THE INFLUENCE OF SOIL ORGANIC CARBON, MOISTURE AND TEMPERATURE ON SOIL SURFACE CO₂ EMISSION IN THE 10TH YEAR OF DIFFERENT TILLAGE-FERTILISATION MANAGEMENT

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Abstract
The study was designed to assess the temporal variability in CO₂ emission from the soil surface during a crop growing season under field conditions, and how these emissions are related to tillage, fertilisation and their interactions in the 10th year of soil management practice. We also aimed to determine if a relationship exists between CO₂ emission and soil moisture content, soil and air temperature. The data revealed that in a loam-textured soil during a 10-week period the mean CO₂ emission in direct drilled plots (NT) was by 54 and 36% higher than in conventional tillage (CT) and reduced tillage (RT), respectively, while in the soil with a sandy loam texture CO₂ emission under NT was by 15 and 9% lower than in CT and RT. Increased fertilisation level (primarily N application) determined an increase in CO₂ emission in both loam and sandy loam soils. Moderate rates in loam soil increased CO₂ emission on average by 12% and high rates by 24% compared to the emission in unfertilised soil. Fertilisers influence in sandy loam soil was similar. Moderate rates increased CO₂ emission on average by 12% and high rates by 27% compared to the emission in unfertilised soil. Growth of soil organic carbon (SOC) content by 0.10% conditioned CO₂ emission expansion by 0.82 µmol mol⁻¹ in loam soil. However, the same growth of SOC content in the sandy loam soil caused CO₂ emission expansion only by 0.34 µmol mol⁻¹. Moreover, low content of SOC (< 1.00%) had a weak and uncertain influence on CO₂ emission character. The higher the soil moisture content (SMC) was the higher the emission was obtained. However, the same SMC in soils with different texture caused unequal CO₂ emission. SMC range from 13.00 to 16.60% in the soil with sandy loam texture conditioned CO₂ emission higher by 28% compared to the emission in the similar moisture conditions in the soil with loam texture. The variation of soil temperature from +10 to +23°C did not significantly influence soil CO₂ emission rate.

Key words: CO₂ emission, tillage, fertilisation, soil organic carbon, moisture, temperature.

Introduction
Historically, many soils used for agriculture have lost 20–40% or more of their carbon through practices that led to low rates of C addition to soil and increased oxidation of soil organic matter. It is evident that under current agricultural practices, many European soils are losing organic carbon and thus constitute sources of atmospheric CO₂ rather than sinks /Bellamy et al., 2005; Weiske, 2007/. Concerns about rising atmospheric CO₂ levels have prompted considerable interest in recent years
regarding the sink potential of soil organic carbon (SOC). The world’s soils are estimated to contain 1500 Gt of SOC (1 Gt = 1.0 \times 10^9 t), roughly double the amount of C in the atmosphere /Schlesinger, 2000/.

Depending on the management practices being used, and their relative effect on C inputs from residues vs. C losses from decomposition, agricultural soils can be either a net source or a net sink for C /Paustian et al., 2000; Lal, 2004; Smith, 2004/. The IPCC methodology estimates net CO2 emissions (sinks and sources) from: (i) changes in C stocks of mineral soils due to changes in land use practices; (ii) CO2 emissions from organic soils converted to agriculture or plantation forestry; and (iii) liming of agricultural soils /Lokupitiya, Paustian, 2006/.

Cropping pattern, tillage practice, and N and irrigation management can influence the exchange of CO2, N2O, and CH4 between soil and the atmosphere /IPCC, 1996/. More CO2 emissions can occur from a tilled than from an undisturbed soil, as tillage produces a soil microenvironment favourable for accelerated microbial decomposition of plant and animal residues /Doran, Linn, 1994; Kessavalou et al., 1998/.

Much of the blame for this loss of C has been assigned to the practice of ploughing the soil /Reicosky, 2007/, and tilled soils are viewed by many as a depleted C reservoir that can be refilled. Changes in soil C can in principle be inferred from continuous measurement of net ecosystem CO2 exchange (NEE) between the land surface and the atmosphere. Tillage of soils often decreases soil organic matter content and increases CO2 emission. Enhanced CO2 emission induced by tillage may provide an early indication of the likely consequences of soil studies in the context of tillage operations and biological management on soil organic C /Otten et al., 2000/. Baker and Griffis (2005) compared two adjacent fields, both in maize/soybean rotation, with one under conventional tillage and the other under strip tillage, a conservation tillage practice in which most of the surface is undisturbed. They found no C sequestration benefit from the conservation tillage, and both systems were apparently small net sources of C over the 2-year period. Verma et al. (2005) measured NEE for 2 years in three adjacent fields in Nebraska, all in no-till. One was in irrigated continuous maize, one in irrigated maize/soybean rotation, and the other in dry land maize. Though there were differences among systems in gross primary productivity and yield, the net carbon balance computed from NEE and yield was essentially zero for all treatments, and the authors concluded that all were either C neutral or slight sources of C. Because soils have lost so much C since tillage began, the idea that a reduction in tillage would sequester C seems plausible /Baker et al., 2007/.

Tillage accelerates soil CO2 emission by improving soil aeration, plant nutrient availability and increasing exposure of soil organic C to microbes for rapid oxidation. The magnitude of CO2 loss from the soil due to tillage practices is highly related to frequency and intensity of soil disturbance caused by tillage. Tillage often increases short-term CO2 flux from soil due to a rapid physical release of CO2 trapped in the soil air space. It is worth to notice that the effect of tillage on CO2 emission, however, was short-lived (< 24 h) and tillage induced CO2 emission was proportional to the volume of soil disturbed /Reicosky, Lindstrom, 1993; Reicocky, Archer, 2007/. In recent studies in USA, Reicosky et al. (2005) and Al-Kaisi and Yin (2005) found a relatively higher CO2 emission for soils under mouldboard than no-till in corn and corn-soybean rotation.
systems. In contrast, La Scala et al. (2006) found that CO₂ emission was highest under chisel relative to mouldboard and no-till shortly after tillage. Relatively fewer studies have been conducted to evaluate long-term effects of tillage on greenhouse gas emissions. However, Curtin et al. (2000) found that CO₂ emission with no-till was significantly less than for conventional tillage. Similarly, Dao (1998) reported a significantly lower CO₂ flux for no-till than for mouldboard plough. In a 3-yr study where emission was measured all year round, Kessavalou et al. (1998) found higher CO₂ emission in native grasses (sod) relative to wheat-fallow rotation and higher annual emission for CT relative to NT. However, while some information is available for short-term CO₂ emission /Al Kaisi, Yin, 2005; Reicosky, 1997/, there is a complete lack of data to assess effects of long-term tillage on long-term CO₂ emission. Vyn et al. (2006) observed that growing season CO₂ emissions were significantly affected by rotation but not by tillage treatments. Elder and Lal (2008) stated that CO₂ emissions were not significantly different among mouldboard ploughing, no-tillage and bare fallow.

Hendrix et al. (1998) measured higher CO₂ emissions from 5- and 6-yr-old no-till soils than from conventionally tilled soil. They found a strong relationship between CO₂ emissions and soil temperature in both treatments but no relationship could be found with soil water. In south-central Texas, lower soil CO₂ emissions were recorded in no tillage than in conventional tillage during the wheat growing season /Franzluebbers et al., 1995/. Fortin et al. (1996) found that differences in soil CO₂ fluxes between CT and first- and second-year NT were related in part to differences in soil temperature. Soil temperature differences could be recorded consistently until the third week of June. Past this date, CT and NT produced similar CO₂ emissions in a wet year. However, in a dry year, CT produced lower CO₂ emissions than NT.

In general, conservation tillage is regarded as one of the most effective agricultural practices for reducing soil CO₂ emission to the atmosphere from agricultural soils /Reicosky, Lindstrom, 1993; Lal, Kimble, 1997/. According to Smith et al. (2000) no-till farming is applicable to 87% of arable area in Europe. According to the EU project INSEA continuous reduced tillage over 20 years is found to add on average 0.2 t C ha⁻¹ a⁻¹ to soil organic carbon compared to conventional tillage, while minimum tillage provides 0.31 t C ha⁻¹ a⁻¹. This could result in a technical potential of 74 and 113 Mt CO₂-equivalent (1 Mt = 1.0 x 10⁶ t), for EU-25 for reduced and minimum tillage, respectively /Weiske, 2007/.

The effect of tillage on CO₂ flux from soil is dependent on the time of the year the measurements are made. According to Prior et al. (2004) spring tillage did not increase CO₂ flux above that from undisturbed soil, while tillage in the fall resulted in higher flux than in undisturbed soil.

Soil temperature and moisture are the main ecological factors controlling the process of soil organic matter decomposition, CO₂ production and emission from soils /Rustad et al., 2000/. A high positive correlation between CO₂ emission rate and soil temperature was found for many soils under natural and agricultural conditions /Kudeyarov, Kurganova, 1998; Raich et al., 2002; Lopes de Gerenyu et al., 2005/. Temperature (soil or air) is the best predictor of the annual and seasonal dynamics of CO₂ evolution rate of soils /Kirschbaum, 2000, Raich et al., 2002, Perrin et al., 2003/.
The most intensive research on soil CO₂ emission related with tillage has been carried out by the USA scientists. Unfortunately, very few data can be found from temperate climatic condition of Eastern Europe /Lokupitiya, Paustian, 2006/. In addition, little is known about the combined effects of tillage and fertilisation on CO₂ flux /Sainju et al., 2006/. Finally, no data have been available on soil CO₂ emission related with tillage, tillage-fertilisation combined action in Lithuania up to now.

The specific objective of this research was to assess the temporal variability in CO₂ fluxes from the soil surface during a crop growing season and how these emissions are related to tillage, fertilisation and their interactions in the 10th year of soil management practice. Our objectives also were to determine if a relationship exists between CO₂ fluxes and soil moisture content, soil and air temperature.

Materials and methods

Soil and site description. The scientific inquiry was done in fields with different soil tillage and fertilisation history. Experiment design involved conventional (CT), reduced (RT) and no-tillage (NT) management. Two field trials were established at the Lithuanian Institute of Agriculture (Dotnuva) on an Endocalcari-Epihypogleyic Cambisol (RDg8-k2) in 1999. According to FAO classification system the soil in the 1st trial was loam, in the 2nd trial sandy loam. The crop rotation was as follows: winter wheat – sugar beet – spring wheat – spring barley – peas – winter wheat – spring oil-seed rape – spring wheat – spring barley. In 2008 spring barley was grown. Post-harvest plant residues (cereal straw, leaves of sugar beet etc.) of previous crop were removed from the field.

Experimental design. The experimental design was a split-plot with 4 replications (Table 1). Each replication consisted of 3 tillage systems and every tillage system consisted of 3 different fertilisation levels. Control treatment of the trial is referred to as conventional tillage treatment CT-1 (deep ploughing + presowing shallow cultivation, not fertilised).

The deep and shallow mouldboard plough treatments (conventional and reduce tillage) were conducted during the autumn soon after harvesting each season. Deep ploughing disturbed the soil down to a depth of approximately 22–25 cm depth, while shallow ploughing – down to 14–16 cm soil depth. Deep and shallow ploughing resulted in a complete inversion of soil surface and nearly 100% incorporation of crop residues (stubble, small leaves) by using a 4-body reversible plough. No-tillage treatments received herbicide glyphosate application (4 l ha⁻¹) in autumn soon after the weeds and volunteer plants had appeared. In this research no-tillage system is defined as having neither autumn nor presowing individual-mechanical tillage operations for soil manipulation.

Presowing tillage for conventional and reduced tillage treatments received one-pass shallow cultivation

Moderate and high rates of mineral PK fertilisers were top-dressed and slightly incorporated in the top-soil by presowing shallow cultivation as a seed-bed preparation in conventional and reduced tillage systems. Under direct-drilling the PK fertilisers were also broadcast before sowing, but not incorporated in to soil. Moderate and high rates of mineral N fertiliser (ammonium nitrate) in all three tillage systems investigated were
broadcast twice as a split-application, i.e. at an early- and medium-stage of spring barley development.

Spring barley in conventional and reduced tillage systems was sown by a common light disc seed drill, while direct drilling under no-tillage was performed by a heavy duty pre-seed shallow disc tillage drilling machine.

Table 1. Field trial design
1 lentelė. Tyrimų schema

<table>
<thead>
<tr>
<th>Tillage (factor A) / Žemės dirbimas (A veiksnys)</th>
<th>Primary / Pagrindinis</th>
<th>Presowing / Priešsėjinis</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT-conventional tillage / Tradicinis dirbimas</td>
<td>Deep ploughing (23–25 cm) Gilus arimas (23–25 cm)</td>
<td>Spring tine cultivation (4–5 cm) Purenimas kombinuotu žemės dirbimo agregatu (4–5 cm)</td>
</tr>
<tr>
<td>RT-reduced tillage Supaprastintas dirbimas</td>
<td>Shallow ploughing (14–16 cm) Seklus arimas (14–16 cm)</td>
<td>Spring tine cultivation (4-5 cm) Purenimas kombinuotu žemės dirbimo agregatu (4–5 cm)</td>
</tr>
<tr>
<td>NT-no-tillage Nedirbama</td>
<td>No-tillage / Nedirbama</td>
<td>Direct drilling / Tiesioginė sėja</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fertilisation (factor B) / Tręšimas (B veiksnys)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Not fertilised / Netręsta</td>
</tr>
<tr>
<td>2 Moderate rates: NPK fertilisers according to soil properties and expected yield Videdinės trąšų normos, atsižvelgiant į dirvožemio savybes bei planuojamą derlingumą</td>
</tr>
<tr>
<td>3 High rates: NPK fertilisers according to soil properties and for 25–30 % greater expected yield</td>
</tr>
</tbody>
</table>

**Experiment methodology.** Our measurements were made 10 years after initiation of different tillage and fertilisation cropping and were expected to provide insights into the time frame in which tillage – induced disturbances of the C cycle might persist under moderate climatic conditions.

Dynamic closed chamber was used to measure in situ CO₂ fluxes with a portable CO₂ analyser (SRS-1000) during the 2008 growing season. CO₂ fluxes from the soil surface were measured at weekly intervals for up to 10 weeks in the barley growing season of 2008. SRS-1000 system consists of a compact programming console and soil respiration chamber. The highly accurate miniaturised CO₂ infrared gas analyser is placed directly adjacent to the soil chamber, ensuring the fastest possible response to gas exchanges in the soil. The chamber has been carefully designed to minimise boundary layer effects and alleviate pressure differences that can suppress CO₂ exchanges. For repeated measurements of the same area, a stainless steel collar was installed in the soil to ensure correct positioning and measurement of total soil flux activity /SRS-1000, 2004/.

Closed (non-steady state) chambers are widely used for quantifying carbon dioxide (CO₂) fluxes between soils or low-stature canopies and the atmosphere. It is well recognised that covering a soil or vegetation by a closed chamber inherently disturbs the natural CO₂ fluxes by altering the concentration gradients between the soil, the
vegetation and the overlying air. Thus, the driving factors of CO₂ fluxes are not constant during the closed chamber experiment and no linear increase or decrease of CO₂ concentration over time within the chamber headspace can be expected /Kutzbach et al., 2007/. The closed chamber method is often applied to quantify the net CO₂ exchange between the atmosphere and low-stature canopies typical for agricultural crop stands /Maljanen et al., 2001; Steduto et al., 2002/.

Soil CO₂ emission (difference in CO₂ concentration through soil chamber, μmol mol⁻¹):

\[ \Delta c = C_{\text{ref}} - C_{\text{an}} \]

where \( C_{\text{ref}} \) – CO₂ flowing into soil chamber, μmol mol⁻¹; \( C_{\text{an}} \) – CO₂ flowing out from soil chamber, μmol mol⁻¹.

The data of CO₂ emission presented in this paper were converted from μmol s⁻¹m⁻² to C g m⁻²d⁻¹ as it is more common for international presentation.

Each CO₂ 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. CO₂ flux was recorded in data logger in about 2 min. when no noticeable changes in CO₂ respiration were registered. Chamber measurements were made about 10 m from plot end to minimize border effect.

The measurements were carried out weekly starting from May 08 between 12.00 and 16.00 hr.

Soil temperature was determined by portable soil thermometers at the same time of CO₂ measurement near the chamber at the depth of 5, 10, 15 and 20 cm. Similarly, gravimetric soil water content was measured near the chamber by collecting soil samples from the 0 to 20 cm depth with a probe (1.5 cm diameter) every time CO₂ flux was measured. The moist soil was oven-dried at 110°C for 48 hrs and water content was determined. In this paper soil moisture content and soil temperature are presented for 0–10 cm soil depth.

Soil organic matter was determined according to Tyurin titrimetric (classical) method before primary tillage application.

Statistical analysis. The data were treated according to two factorial analysis method by using PC programme ANOVA. Correlation-regression analysis was done according to Clewer and Scarisbrick (2001) by PC programme STAT ENG. The least significant differences (LSD) were calculated at 0.01, 0.05 and 0.10 probability levels.

Results and discussion

Soil CO₂ emission (ΔC). The CO₂ flux from the soil indicates the biological activity in the soil. The most active layer in soil is closest to the surface, thus measuring the CO₂ profile close to the surface layer gives information of the CO₂ flux from the soil to the atmosphere. Most measurements, also those with agricultural applications, are made fairly close to the surface layer of the soil /Kähkönen et al., 2002; Pumpanen et al., 2003/.

Soil CO₂ gas fluctuation was not monotonous during active crop growth period (Fig. 1). Moreover, it depended on soil texture. CO₂ emission ranged from 0 to 85 μmol mol⁻¹ in the soil with loam texture, while the fluctuation interval was wider in the soil with sandy loam texture and reached to 130 μmol mol⁻¹. In the dry period of spring it
was a 2-week period (3rd ten-day period of May) when CO₂ emission did not proceed. However, inverse process (accumulation of CO₂) to emission at this 2 week period was more pronounced in loam soil. Here plants were stronger developed compared to plants in sandy loam. Moreover, the plants and their interaction with soil microbiological environment reacted sharply to this dry period in a very special way. It is likely that C consumption process took over CO₂ emission and was more pronounced in the loam soil having higher organic matter content, which could influence vitality the microbiological environment.

Figure 1. CO₂ emission dynamics during active crop growth season in the soils with loam and sandy loam texture in the 10th year of different tillage-fertilisation management

Surplus of water supply (heavy rain at the end of the 2nd ten-day period of June) led to unexpected increase of CO₂ emission. The CO₂ emission curve rose to 85 C µmol mol⁻¹ in loam soil and to 130 C µmol mol⁻¹ in the sandy loam soil.
The soil surface CO₂ emission in loam soil differed significantly among tillage treatments \((F_{\text{act}} = 92.85^{**}, P = 0.000, \text{LSD}_{05} = 1.064)\), fertilisation treatments \((F_{\text{act}} = 20.21^{**}, P = 0.000, \text{LSD}_{05} = 1.064)\), sampling date \((F_{\text{act}} = 522.97^{**}, P = 0.000, \text{LSD}_{05} = 2.257)\). Significant interactions between tillage x fertilisation \((F_{\text{act}} = 3.21^*, P = 0.013, \text{LSD}_{05} = 2.141)\), between tillage x sample date \((F_{\text{act}} = 21.95^{**}, P = 0.000, \text{LSD}_{05} = 3.365)\), between fertilisation x sample date \((F_{\text{act}} = 3.88^{**}, P = 0.000, \text{LSD}_{05} = 3.365)\), and among tillage x fertilisation x sample date \((F_{\text{act}} = 3.24^{**}, P = 0.000, \text{LSD}_{05} = 6.180)\), were also observed. Mean CO₂ emission in NT was higher by 54 and 36% than in CT and RT, respectively. It ranged from 6.57 to 89.86 C µmol mol⁻¹, from 5.18 to 48.67 C µmol mol⁻¹, and from 10.02 to 83.98 for CT, RT and NT treatments, respectively (Fig. 1).

The soil surface CO₂ emission in sandy loam soil differed significantly among tillage treatments \((F_{\text{act}} = 8.12^{**}, P = 0.000, \text{LSD}_{05} = 1.236)\), fertilisation treatments \((F_{\text{act}} = 17.06^{**}, P = 0.000, \text{LSD}_{05} = 1.236)\), sampling date \((F_{\text{act}} = 537.26^{**}, P = 0.000, \text{LSD}_{05} = 2.622)\). Significant interaction between tillage x sample date \((F_{\text{act}} = 4.31^{**}, P = 0.000, \text{LSD}_{05} = 3.909)\) was also observed. Mean CO₂ emission in NT was lower by 15 and 9% than in CT and RT, respectively. It ranged from 3.89 to 125.37 C µmol mol⁻¹, from 6.48 to 105.50 C µmol mol⁻¹, and from 7.52 to 108.60 for CT, RT and NT treatments, respectively (Fig. 1).

We found that in the 10th year of soil management practice, the highest CO₂ emission in loam soil was under NT during almost all active crop growth period. However, rainy conditions at the end of the 2nd ten-day period of June caused significantly (by 8%) lower CO₂ emission in NT compared to CT. It is important that dry conditions (3rd ten-day period of May) destined accumulation of CO₂ process in CT and RT, while CO₂ emission in NT was clearly pronounced. Hence, NT management in loam soil conditioned higher CO₂ emission.

Converse results were obtained in sandy loam soil (Fig. 1). The highest CO₂ emission here was under CT during almost all active crop growth period. It is important that dry conditions (3rd ten-day period of May) destined more intensive accumulation of CO₂ in the NT and RT than in the CT.

Increase of fertilisation level (primarily N application) determined rising of CO₂ emission in both loam and sandy loam soils. Moderate rates in loam soil increased CO₂ emission on average by 12% and high rates by 24% compared to emission in unfertilised soil. Fertilisers influence in sandy loam soil was similar. Moderate rates increased CO₂ emission on average by 12% and high rates by 27% compared to emission in unfertilised soil.

Mean data of CO₂ emission confirmed the same regularities as dynamics data (Fig. 2). In the loam soil, during 10-week period mean CO₂ emission was the highest under NT-3 (direct drilling + high fertilisers’ rates). In sandy loam, the highest soil CO₂ flux was found under CT-3 (conventional tillage + high fertilisers’ rates).
Figure 2. Mean soil CO₂ emission in the soils with loam and sandy loam texture in the 10th year of different tillage-fertilisation management

Soil organic carbon (SOC). A good farming practice can decrease CO₂ evolution from soil into the atmosphere and enhance soil fertility and thus productivity /Lal, 2004/. Reduced tillage or no-tillage is the likely cause of C sequestration in the no-till system /Paul et al., 1997; Robertson et al., 2000/.

Increase of SOC content was registered within 0–10 cm depth under NT application in both field trials at the 10th experimental year. In the 1st trial (loam) mean SOC content in CT was 1.13%, in RT – 1.16% and in NT – 1.29%. In the 2nd trial (sandy loam) the SOC content under CT, RT and NT application was 0.88, 0.92 and 1.07%, respectively (Fig. 3).

The higher the rates of mineral fertilisers were used in both trials, the higher SOC content was registered. The reason for this – the higher amount of nutrients led the plants to produce a higher amount above-ground vegetative parts (straw) and roots as well. Due to this, more organic matter was involved in subsequent SOC accumulation process.

Figure 3. Soil organic carbon in the soils with loam and sandy loam texture in the 10th year of different tillage-fertilisation management
Our data are in line with other research results, stating that clearly pronounced SOC stratification and its concentration on top-soil is registered under NT /McGechan et al., 2005; Feiziene et al., 2008/. Ratio SOC content within 0–10 cm soil layer / SOC content within 10–20 cm soil layer under long-term NT practice was higher in the 1\textsuperscript{st} trial by 7–9\% and in the 2\textsuperscript{nd} trial by 18–21\% compared to CT and RT (Table 2). That represents the higher biological activity in the soil surface and higher influence of SOC on CO\textsubscript{2} emission is in the NT system (Fig. 4).

**Table 2.** Ratio “SOC content in 0–10 cm layer / SOC content in 10–20 cm layer” in the soils with loam and sandy loam texture in the 10\textsuperscript{th} year of different tillage-fertilisation management

<table>
<thead>
<tr>
<th>Soil texture</th>
<th>Treatments / Tyrimo variantai</th>
<th>Mean / Vidutiniškai</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.04 1.01 1.02 1.02 0.98 1.04 0.12 1.10</td>
<td>CT-1 CT-2 CT-3 RT-1 RT-2 RT-3 NT-1 NT-2 NT-3</td>
<td>1.03 1.00</td>
</tr>
<tr>
<td>1.01 0.98 0.97 0.94 0.99 1.00 1.13 1.17 1.17</td>
<td>Loam / Vidutinio sunkumo priemolis</td>
<td>1.09 0.98 0.97 1.16</td>
</tr>
<tr>
<td>1.04 1.01 1.02 1.02 0.98 1.04 0.12 1.10</td>
<td>Sandy loam / Lengvas smėlingas priemolis</td>
<td>1.10 1.10 1.18 1.17 1.17</td>
</tr>
</tbody>
</table>

**SOC influence on soil CO\textsubscript{2} emission.** Rising content of SOC (from 1.09 to 1.34\%) in the soil with loam texture determined sharper increase of CO\textsubscript{2} emission than in sandy loam (Fig. 4).

**Figure 4.** The correlation between SOC content and CO\textsubscript{2} emission in the soils with loam and sandy loam texture in the 10\textsuperscript{th} year of different tillage-fertilisation management

The data revealed that growth of soil organic C content by 0.10\% conditioned CO\textsubscript{2} emission expansion by 0.82 µmol mol\textsuperscript{-1} in loam soil. However, the same growth of soil organic C content in the sandy loam soil caused CO\textsubscript{2} emission expansion only by
0.34 µmol mol\(^{-1}\). Moreover, the correlation analysis showed that low content of SOC (< 1.00%) had weak and uncertain influence on CO\(_2\) emission character. Integrated analysis of our experimental data suggested that interaction between worse physical conditions and low SOC content in sandy loam soil /Feiza et al., 2008/ could decrease soil live environment vitality and therefore decrease soil respiration, carbon exchange rate and CO\(_2\) emission.

**Soil surface moisture content (SMC).** Soil moisture is another important factor influencing soil CO\(_2\) exchange rate and emission. Soil CO\(_2\) efflux is usually low under dry conditions due to low root and microbial activity, and increases with soil moisture to a certain limit. At very high moisture conditions, soil CO\(_2\) efflux is reduced due to a limitation of diffusion of oxygen. The understanding of the relationship between soil moisture and soil CO\(_2\) emission and the underlying mechanisms is still limited /Lopes de Gerenyu et al., 2005; Elder, Lal, 2008/.

The SMC in loam soil differed significantly among treatments (\(F_{act} = 53.49**, P = 0.000, \text{LSD}_{05} = 0.211\)), sampling date (\(F_{act} = 77.63**, P = 0.000, \text{LSD}_{05} = 0.448\)) and significant interaction between tillage x sample date was also observed (\(F_{act} = 2.34**, P = 0.003, \text{LSD}_{05} = 0.805\)). SMC was higher in NT than in RT and CT. SMC ranged from 7.14 to 14.08%, from 5.68 to 13.23%, and from 8.96 to 15.66% for CT, RT and NT treatments, respectively (Fig. 5).

The SMC in sandy loam differed significantly among treatments (\(F_{act} = 53.49**, P = 0.000, \text{LSD}_{05} = 0.204\)) and sampling date (\(F_{act} = 77.63**, P = 0.000, \text{LSD}_{05} = 0.433\)). SMC was higher in NT than in RT and CT. SMC ranged from 5.66% to 12.78%, from 4.39% to 12.30%, and from 6.55% to 13.72% for CT, RT and NT treatments, respectively (Fig. 5).

**Figure 5.** Soil surface moisture content dynamics during active crop growth season in the soils with loam and sandy loam texture in the 10th year of different tillage-fertilisation management

**5 paveikslas. Dirvožemio paviršius drėgmės kiekio dinamika aktyviojo augalų vegetacijos tarpsniu vidutinio sunkumo priemolio bei smėlingo lengvo priemolio dirvožemyje 10-aisiais įvairių žemės dirbimo ir tręšimo sistemų taikymo metais**

On May 28–June 11 of 2008 a rapid decrease in SMC was noted in all tillage treatments. This trend can be partially attributed to higher soil temperatures at 0–10 cm layer compared to temperatures on other dates. Comparatively higher SMC in NT during period of investigations may be a result of increase in water loss due to intensive tillage
in CT and RT plots, and reduced evaporation at the soil surface due to lack of soil disturbance in NT /Franzluebbers et al., 1995; Elder, Lal, 2008/.

**Soil moisture influence on soil CO₂ emission.** Soil CO₂ emission usually responds most to whichever of the two factors, temperature or moisture, is the most limiting. If the soil is very dry, the soil CO₂ flux is not sensitive to temperature. When the moisture level increases, the level of CO₂ exchange rate becomes much more sensitive to temperature. Similarly, at temperatures below 5°C soil respiration is not sensitive to moisture, but becomes increasingly responsive at higher temperatures.

Our data revealed that in both trials with different texture CO₂ emission responded to soil surface moisture (Fig. 6). The higher SMC was in the soil the higher emission was obtained. However, the same SMC in soils with different texture caused unequal CO₂ emission. SMC range from 13.00 to 16.60% in the soil with sandy loam texture conditioned CO₂ emission higher by 28% compared to emission in the similar moisture conditions in the soil with loam texture. In loam soil under dry conditions (May 21–28) CO₂ emission did not proceed in CT and RT, however carbon gas flux in NT was clearly expressed. NT trait to conserve soil moisture in loam soil conditioned higher CO₂ emission. Importantly that in sandy loam soil CO₂ emission process discontinued in all tillage systems for shorter period, i.e. reverse process for emission (accumulation) was registered only on May 21. Moreover, the extent of CO₂ emission in sandy loam soil at this dry period end (May 28) was very low (5.36, 5.96 and 2.42 µmol mol⁻¹ for CT, RT and NT treatments, respectively).

**Figure 6.** The correlation between SMC and CO₂ emission in the soils with loam and sandy loam texture in the 10th year of different tillage-fertilisation management

**6 paveikslas.** Dirvožemio paviršiaus drėgno kiekio ir CO₂ emisijos koreliacija vidutinio sunkumo priemolio bei smėlingo lengvo priemolio dirvožemyje 10-aisiais įvairių žemės dirbimo ir trešimo sistemų taikymo metais

**Soil surface temperature.** Soil temperature is the most dominant factor in regulating soil CO₂ flux. The temperature varies depending on geographical location, season, time of the day, and weather conditions /Franzluebbers et al., 1995; Elder, Lal, 2008/.

Significant difference for soil temperature in loam at the 0–10 cm depth was observed for date of sampling (F_{act} = 271.12**, P = 0.000, LSD_{05} = 0.431) and for date of sampling x treatment interaction (F_{act} = 2.03*, P = 0.012, LSD_{05} = 0.773). Significant difference in sandy loam for soil temperature was determined only for date of sampling (F_{act} = 527.18**, P = 0.000, LSD_{05} = 0.362). Mean soil surface temperature at period of
investigations in loam soil was 19.06 ± 0.08, 19.11 ± 0.03 and 19.25 ± 0.11°C for CT, RT and NT, respectively. In sandy loam soil it was 20.02 ± 0.08, 20.12 ± 0.02 and 20.15 ± 0.06°C for CT, RT and NT, respectively.

Spring (in the 1st–2nd ten-day periods of May, 2008) soil temperature in the soil with loam texture was cooler by 0.5–0.6°C under NT than under CT, while it did no differ among tillage treatments in the soil with sandy loam texture.

**Figure 7.** Soil surface temperature dynamics during active crop growth season in the soils with loam and sandy loam texture in the 10th year of different tillage-fertilisation management

7 paveikslas. Dirvožemio paviršiaus temperatūros dinamika aktyviuoju augalų vegetacijos tarpsniai vidutinio sunkumo sunkumo priemolio bei smėlio lengvo priemolio dirvožemioje 10-aisiais įvairių žemės dirbimo ir tręšimo sistemų taikymo metais

**Soil temperature influence on soil CO₂ emission.** The correlation between soil surface temperature and CO₂ emission was weak and it confirmed other research conclusions that significant data can be obtained if temperature range is in a wide diapason (from < 5°C to > 30°C). Hence, variation of soil temperature from 10 to 23°C did not significantly influence soil CO₂ emission extent (Fig. 8).

**Figure 8.** The correlation between soil surface temperature and CO₂ emission in the soils with loam and sandy loam texture in the 10th year of different tillage-fertilisation management

8 paveikslas. Dirvožemio paviršiaus temperatūros ir CO₂ emisijos koreliacija vidutinio sunkumo priemolio bei smėlio lengvo priemolio dirvožemioje 10-aisiais įvairių žemės dirbimo ir tręšimo sistemų taikymo metais
Conclusions

1. Mean CO₂ emission in the soil with loam texture, during a 10-week period in NT was by 54 and 36% higher than in CT and RT, respectively, while in the soil with sandy loam texture CO₂ emission under NT was by 15 and 9% lower than in CT and RT, respectively.

2. Increase of fertilisation level (primarily N application) determined rising of CO₂ emission in both loam and sandy loam soils. Moderate rates in loam soil increased CO₂ emission on average by 12% and high rates by 24% compared to emission in unfertilised soil. Fertilisers influence in sandy loam soil was similar. Moderate rates increased CO₂ emission on average by 12% and high rates by 27% compared to emission in unfertilised soil.

3. Growth of SOC by 0.10% conditioned CO₂ emission expansion by 0.82 µmol mol⁻¹ in loam soil. However, the same growth of soil organic C content in the sandy loam soil caused CO₂ emission expansion only by 0.34 µmol mol⁻¹. Moreover, low content of SOC (<1.00%) have weak and uncertain influence on CO₂ emission character.

4. The higher SMC was in the soil, the higher emission was obtained. However, the same SMC in soils with different texture caused unequal CO₂ emission. SMC range from 13.00 to 16.60% in the soil with sandy loam texture conditioned CO₂ emission higher by 28% compared to the emission in the similar moisture conditions in the soil with loam texture.

5. Variation of soil temperature from 10 to 23ºC did not significantly influence soil CO₂ emission extent.

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Tyrimo tikslas – nustatyti CO₂ emisiją iš dirvos paviršiaus įvairiai augalų vegetacijos tarpsniais lauko sąlygomis bei tai, kaip minėtą emisiją veikia žemės dirbimas, tręšimas bei jų sąveiką dešimtmečiais įvairių žemės dirbimo ir tręšimo sistemų taikymo metais. Tyrimo uždaviniai – nustatyti, ar yra ryšys tarp CO₂ emisijos bei dirvos drėgmės kiekiui ir dirvos temperatūros. Nustatyta, kad vidutinio sunkumo priemolio dirvoje, kur taikytos tiesioginės (NT), 10 savaičių trukmės tyrimų laikotarpiu vidutinė CO₂ emisija buvo 54 ir 36 % didesnė nei dirvoje, kur taikytas tradicinis (CT) ir supaprastintas (RT) žemės dirbimas. O smėlinio priemolio dirvoje, taikant tiesioginę (NT), vidutinė CO₂ emisija buvo 15 ir 9 % mažesnė nei žemės dirbant tradiciniu (CT) bei supaprastintu būdu (RT). Trąšų normų didinimas (visų pirma N trąšų) CO₂ emisiją didino ir vidutinio sunkumo priemolio, ir smėlinio priemolio dirvožemyje. Vidutinio sunkumo priemolio dirvožemyje tręšiant vidutinėmis trąšų normomis CO₂ emisiją padidino 12 %, o tręšiant didesnėmis trąšų normomis – 24 %, palyginti su dešimt metų netręsta dirva. Trąšų įtaka CO₂ emisijai buvo panasi ir smėlinio priemolio dirvožemyje. Tręšiant vidutinėmis trąšų normomis CO₂ emisija didėjo vidutiniškai 12 %, o tręšiant didesnėmis normomis – 27 %, palyginti su netręsta dirva. Dirvožemio organinės anglies (SOC) kiekio padidėjimas 0,10 % lengvo priemolio dirvožemyje sakytojo CO₂ emisijos padidėjimą 0,82 µmol mol⁻¹. Tačiau smėlinio priemolio dirvožemyje toks pat SOC kiekio padidėjimas CO₂ srautą padidino tik 0,34 µmol mol⁻¹. Be to, mažas SOC (<1,0 %) kiekis sakytojo nedidelę CO₂ emisiją iš dirvožemio. Viršutiniame dirvos sluoksnyje didėjant drėgmės kiekiui CO₂ emisija taip pat didėjo. Vienodas drėgmės kiekių įvairios granuliometrinės sudėties dirvožemiuose nevienodai veikė ir CO₂ emisiją. Dirvožemio drėgniui esant nuo 13,00 iki 16,60 %, CO₂ emisija smėlinio priemolio dirvožemyje buvo 28 % didesnė nei lengvame priemolyje. Dirvožemio temperatūros pokyčiai nuo +10 iki +23 °C neturėjo esminės įtakos CO₂ emisijai iš dirvožemio.

Reikšminiai žodžiai: CO₂ emisija, žemės dirbimas, tręšimas, dirvožemio organinė medžiaga, temperatūra, drėgmė.