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THE INFLUENCE OF SOIL ORGANIC CARBON, MOISTURE AND TEMPERATURE ON SOIL SURFACE CO_2 EMISSION IN THE 10^{TH} YEAR OF DIFFERENT TILLAGE-FERTILISATION MANAGEMENT

Dalia FEIZIENĖ, Gražina KADŽIENĖ

Lithuanian Institute of Agriculture
Instituto al. 1, Akademija, Kėdainiai district
E-mail: daliaf@lzi.lt

Abstract

The study was designed to assess the temporal variability in CO_2 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 CO_2 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 CO_2 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 CO_2 emission under NT was by 15 and 9% lower than in CT and RT. Increased fertilisation level (primarily N application) determined an increase in CO_2 emission in both loam and sandy loam soils. Moderate rates in loam soil increased CO_2 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 CO_2 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 CO_2 emission expansion by 0.82 μmol mol^{-1} in loam soil. However, the same growth of SOC content in the sandy loam soil caused CO_2 emission expansion only by 0.34 μmol mol^{-1}. Moreover, low content of SOC (< 1.00%) had a weak and uncertain influence on CO_2 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 CO_2 emission. SMC range from 13.00 to 16.60% in the soil with sandy loam texture conditioned CO_2 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 +23ºC did not significantly influence soil CO_2 emission rate.

Key words: CO_2 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 CO_2 rather than sinks /Bellamy et al., 2005; Weiske, 2007/. Concerns about rising atmospheric CO_2 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 x 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 CO_2 emissions (sinks and sources) from: (i) changes in C stocks of mineral soils due to changes in land use practices; (ii) CO_2 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 CO_2, N_2O, and CH_4 between soil and the atmosphere /IPCC, 1996/. More CO_2 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 CO_2 exchange (NEE) between the land surface and the atmosphere. Tillage of soils often decreases soil organic matter content and increases CO_2 emission. Enhanced CO_2 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 CO_2 emission by improving soil aeration, plant nutrient availability and increasing exposure of soil organic C to microbes for rapid oxidation. 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. Tillage often increases short-term CO_2 flux from soil due to a rapid physical release of CO_2 trapped in the soil air space. It is worth to notice that the effect of tillage on CO_2 emission, however, was short-lived (< 24 h) and tillage induced CO_2 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 CO_2 emission for soils under mouldboard than no-till 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 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 CO_2 emission with no-till was significantly less than for conventional tillage. Similarly, Dao (1998) reported a significantly lower CO_2 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 CO_2 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 CO_2 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 CO_2 emissions were not significantly different among mouldboard ploughing, no-tillage and bare fallow.

Hendrix et al. (1998) measured higher CO_2 emissions from 5- and 6-yr-old no-till soils than from conventionally tilled soil. They found a strong relationship between CO_2 emissions and soil temperature in both treatments but no relationship could be found with soil water. In south-central Texas, lower soil CO_2 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 CO_2 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 CO_2 emissions in a wet year. However, in a dry year, CT produced lower CO_2 emissions than NT.

In general, conservation tillage is regarded as one of the most effective agricultural practices for reducing soil CO_2 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 CO_2-equivalent (1 Mt = 1.0×10^6 t), for EU-25 for reduced and minimum tillage, respectively /Weiske, 2007/.

The effect of tillage on CO_2 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 CO_2 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, CO_2 production and emission from soils /Rustad et al., 2000/. A high positive correlation between CO_2 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 CO_2 evolution rate of soils /Kirschbaum, 2000, Raich et al., 2002, Perrin et al., 2003/.

The most intensive research on soil CO_2 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 CO_2 flux /Sainju et al., 2006/. Finally, no data have been available on soil CO_2 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 CO_2 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 CO_2 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*

Tillage (factor A) / *Žemės dirbimas (A veiksnys)*		
Abbreviation *Sutrumpinimas*	Primary / *Pagrindinis*	Presowing / *Priešsėjinis*
CT-conventional tillage / *Tradicinis dirbimas*	Deep ploughing (23–25 cm) *Gilus arimas (23–25 cm)*	Spring tine cultivation (4–5 cm) *Purenimas kombinuotu žemės dirbimo agregatu (4–5 cm)*
RT-reduced tillage *Supaprastintas dirbimas*	Shallow ploughing (14–16 cm) *Seklus arimas (14–16 cm)*	Spring tine cultivation (4-5 cm) *Purenimas kombinuotu žemės dirbimo agregatu (4–5 cm)*
NT-no-tollage *Nedirbama*	No-tillage / *Nedirbama*	Direct drilling / *Tiesioginė sėja*
Fertilisation (factor B) / *Tręšimas (B veiksnys)*		
1	Not fertilised / *Netręšta*	
2	Moderate rates: NPK fertilisers according to soil properties and expected yield *Vidutinės trąšų normos, atsižvelgiant į dirvožemio savybes bei planuojamą derlingumą*	
3	High rates: NPK fertilisers according to soil properties and for 25–30 % greater expected yield than in treatment 2 *Didesnės trąšų normos: 25–30 % didesniam planuojamam derliui nei antrajame variante*	

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 CO_2 fluxes with a portable CO_2 analyser (SRS-1000) during the 2008 growing season. CO_2 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 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 chamber has been carefully designed to minimise boundary layer effects and alleviate pressure differences that can suppress CO_2 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 (CO_2) 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 CO_2 fluxes by altering the concentration gradients between the soil, the vegetation and the overlying air. Thus, the driving factors of CO_2 fluxes are not constant during the closed chamber experiment and no linear increase or decrease of CO_2 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 CO_2 exchange between the atmosphere and low-stature canopies typical for agricultural crop stands /Maljanen et al., 2001; Steduto et al., 2002/.

Soil CO_2 emission (difference in CO_2 concentration through soil chamber, μmol mol^{-1}):

$$\Delta c = C_{ref} - C_{an}$$

where 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 emission presented in this paper were converted from μmol $s^{-1}m^{-2}$ to C g m^{-2} d^{-1} as it is more common for international 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. 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 CO_2 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 CO_2 flux was measured. The moist soil was oven-dried at 110ºC 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 CO_2 emission (ΔC). The CO_2 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 CO_2 profile close to the surface layer gives information of the CO_2 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 CO_2 gas fluctuation was not monotonous during active crop growth period (Fig. 1). Moreover, it depended on soil texture. CO_2 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 CO_2 emission did not proceed. However, inverse process (accumulation of CO_2) 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 CO_2 emission and was more pronounced in the loam soil having higher organic matter content, which could influence vitality the microbiological environment.

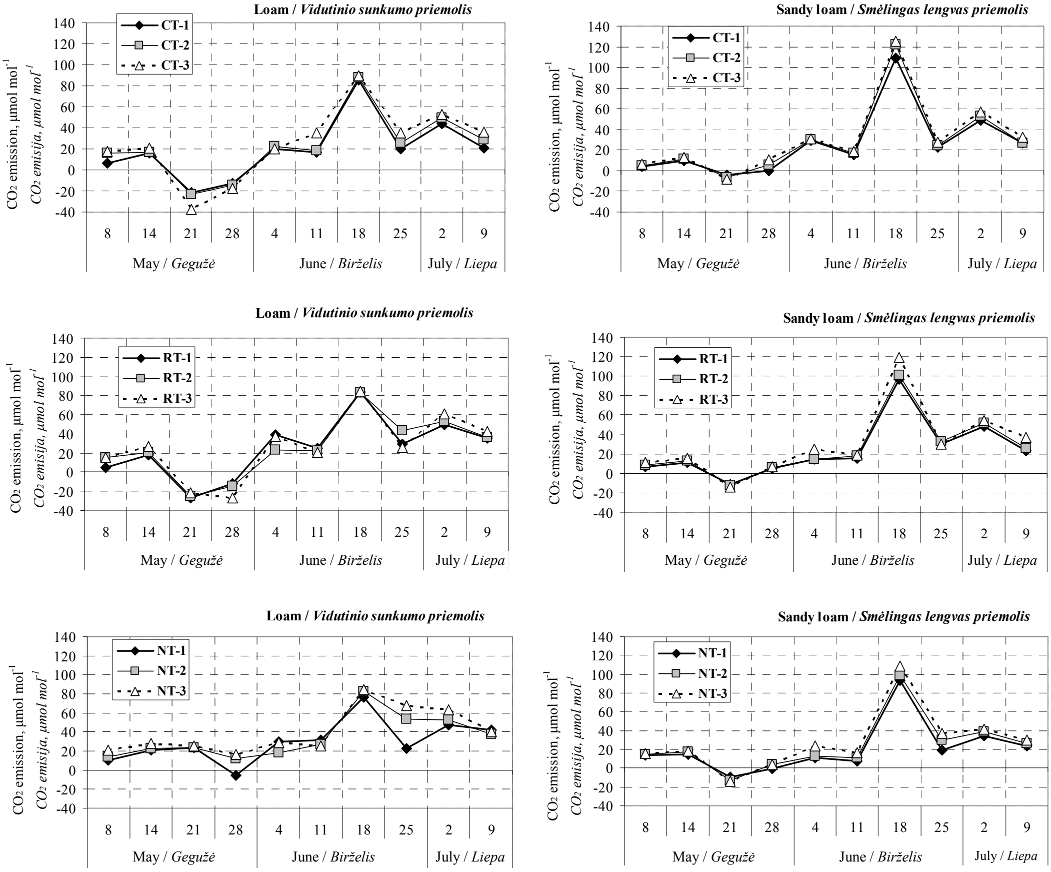

Figure 1. CO_2 emission dynamics during active crop growth season in the soils with loam and sandy loam texture in the 10th year of different tillage-fertilisation management
1 paveikslas. *CO_2 emisijos dinamika augalų aktyvios vegetacijos metu vidutinio sunkumo priemolio bei smėlingo lengvo priemolio dirvožemyje 10-aisiais įvairių žemės dirbimo ir tręšimo sistemų taikymo metais*

Surplus of water supply (heavy rain at the end of the 2nd ten-day period of June) led to unexpected increase of CO_2 emission. The CO_2 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 CO_2 emission in loam soil differed significantly among tillage treatments (F_{act} = 92.85**, P = 0.000, LSD_{05} = 1.064), fertilisation treatments (F_{act} = 20.21**, P = 0.000, LSD_{05} = 1.064), sampling date (F_{act} = 522.97**, P = 0.000, LSD_{05} = 2.257). Significant interactions between tillage x fertilisation (F_{act} = 3.21*, P = 0.013, LSD_{05} = 2.141), between tillage x sample date (F_{act} = 21.95**, P = 0.000, LSD_{05} = 3.365), between fertilisation x sample date (F_{act} = 3.88**, P = 0.000, LSD_{05} = 3.365), and among tillage x fertilisation x sample date (F_{act} = 3.24**, P = 0.000, LSD_{05} = 6.180), were also observed. Mean CO_2 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 CO_2 emission in sandy loam soil differed significantly among tillage treatments (F_{act} = 8.12**, P = 0.000, LSD_{05} = 1.236), fertilisation treatments (F_{act} = 17.06**, P = 0.000, LSD_{05} = 1.236), sampling date (F_{act} = 537.26**, P = 0.000, LSD_{05} = 2.622). Significant interaction between tillage x sample date (F_{act} = 4.31**, P = 0.000, LSD_{05} = 3.909) was also observed. Mean CO_2 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 CO_2 emission in loam soil was under NT during almost all active crop growth period. However, rainy conditions at the end of the 2^{nd} ten-day period of June caused significantly (by 8%) lower CO_2 emission in NT compared to CT. it is important that dry conditions (3^{rd} ten-day period of May) destined accumulation of CO_2 process in CT and RT, while CO_2 emission in NT was clearly pronounced. Hence, NT management in loam soil conditioned higher CO_2 emission.

Converse results were obtained in sandy loam soil (Fig. 1). The highest CO_2 emission here was under CT during almost all active crop growth period. It is important that dry conditions (3^{rd} ten-day period of May) destined more intensive accumulation of CO_2 in the NT and RT than in the CT.

Increase of fertilisation level (primarily N application) determined rising of CO_2 emission in both loam and sandy loam soils. Moderate rates in loam soil increased CO_2 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 CO_2 emission on average by 12% and high rates by 27% compared to emission in unfertilised soil.

Mean data of CO_2 emission confirmed the same regularities as dynamics data (Fig. 2). In the loam soil, during 10-week period mean CO_2 emission was the highest under NT-3 (direct drilling + high fertilisers' rates). In sandy loam, the highest soil CO_2 flux was found under CT-3 (conventional tillage + high fertilisers' rates).

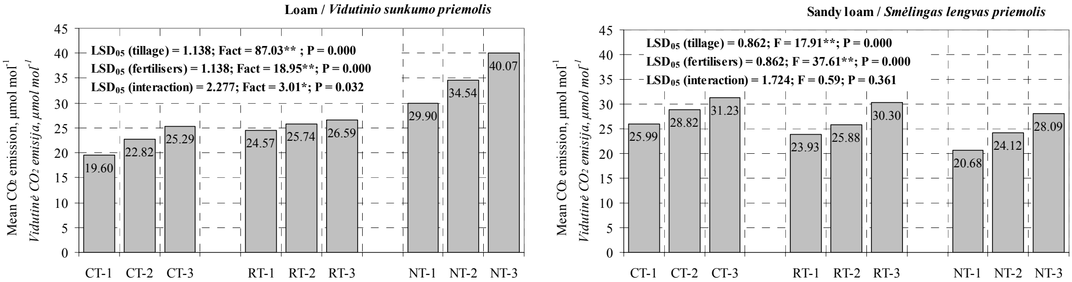

Figure 2. Mean soil CO_2 emission in the soils with loam and sandy loam texture in the 10th year of different tillage-fertilisation management

2 paveikslas. *Vidutinė CO_2 emisija vidutinio sunkumo priemolio bei smėlingo lengvo priemolio dirvožemyje 10-aisiais įvairių žemės dirbimo ir tręšimo sistemų taikymo metais*

Soil organic carbon (SOC). A good farming practice can decrease CO_2 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.

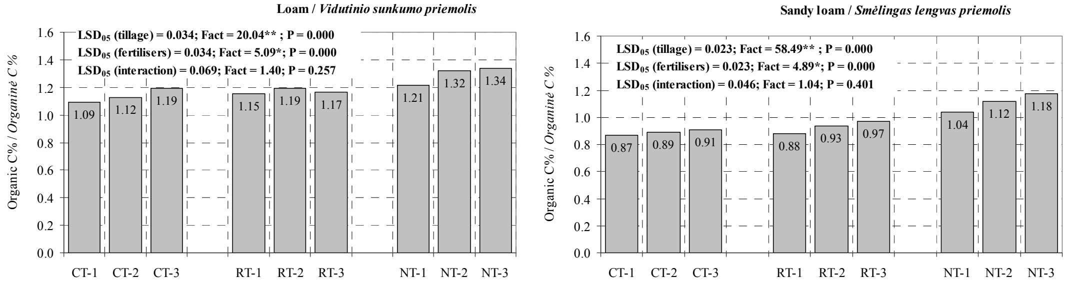

Figure 3. Soil organic carbon in the soils with loam and sandy loam texture in the 10th year of different tillage-fertilisation management

3 paveikslas. *Dirvožemio organinė anglis vidutinio sunkumo priemolio bei smėlingo lengvo priemolio dirvožemyje 10-aisiais įvairių žemės dirbimo ir tręšimo sistemų taikymo metais*

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 1st trial by 7–9% and in the 2nd 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_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 10th year of different tillage-fertilisation management

2 lentelė*. Santykis „Dirvožemio organinės anglies (DOA) kiekis 0–10 cm sluoksnyje / DOA 10–20 cm sluoksnyje" vidutinio sunkumo priemolio bei lengvo smėlingo lengvo priemolio dirvožemiuose 10-aisiais įvairių žemės dirbimo ir tręšimo sistemų taikymo metais*

Soil texture *Dirvožemio granuliometrinė sudėtis*	Treatments / *Tyrimo variantai*								
	CT-1	CT-2	CT-3	RT-1	RT-2	RT-3	NT-1	NT-2	NT-3
Loam / *Vidutinio sunkumo priemolis*	1.04	1.01	1.02	1.02	1.01	0.98	1.04	0.12	1.10
Mean / *Vidutiniškai*		1.03			1.00			1.09	
Sandy loam / *Lengvas smėlingas priemolis*	1.01	0.98	0.97	0.94	0.99	1.00	1.13	1.17	1.17
Mean / *Vidutiniškai*		0.98			0.97			1.16	

SOC influence on soil CO_2 emission. Rising content of SOC (from 1.09 to 1.34%) in the soil with loam texture determined sharper increase of CO_2 emission than in sandy loam (Fig. 4).

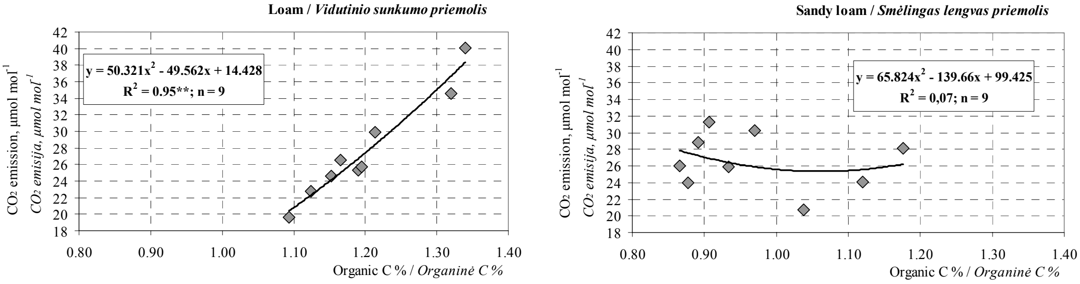

Figure 4. The correlation between SOC content and CO_2 emission in the soils with loam and sandy loam texture in the 10th year of different tillage-fertilisation management

4 paveikslas. ***Dirvožemio organinės anglies kiekio ir CO_2 emisijos koreliacija vidutinio sunkumo priemolio bei smėlingo lengvo priemolio dirvožemyje 10-aisiais įvairių žemės dirbimo ir tręšimo sistemų taikymo metais***

The data revealed that growth of soil organic C content by 0.10% conditioned CO_2 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 CO_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, LSD_{05} = 0.211), sampling date (F_{act} = 77.63**, P = 0.000, LSD_{05} = 0.448) and significant interaction between tillage x sample date was also observed (F_{act} = 2.34**, P = 0.003, 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, LSD_{05} = 0.204) and sampling date (F_{act} = 77.63**, P = 0.000, 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).

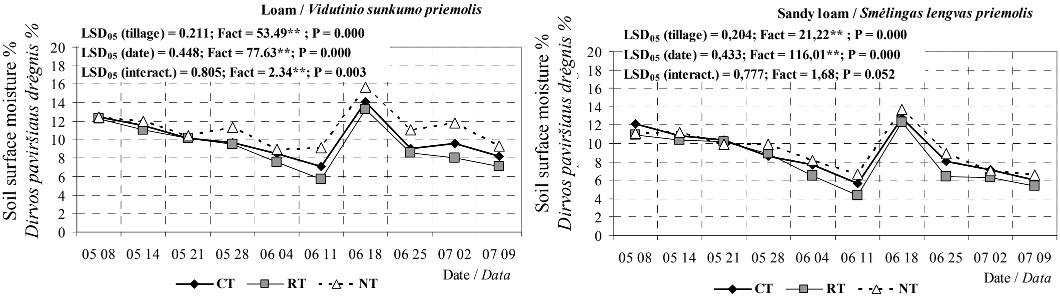

Figure 5. Soil surface moisture content dynamics during active crop growth season in the soils with loam and sandy loam texture in the 10th year of different tillage-fertilisation management

5 paveikslas. *Dirvožemio paviršiaus drėgmės kiekio dinamika aktyviuoju 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 CO_2 emission. Soil CO_2 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 CO_2 flux is not sensitive to temperature. When the moisture level increases, the level of CO_2 exchange rate becomes much more sensitive to temperature. Similarly, at temperatures below 5ºC soil respiration is not sensitive to moisture, but becomes increasingly responsive at higher temperatures.

Our data revealed that in both trials with different texture CO_2 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 CO_2 emission. SMC range from 13.00 to 16.60% in the soil with sandy loam texture conditioned CO_2 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) CO_2 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 CO_2 emission. Importantly that in sandy loam soil CO_2 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 CO_2 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).

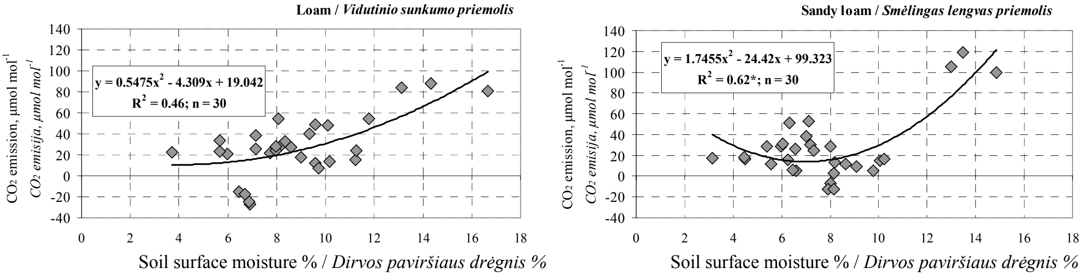

Figure 6. The correlation between SMC and CO_2 emission in the soils with loam and sandy loam texture in the 10th year of different tillage-fertilisation management
6 paveikslas. *Dirvožemio paviršiaus drėgmės kiekio ir CO_2 emisijos koreliacija vidutinio sunkumo priemolio bei smėlingo lengvo priemolio dirvožemyje 10-aisiais įvairių žemės dirbimo ir tręšimo sistemų taikymo metais*

Soil surface temperature. Soil temperature is the most dominant factor in regulating soil CO_2 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 ± 0.11ºC for CT, RT and NT, respectively. In sandy loam soil it was 20.02 ± 0.08, 20.12 ± 0.02 and 20.15 ± 0.06ºC 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 0.5–0.6ºC under NT than under CT, while it did no differ among tillage treatments in the soil with sandy loam texture.

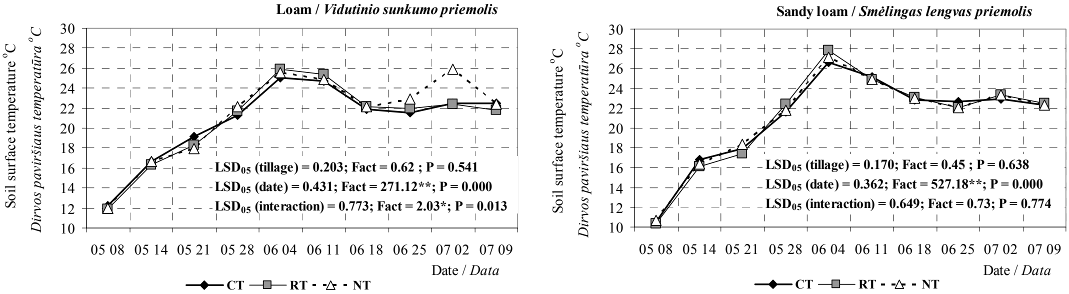

Figure 7. Soil surface temperature dynamics during active crop growth season in the soils with loam and sandy loam texture in the 10th year of different tillage-fertilisation management

7 paveikslas. *Dirvožemio paviršiaus temperatūros dinamika aktyviuoju augalų vegetacijos tarpsniu vidutinio sunkumo priemolio bei smėlingo lengvo priemolio dirvožemyje 10-aisiais įvairių žemės dirbimo ir tręšimo sistemų taikymo metais*

Soil temperature influence on soil CO_2 emission. The correlation between soil surface temperature and CO_2 emission was weak and it confirmed other research conclusions that significant data can be obtained if temperature range is in a wide diapason (from < 5ºC to > 30ºC). Hence, variation of soil temperature from 10 to 23ºC did not significantly influence soil CO_2 emission extent (Fig. 8).

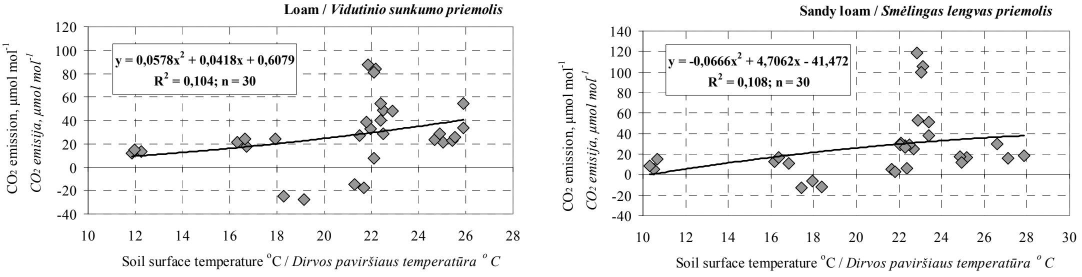

Figure 8. The correlation between soil surface temperature and CO_2 emission in the soils with loam and sandy loam texture in the 10th year of different tillage-fertilisation management

8 paveikslas. *Dirvožemio paviršiaus temperatūros ir CO_2 emisijos koreliacija vidutinio sunkumo priemolio bei smėlingo lengvo priemolio dirvožemyje 10-aisiais įvairių žemės dirbimo ir tręšimo sistemų taikymo metais*

Conclusions

1. Mean CO_2 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 CO_2 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 CO_2 emission in both loam and sandy loam soils. Moderate rates in loam soil increased CO_2 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 CO_2 emission on average by 12% and high rates by 27% compared to emission in unfertilised soil.

3. Growth of SOC by 0.10% conditioned CO_2 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 CO_2 emission expansion only by 0.34 μmol mol^{-1}. Moreover, low content of SOC (<1.00%) have weak and uncertain influence on CO_2 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 CO_2 emission. SMC range from 13.00 to 16.60% in the soil with sandy loam texture conditioned CO_2 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 CO_2 emission extent.

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ORGANINĖS ANGLIES, DRĖGMĖS IR TEMPERATŪROS ĮTAKA DIRVOS PAVIRŠIAUS CO_2 EMISIJAI 10-AISIAIS ĮVAIRIŲ ŽEMĖS DIRBIMO IR TRĘŠIMO SISTEMŲ TAIKYMO METAIS

D. Feizienė, G. Kadžienė

Santrauka

Tyrimo tikslas – nustatyti CO_2 emisiją iš dirvos paviršiaus įvairiais augalų vegetacijos tarpsniais lauko sąlygomis bei tai, kaip minėtą emisiją veikia žemės dirbimas, tręšimas bei jų sąveika dešimtaisiais įvairių žemės dirbimo ir tręšimo sistemų taikymo metais. Tyrimo uždaviniai – nustatyti, ar yra ryšys tarp CO_2 emisijos bei dirvos drėgmės kiekio ir dirvos temperatūros. Nustatyta, kad vidutinio sunkumo priemolio dirvoje, kur taikyta tiesioginė sėja (NT), 10 savaičių trukmės tyrimų laikotarpiu vidutinė CO_2 emisija buvo 54 ir 36 % didesnė nei dirvoje, kur taikytas tradicinis (CT) ir supaprastintas (RT) žemės dirbimas. O smėlingo priemolio dirvoje, taikant tiesioginę sėją (NT), vidutinė CO_2 emisija buvo 15 ir 9 % mažesnė nei žemę dirbant tradiciniu (CT) bei supaprastintu būdu (RT). Trąšų normų didinimas (visų pirma N trąšų) CO_2 emisiją didino ir vidutinio sunkumo priemolio, ir smėlingo priemolio dirvožemyje. Vidutinio sunkumo priemolio dirvožemyje tręšiant vidutinėmis trąšų normomis CO_2 emisija vidutiniškai padidėjo 12 %, o tręšiant didesnėmis trąšų normomis – 24 %, palyginti su dešimt metų netręšta dirva. Trąšų įtaka CO_2 emisijai buvo panaši ir smėlingo priemolio dirvožemyje. Tręšiant vidutinėmis trąšų normomis CO_2, emisija padidėjo vidutiniškai 12 %, o tręšiant didesnėmis normomis – 27 %, palyginti su netręšta dirva. Dirvožemio organinės anglies (SOC) kiekio padidėjimas 0,10 % lengvo priemolio dirvožemyje sąlygojo CO_2 emisijos padidėjimą 0,82 μmol mol^{-1}. Tačiau smėlingo priemolio dirvožemyje toks pat SOC kiekio padidėjimas CO_2 srautą padidino tik 0,34 μmol mol^{-1}. Be to, mažas SOC (<1,0 %) kiekis sąlygojo nedidelę CO_2 emisiją iš dirvožemio. Viršutiniame dirvos sluoksnyje didėjant drėgmės kiekiui CO_2 emisija taip pat didėjo. Vienodas drėgmės kiekis įvairios granuliometrinės sudėties dirvožemiuose nevienodai veikė ir CO_2 emisiją. Dirvožemio drėgniui esant nuo 13,00 iki 16,60 %, CO_2 emisija smėlingo priemolio dirvožemyje buvo 28 % didesnė nei lengvame priemolyje. Dirvožemio temperatūros pokyčiai nuo +10 iki +23 °C neturėjo esminės įtakos CO_2 emisijai iš dirvožemio.

Reikšminiai žodžiai: CO_2 emisija, žemės dirbimas, tręšimas, dirvožemio organinė medžiaga, temperatūra, drėgmė.