CT and RT, but on the sandy loam there were no differences. In 2009, this relationship on the loam was stronger in NT system ($r(Y) = 0.78^*$) than in CT and RT, but on the sandy loam it was more clearly expressed in CT and RT than in NT.

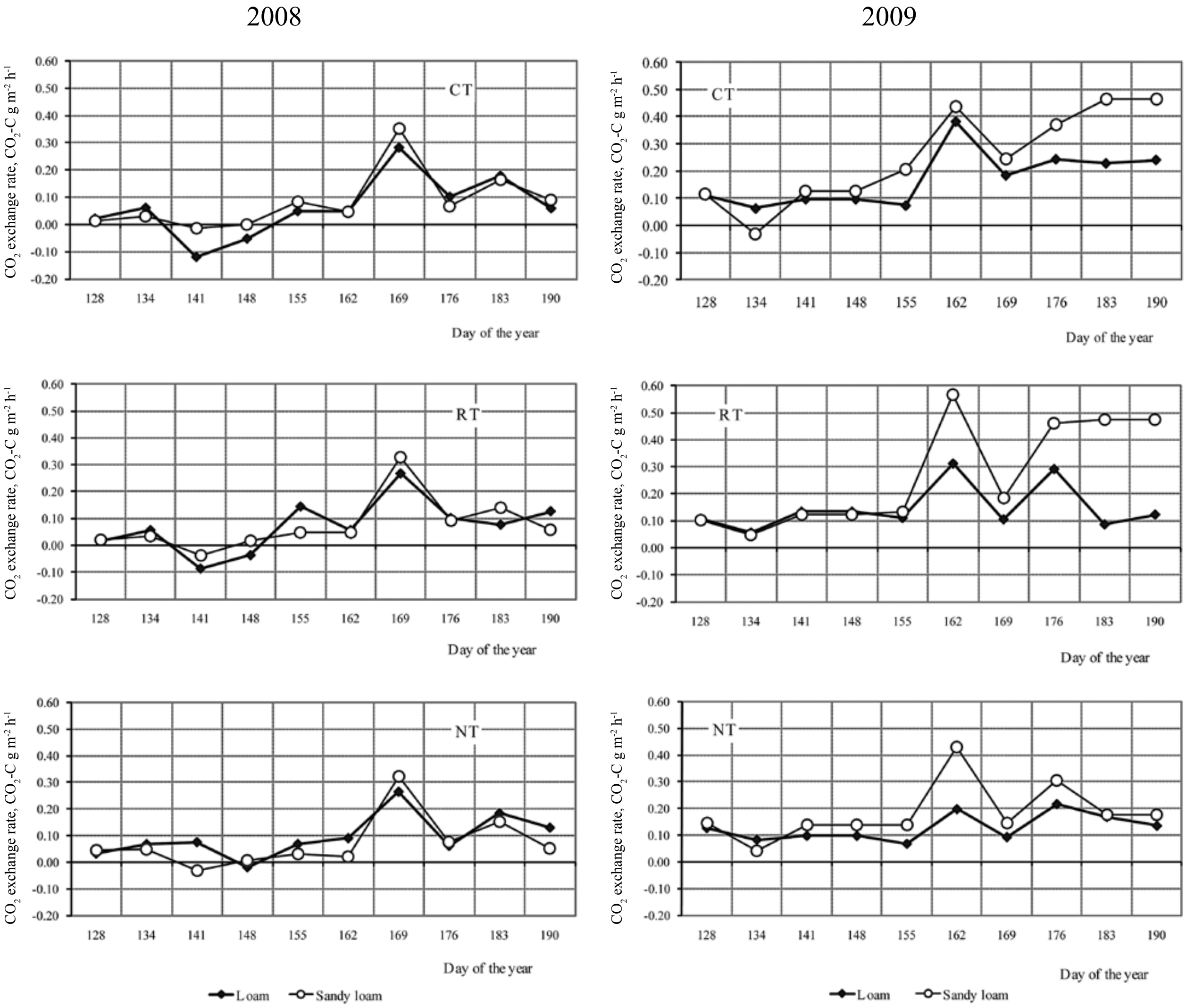


Figure 6. Effect of soil texture and tillage practices (CT – conventional, RT – reduced, NT – no-tillage) on soil surface CO_2 exchange rate under different meteorological conditions

Total effect of ***air temperature*** and its interactions with other environmental factors on soil NCER in dry 2008 on the loam was more definite in NT system ($r(Y)$ = 0.55*) than in CT and RT, but on the sandy loam it was significant only in CT ($r(Y)$ = 0.47*). In wet 2009, the direct influence and total effect of air temperature through its interactions with other environmental factors on soil NCER was significant on both loam and sandy loam and in all tillage systems.

Close interaction of different environmental factors drastically corrected direct impact of soil GWC on soil NCER in both 2008 and 2009. Accordingly, total effect of GWC on CO_2 flux was not substantial ($r(Y)$ in different tillage treatments ranged from −0.09 to 0.52*). Naturally, under dry conditions in 2008 the rise in air temperature clearly increased soil temperature (correlation coefficient in different tillage treatments ranged from 0.64* to 0.68*) and after that this given result caused a significant decrease in soil water content (correlation coefficient in different tillage treatments ranged from −0.35 to 0.72*). GWC ranged from 61.4 to 156.6 on the loam and from 50.0 to 137.2 g kg^{-1} on the sandy loam, but GWC, being higher than 100.0 g kg^{-1}, was registered only in 3/10 of measurements, whereas, soil temperature, being higher than 20.0ºC, was registered in 7/10 of measurements. Changes in air temperature under wet conditions in 2009 did not significantly change soil temperature (correlation coefficient in different tillage treatments ranged from 0.16 to 0.29) on both loamy soil and sandy loam. However, there was registered a significant interaction between GWC and soil temperature (correlation coefficient ranged from −0.86** to −0.90**). Nevertheless, integrated influence of other factors intensively buffered direct influence of GWC on soil NCER. Consequently, total effect of

GWC on the sandy loam was not significant ($r(Y)$ varied from −0.09 to 0.40) in both 2008 and 2009 and in all tillage systems. Soil GWC significantly conditioned CO_2 flux in NT treatment in dry 2008 and in RT treatment in wet 2009.

Table 5. Correlation matrix and Path relationships of soil CO_2 exchange rate and selected indices on soil with different texture and tillage practices (CT – conventional, RT – reduced, NT – no-tillage), under dry environmental conditions (2008)

Tillage	Indi-ces	Index value range		Correlation matrix					Path coefficient					1 r(Y)
		from	to	2	3	4	5	6	2	3	4	5	6	
Loam CT	1(Y)	−28.86	67.77	0.51*	0.37	0.33	0.29	0.87**						
	2	50.00	73.00		0.65*	0.11	0.02	0.44*	**0.787**	−0.660	−0.013	0.017	0.377	**0.51* N**
	3	11.60	22.70			−0.35	0.68*	0.35	0.509	**−1.021**	0.040	0.542	0.303	**0.37ns N**
	4	61.40	140.80				−0.57*	0.54*	0.087	0.355	**−0.115**	−0.457	0.463	**0.33ns N**
	5	12.00	24.99					0.11	0.017	−0.690	0.065	**0.803**	0.098	**0.29ns N**
	6	0.00	13.5						0.347	−0.361	−0.062	0.092	**0.855**	**0.87** L**
Loam RT	1(Y)	−20.88	63.97	0.49*	0.40	0.20	0.41	0.66*						
	2	50.00	73.00		0.65*	0.06	0.02	0.44*	**1.119**	−0.733	0.030	0.023	0.054	**0.49* N**
	3	11.60	22.70			−0.41	0.67*	0.35	0.724	**−1.134**	−0.200	0.971	0.043	**0.40ns N**
	4	64.30	137.30				−0.61	0.51*	0.068	0.460	**0.492**	−0.881	0.062	**0.20ns N**
	5	11.60	24.31					0.13	0.018	−0.763	−0.300	**1.443**	0.016	**0.41ns N**
	6	0.00	13.5						0.494	−0.401	0.252	0.191	**0.121**	**0.66* L**
Loam NT	1(Y)	−4.58	63.81	0.59*	0.55*	0.52*	0.33	0.84**						
	2	50.00	73.00		0.65*	0.13	0.03	0.44*	**0.460**	−0.091	0.040	0.012	0.166	**0.59* N**
	3	11.60	22.70			−0.20	0.67*	0.35	0.297	**−0.141**	−0.060	0.316	0.133	**0.55* N**
	4	90.90	156.60				−0.35	0.78**	0.061	0.028	**0.306**	−0.166	0.291	**0.52* N**
	5	11.39	23.81					0.15	0.012	−0.095	−0.109	**0.469**	0.055	**0.33ns N**
	6	0.00	13.5						0.203	−0.050	0.238	0.069	**0.375**	**0.84** L**
Sandy loam CT	1(Y)	−3.38	84.75	0.49*	0.47*	0.23	0.30	0.89**						
	2	50.00	73.00		0.65*	−0.10	−0.01	0.44*	**0.573**	−0.227	−0.064	−0.008	0.217	**0.49* N**
	3	11.60	22.70			−0.53*	0.64*	0.35	0.371	**−0.351**	−0.324	0.602	0.174	**0.47* N**
	4	56.60	127.80				−0.72*	0.32	−0.060	0.185	**0.616**	−0.671	0.158	**0.23ns N**
	5	10.26	25.48					0.08	−0.005	−0.226	−0.442	**0.936**	0.037	**0.30ns N**
	6	0.00	13.5						0.253	−0.124	0.198	0.070	**0.491**	**0.89** L**
Sandy loam RT	1(Y)	−8.93	78.82	0.43*	0.39	0.24	0.22	0.92**						
	2	50.00	73.00		0.65*	−0.18	0.00	0.44*	**0.382**	−0.212	−0.060	−0.001	0.318	**0.43* N**
	3	11.60	22.70			−0.55*	0.64*	0.35	0.247	**−0.328**	−0.186	0.398	0.255	**0.39ns N**
	4	43.90	123.00				−0.68*	0.30	−0.068	0.179	**0.340**	−0.426	0.220	**0.24ns N**
	5	10.58	26.14					0.06	−0.001	−0.210	−0.233	**0.623**	0.044	**0.22ns N**
	6	0.00	13.5						0.169	−0.116	0.104	0.038	**0.721**	**0.92** L**
Sandy loam NT	1(Y)	−7.52	77.17	0.46*	0.32	0.40	0.11	0.95**						
	2	50.00	73.00		0.65*	−0.24	0.01	0.44*	**0.558**	−0.288	−0.105	0.005	0.293	**0.46* N**
	3	11.60	22.70			−0.50*	0.65*	0.35	0.361	**−0.446**	−0.219	0.393	0.235	**0.32ns N**
	4	65.50	137.20				−0.59*	0.35	−0.135	0.225	**0.434**	−0.356	0.232	**0.40ns N**
	5	10.73	25.08					0.07	0.004	−0.290	−0.255	**0.605**	0.046	**0.11ns N**
	6	0.00	13.5						0.246	−0.158	0.152	0.042	**0.663**	**0.95** L**

Notes. $1(Y)$ – CO_2 flux (g CO_2-C m^{-2} h^{-1}), 2 – air humidity (%), 3 – air temperature (ºC), 4 – soil water content (g kg^{-1}), 5 – soil temperature (ºC), 6 – total rainfall of 3 last days (mm); *, ** and *** – least significant difference at $P < 0.05$, $P < 0.01$ and $P < 0.001$ respectively, ns – not significant. Number in bold – direct effect, underlined number – dominant effect; N – nonlinear correlation, L – linear correlation.

Table 6. Correlation matrix and Path relationships of soil CO_2 exchange rate and selected indices on soil with different texture and tillage practices (CT – conventional, RT – reduced, NT – no-tillage), under wet environmental conditions (2009)

Tillage	Indi-ces	Index value range		Correlation matrix					Path coefficient					*1 r(Y)*
		from	to	2	3	4	5	6	2	3	4	5	6	
Loam CT	*1*(*Y*)	15.11	91.45	0.66*	0.71*	0.09	−0.03	0.42						
	2	55.00	80.00		0.55*	−0.07	−0.19	0.33	**0.154**	0.359	0.071	−0.162	0.237	**0.66* L**
	3	13.40	24.30			0.29	0.26	0.06	0.085	**0.654**	−0.292	0.219	0.045	**0.71* L**
	4	156.30	256.80				−0.89**	0.22	−0.011	0.190	**−1.008**	0.758	0.157	**0.09^{ns} N**
	5	15.23	25.68					−0.18	−0.029	0.168	−0.894	**0.854**	−0.130	**−0.03^{ns} N**
	6	0.70	28.30						0.052	0.041	−0.224	−0.157	**0.709**	**0.42^{ns} N**
Loam RT	*1*(*Y*)	13.59	74.91	0.58*	0.49*	0.47*	0.47*	0.16						
	2	55.00	80.00		0.55*	−0.05	−0.17	0.33	**0.663**	−0.008	0.026	−0.185	0.082	**0.58* N**
	3	13.40	24.30			0.28	0.25	0.06	0.364	**−0.015**	−0.145	0.269	0.016	**0.49* N**
	4	156.30	253.90				−0.89**	0.23	−0.033	−0.004	**−0.519**	0.968	0.057	**0.47* N**
	5	15.23	25.39					−0.18	−0.112	−0.004	−0.461	**1.090**	−0.044	**0.47* N**
	6	0.70	28.30						0.221	−0.001	−0.119	−0.193	**0.247**	**0.16^{ns} N**
Loam NT	*1*(*Y*)	16.16	52.28	0.78**	0.79**	0.09	0.15	0.11						
	2	55.00	80.00		0.55*	−0.08	−0.17	0.33	**0.591**	0.195	0.078	−0.182	0.096	**0.78** L**
	3	13.40	24.30			0.23	0.29	0.06	0.324	**0.356**	−0.225	0.322	0.018	**0.79** L**
	4	152.30	261.60				−0.90**	0.18	−0.047	0.081	**−0.988**	0.989	0.051	**0.09^{ns} N**
	5	15.18	25.17					−0.20	−0.098	0.105	−0.894	**1.093**	−0.058	**0.15^{ns} N**
	6	0.70	28.30						0.197	0.022	−0.176	−0.219	**0.288**	**0.11^{ns} N**
Sandy loam CT	*1*(*Y*)	−7.60	111.22	0.84**	0.67*	−0.18	−0.39	0.49*						
	2	55.00	80.00		0.55*	−0.13	−0.26	0.33	**0.382**	0.281	0.033	0.019	0.124	**0.84** L**
	3	13.40	24.30			0.23	0.18	0.06	0.209	**0.511**	−0.059	−0.013	0.023	**0.67* L**
	4	154.90	243.80				−0.86**	0.22	−0.048	0.115	**−0.261**	−0.063	0.081	**−0.18^{ns} N**
	5	15.09	24.38					−0.23	−0.101	0.093	−0.225	**−0.073**	−0.086	**−0.39^{ns} N**
	6	0.70	28.30						0.127	0.032	−0.057	0.017	**0.372**	**0.49* N**
Sandy loam RT	*1*(*Y*)	11.79	135.93	0.83**	0.74*	−0.09	−0.23	0.45*						
	2	55.00	80.00		0.55*	−0.16	−0.25	0.33	**0.417**	0.283	0.025	0.001	0.101	**0.83** L**
	3	13.40	24.30			0.16	0.17	0.06	0.229	**0.516**	−0.025	−0.001	0.019	**0.74* L**
	4	149.90	246.70				−0.90**	0.17	−0.066	0.083	**−0.157**	−0.004	0.052	**−0.09^{ns} N**
	5	14.99	24.67					−0.21	−0.103	0.087	−0.141	**−0.005**	−0.064	**−0.23^{ns} N**
	6	0.70	28.30						0.139	0.033	−0.027	0.001	**0.302**	**0.45* N**
Sandy loam NT	*1*(*Y*)	9.76	102.85	0.66*	0.63*	0.20	0.23	0.29						
	2	55.00	80.00		0.55*	−0.15	−0.25	0.33	**0.458**	0.164	0.193	−0.394	0.243	**0.66* L**
	3	13.40	24.30			0.19	0.18	0.06	0.251	**0.300**	−0.258	0.295	0.046	**0.63* L**
	4	156.30	249.30				−0.87**	0.20	−0.067	0.058	**−1.326**	1.392	0.146	**0.20^{ns} N**
	5	15.00	24.21					−0.21	−0.113	0.055	−1.155	**1.599**	−0.156	**0.23^{ns} N**
	6	0.70	28.30						0.153	0.019	−0.267	−0.342	**0.727**	**0.29^{ns} N**

Notes. *1*(*Y*) – CO_2 flux (g CO_2-C m^{-2} h^{-1}), 2 – air humidity (%), 3 – air temperature (ºC), 4 – soil water content (g kg^{-1}), 5 – soil temperature (ºC), 6 – total rainfall of 3 last days (mm); *, ** and *** – least significant difference at $P < 0.05$, $P < 0.01$ and $P < 0.001$ respectively, ns – not significant. Number in bold – direct effect, underlined number – dominant effect; N – nonlinear correlation, L – linear correlation.

Soil temperature is the most dominant factor in determining CO_2 evolution from the soil. However, we consider that analysing of integrated action of more than two indices is more expedient and revealing a real state of soil responses to changes. Direct effect of soil temperature on soil NCER was very strong on both loam and sandy loam in 2008 (Path coefficient ranged from 0.469 to 1.443 on loam and from 0.605 to 0.936 on sandy loam). However, integrated influence of other factors intensively buffered direct influence of soil temperature. Therefore, the total effect of soil temperature on soil CO_2 flux was not significant in 2008 on both loam and sandy loam (correlation coefficient varied from 0.11 to 0.41). In 2009, direct effect of soil temperature was the strongest in RT (Path coefficient 1.090) and NT (Path coefficient 1.093) systems on the loamy soil and only in NT system on the sandy loam (Path coefficient 1.599), but total effect was significant only on the loam under RT application ($I(Y) = 0.47^*$).

Direct effect of ***rainfall*** on Ncer was significant in 2008 on both loam and sandy loam (Path coefficient varied from 0.121 to 0.855). Its total influence through integrated influence of other factors was significant also ($I(Y)$ ranged from 0.66* to 0.95**). Direct effect of rainfall on CO_2 flux in 2009 was pronounced (Path coefficient varied from 0.247 to 0.727), while total effect was significant only on the sandy loam in CT and RT systems ($I(Y) = 0.49^*$ and $I(Y) = 0.45^*$, respectively). Summarising our data we can state that analysing of only individual indices could not be enough for an objective understanding and evaluation of real phenomena occurring in nature. We found that CO_2 flux was in positive nonlinear relationship with soil GWC in both dry 2008 and rainy 2009 years and on both loam and sandy loam. In dry 2008, on the loamy soil NCER was 3.3 fold larger at 24ºC than that at 12ºC, and on the sandy loam NCER was 2.1 fold larger at 25ºC than that at 11ºC. In contrast, in rainy 2009 on the loam NCER was 1.5 fold lesser at 25ºC than that at 15ºC, and on the sandy loam it was 2.9 fold lesser at 24ºC than that at 15ºC. Hence we may conclude that close interaction of more than two environmental factors reduced or enhanced direct action of one selected index on CO_2 flux. Consequently, many researchers obtained and presented different contrasting data. In comparison, Moore and Dalva (1997) simulated soil temperature and water table position to determine their influence on CO_2 emission. At 23ºC, emission of CO_2 was 2.4 times larger than that at 10ºC, and CO_2 emission showed a positive, linear relation with water content of the soil. Bajracharya et al. (2000) observed a significant correlation of soil C flux with soil temperature (R^2 = 0.80) and air temperature (R^2 = 0.80), but not with soil moisture.

Finally, in dry 2008 on both loam and sandy loam, nonlinear relationships was expressed between NCER and relative air humidity (Tables 5 and 6), air temperature, soil GWC and soil temperature, but the correlation between NCER and rainfall content was linearly directed. In wet 2009, linear correlation was determined between NCER and relative air humidity and air temperature, but the relationships between NCER and the rest of the indicators (in all tillage management systems) were nonlinear. This indicates that high air and soil temperatures, low soil GWC under dry and relatively warm environmental conditions in moderate climatic of the Baltic region, acted as forces with significant limiting native potential to reduce NCER on both soils with different texture and in all different tillage systems. Even insignificant rainfall essentially enhanced CO_2 flux. Under wet and relatively warm environmental conditions high GWC, soil temperature and higher than normal rainfall suspended NCER, but rising air humidity and air temperature significantly increased NCER on the loamy soil and sandy loam in all tillage treatments. Nevertheless, NCER more sensitively responded to the change of environmental conditions on the sandy loam compared to the loam. Moreover, soil NCER under both dry and wet environmental conditions responded to changes of weather and soil state more sensitively in NT than in RT and CT.

Conclusions

1. Tillage practices and weather conditions influenced soil temperature and water content which in turn, affected soil surface CO_2 flux on *Endocalcari-Epihypogleyic Cambisol* (*CMg-p-w-can*) under moderate climate conditions. Application of NT on both loam and sandy loam increased soil GWC and decreased soil temperature under different weather conditions compared to CT and RT.

2. NCER at dry weather conditions, on the loam soil in NT was higher than in RT and CT, while on the sandy loam it was lesser in CT, but did not differ significantly from RT.

3. NCER at wet weather conditions, on the loam in NT was lesser than in CT, but did not differ significantly from RT ($P \leq 0.05$).

4. NCER on the sandy loam was lesser in NT than in RT and CT. High air and soil temperatures, low soil GWC under dry and relatively warm environmental conditions acted as forces with significant limiting potential to reduce NCER on both soils with different texture and in all different tillage systems. Even insignificant rainfall (varying from 0.0 to 13.5 mm) essentially enhanced CO_2 flux.

5. Under wet and relatively warm environmental conditions high GWC, soil temperature and higher than normal rainfall suspended NCER. Soil NCER under both dry and wet environmental conditions responded to changes of weather and soil state more sensitively in NT than in RT and CT. Further long-term studies are needed to determine the expanded effects of management practices on CO_2 flux and soil C levels under various soil chemical and physical properties, climate, and environmental conditions in the Baltic region.

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Anglies dioksido apykaitos kitimas dirvožemio paviršiuje priklausomai nuo dirvožemio granuliometrinės sudėties, ilgamečio tausojamojo žemės dirbimo ir oro sąlygų

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Santrauka

Dirvožemio CO_2 apykaitos intensyvumo sąveikai su dirvožemio savybėmis ir klimato sąlygomis nustatyti, taikant skirtingas žemės dirbimo sistemas, giliau karbonatingame sekliai glėjiškame rudžemyje (RDg4-k2), Dotnuvoje, Lietuvos žemdirbystės institute, buvo tirta oro ir dirvožemio temperatūrų, oro santykinės drėgmės, taip pat dirvožemio gravimetrinės drėgmės (GWC) kiekio įtaka dirvožemio CO_2 apykaitos intensyvumui tradicinio (CT) bei supaprastinto (RT) žemės dirbimo ir tiesioginės sėjos (NT) taikymo dešimtaisiais ir vienuoliktaisiais (2008 ir 2009) metais.
NT taikymas priemolio ir smėlingo priemolio dirvožemiuose, esant ir sausiems, ir drėgniems orams, padidino GWC ir sumažino dirvožemio temperatūrą, palyginti su CT ir RT taikymu. CO_2 apykaitos intensyvumas, esant sausiems orams, priemolio dirvožemyje taikant NT buvo 0,024–0,033 g CO_2-C m^{-2} h^{-1} didesnis nei taikant RT bei CT, tačiau smėlingame priemolyje CO_2 apykaitos intensyvumas buvo 0,011 g CO_2-C m^{-2} h^{-1} mažesnis nei taikant CT. Tarp NT bei RT taikymo esminių skirtumų nenustatyta. CO_2 apykaitos intensyvumas, esant drėgniems orams, priemolio dirvožemyje taikant NT buvo 0,043 g CO_2-C m^{-2} h^{-1} mažesnis, palyginti su CT, ir esmingai nesiskyrė nuo RT; smėlingo priemolio dirvožemyje CO_2 apykaitos intensyvumas, esant drėgniems orams, buvo 0,069–0,087 g CO_2-C m^{-2} h^{-1} mažesnis, palyginti su RT bei CT taikymu. Sąlygiškai karšti orai vasaros metu smarkiai padidina dirvožemio temperatūrą ir sumažina jo GWC. Baltijos regione vidutinio klimato sąlygomis sausas ir karštas oras gali būti įvardijamas kaip CO_2 apykaitos intensyvumą mažinantis veiksnys priemolio bei smėlingo priemolio dirvožemiuose ir taikant skirtingas žemės dirbimo sistemas. Sausais metais CO_2 apykaitos intensyvumą smarkiai suaktyvino net negausus lietus (iki 13,5 mm kritulių). Nustatyta, jog esant šiltiems, bet lietingiems (daugiau nei vidutinis kritulių kiekis) orams, CO_2 apykaitos intensyvumas sumažėjo. Dirvožemio CO_2 apykaitos intensyvumas ir sausais, ir drėgnais metais labiau priklausė nuo oro ir dirvožemio sąlygų taikant NT negu RT bei CT sistemas.

Reikšminiai žodžiai: rudžemis, priemolis, smėlingas priemolis, CO_2 apykaitos intensyvumas, žemės dirbimas, klimato sąlygos.