ORIGINAL SCIENTIFIC PAPER

Soil fluxes of carbon dioxide in winter wheat (*Triticum aestivum* L.) agroecosystem

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Abstract
The increasing release of greenhouse gasses from soil to the atmosphere is an important contributor to global climate change. A research study was conducted to compare data of carbon dioxide emission from soil during winter wheat vegetation in 2012 and 2016. Also, the relationships between soil CO_2 emissions, agro-ecological factors, and N fertilization were determined. The soil CO_2 emissions were higher in 2012 compared to 2016 due to the higher temperature during summer period. The lower precipitation in 2012 did not reduce the soil respiration. Statistical analyses determined that the same N fertilization treatments significantly differed between studied years in I, II, IV, VI treatment. The observed differences among treatments in soil CO_2 emissions show that the addition of N fertilizers increased soil respiration.

Key words: CO_2 flux, soil temperature, soil moisture, vegetation

Introduction
Including all of the problems that the humanity is facing on a daily basis, climate change caused by the increase of greenhouse gas emissions, represents one of the major problems today (Mohammed et al., 2020). In many agricultural regions, including Croatia, climate trends have been fairly rapid (Galić et al., 2020). The three largest individual contributors to global warming are CO_2, CH_4, and N_2O. The agricultural sector, including the agricultural activities also represents a source of greenhouse gasses. Depending on how they are managed, soils have the capacity to generate or store greenhouse gases. Thus, many scientists have contributed in study of the factors which influence CO_2 production and emissions rates from the soil. Emissions are released because of respiration of soil microorganisms and plant roots, microbial decay and burning of plant residue (Raich and Tufekcioglu, 2000; Smith et al., 2008). Furthermore, soil properties including soil temperature, soil moisture, and soil organic matter also affect the CO_2 emissions (Smith et al., 2008; Bilandžija et al., 2014). Recently, the greenhouse gas emissions from different types of agricultural activities including irrigation, tillage, soil amendments and fertilization have been estimated in many studies (Bilandžija et al., 2016; Galić et al., 2019).
This study aimed to measure, analyze, and compare data of carbon dioxide emission from soil obtained in 2012 and 2016 during winter wheat vegetation. Also, the goal was to analyze the relationships between soil CO_2 emissions, agro-ecological factors, and fertilization.

Materials and methods
Site description with experimental design and cover crop
The study area with 10 different fertilization treatments is located in Popovača in the Western Pannonian sub-region of Croatia (N 45° 33' 21.42", E 16° 31' 44.62"). The soil type is classified as district Stagnosols (IUSS Working group, WRB 2015). Soil texture of arable

topsoil was defined as loam (Šestak et al., 2019). Soil physical and chemical properties are described in Mesić et al. (2011). Each trial treatment has a dimension of 30 × 130 m^2 including blank space. The distance between treatments was 2 m by each side, as well as between 4 replicates. 10 fertilization treatments were: I) control treatment; II) 0 kg N ha^{-1}+P+K; III) 100 kg N ha^{-1}+P+K; IV) 150 kg N ha^{-1}+P+K; V) 200 kg N ha^{-1}+P+K; VI) 250 kg N ha^{-1}+P+K; VII) 250 kg N ha^{-1}+P+K+ 20 t ha^{-1} of solid farmyard mixed manure; VIII) 250 kg N ha^{-1}+P+K+ 40 t ha^{-1} of solid farmyard mixed manure; IX) 300 kg N ha^{-1}+P+K and X) black fallow. The fertilization with phosphorus (P) and potassium (K) was uniform for all treatments (120 kg ha^{-1} for P and 180 kg ha^{-1} for K).
The cover crop at the experimental plot in investigated 2012 and 2016 was winter wheat (*Triticum aestivum* L. – Srpanjka).

Table 1. Dates of winter wheat sowing and harvesting

Triticum aestivum L.	**2012**	**2016**
Seeded	05.11.2011.	12.11.2015.
Harvested	11.07.2012.	09.07.2016.

Measurements of soil CO_2 concentration and agro-ecological factors

Field measurements of soil CO_2 concentrations were conducted once per month during the vegetation season except in some winter months when measurement was not possible considering unfavorable weather conditions (e.g. to wet, frozen soil, snow cover). Seven measurements of soil CO_2 concentrations were conducted during the investigated 2012, and ten measurements during the investigated 2016, in three repetitions on each of 10 treatments. Measurement of soil CO_2 concentrations were done by in situ closed static chamber method with portable infrared detector of carbon dioxide (Galić et al., 2020), where the soil carbon dioxide flux was calculated according to Bilandžija et al. (2014). Air temperature (°C), relative air humidity (%) and air pressure (hPa) were measured with the Testo 610, 2011 and Testo 511, 2011. Soil temperature, soil moisture and electroconductivity were measured with instrument IMKO HD2 – probe Trime, Pico64, 2011 at 10 cm depth near each chamber on each measurement date.

Data analysis

SAS software (version 9.1.3.) was used for statistical analyse of the data. Variability between years on each treatment was evaluated with analysis of variance (ANOVA) and tested with Fisher's least significant difference procedure. In all statistical tests the significance level was 5 %.

Results and discussion

Meteorological conditions

Climate of study area is continental, with an average annual air temperature of 10.6 °C and average annual precipitation amount of 865 mm, in the reference period 1961. – 1990. (Galić, 2019). According to the Lang´s rain factor, the reference period was characterized by a humid climate (Lf=82). In investigated years, average annual temperature and average annual precipitation amount was as follows: 2012 (12.4°C, 811 mm, Lf=65.3—semiarid climate), 2016 (12.1 °C, 1024 mm, Lf=84.5—semihumid climate) (Gračanin, 1950). Average air temperature of the growing season 2012 was 1.8 °C higher compared to reference period as well as 2016 (1.5 °C). Difference in precipitation amounts is also determined between studied 2012/2016 and 1961–1990 average. In the terms of the annual amount of total precipitation, investigated 2012 was very similar to the reference period (7 % less precipitation occurred in the 2012 compared with the reference period). In 2016 occurred 18

% more precipitation compared to the reference period. In 2012 and 2016 the high variability and extremes in the amount of precipitation between the months was noted.

Contribution of agro-ecological factors and vegetation to soil CO_2 flux

Average monthly agro-ecological factors and daily CO_2 flux in 2012 and 2016 were in the range, respectively: soil temperatures 14.2–39.0 °C and 17.6–37.7 °C; soil moisture 11.1 %–34.6 % and 19.7 %–34.1 %; average daily soil CO_2 flux 0.7–85.3 kg ha^{-1} day^{-1} and 1.9–54.3 kg ha^{-1} day^{-1} (Figure 1 (a) and (b)). Average monthly CO_2 flux ranged from 6.5–53.4 kg ha^{-1} day^{-1} for 2012 and 2.9–37.9 kg ha^{-1} day^{-1} for 2016. Numerous studies have investigated the influence of soil temperature and soil moisture on the GHG emissions (Galić et al., 2019; Ray et al., 2020). In Zhang et al. (2014) research, soil temperature (0-5 cm depth) and soil moisture (0-20 cm) combined together explained 55-70 % of soil CO_2 emissions, with root interference, and 62-78 % without root interference. In this research, in year 2012, there was no correlation between average CO_2 fluxes and soil temperatures at 10 cm depth (r=0.01), but average CO_2 fluxes were moderately positively correlated with soil moisture content at 10 cm depth (r=0.46) (Reis et al., 2014). In 2016 average CO_2 fluxes were strongly positively correlated with soil temperatures at 10 cm depth (r=0.56) and soil moisture content at 10 cm depth (r=0.51) (Galić et al., 2019). In Velasco et al. (2013) states that vegetation with corresponding belowground activity, through photosynthesis, removes CO_2 from the atmosphere during the day and releases a fraction of it through respiration. On Figure 1 (a) and (b) we can notice higher CO_2 flux in months where vegetation was present compared with the months without the plant cover. Treatments without plant cover noted the lowest CO_2 flux (Figure 2). The soil CO_2 emissions measured in this study were higher than in Bilandžija et al. (2016) on the same soil type and culture.

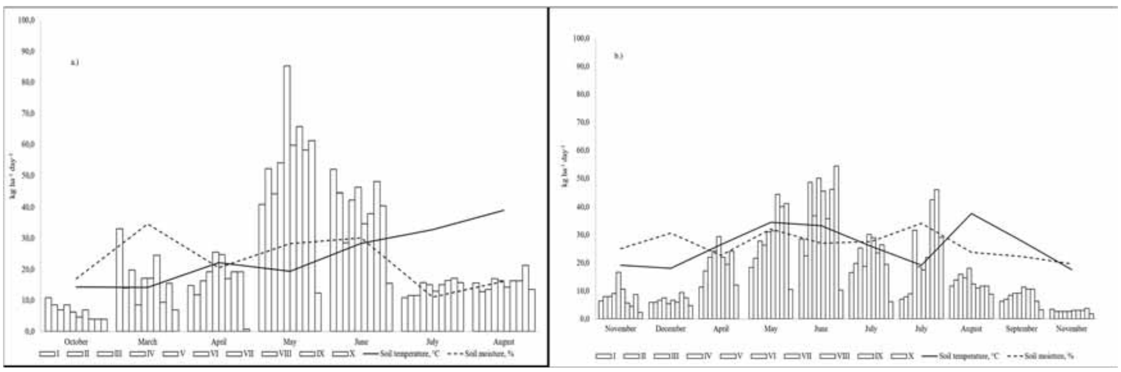

Figure 1 (a) and (b). Average daily values of soil respiration (C-CO_2 kg ha^{-1} day^{-1}) including soil temperature (°C) and soil moisture (%) in 2012 (a) and 2016 (b)

Fertilization and soil CO_2 flux relationship

According to Zhang et al. (2014), changes and releases of soil C and N to the atmosphere are particularly sensitive to the management practices such as fertilization. Figure 2 shows the average annual soil CO_2 flux considering fertilization treatments in 2012 and 2016. In 2012, CO_2 flux ranged from 9.8 C-CO_2 kg ha^{-1} day^{-1} on treatment X (black fallow) to 30.3 C-CO_2 kg ha^{-1} day^{-1} on the treatment V (200 kg N ha^{-1}+P+K). In 2016, CO_2 flux ranged from 7.7 C-CO_2 kg ha^{-1} day^{-1} on treatment X (black fallow) to 21.9 C-CO_2 kg ha^{-1} day^{-1} on the treatment VIII (250 kg N ha^{-1}+P+K+40 t ha^{-1} of solid farmyard mixed manure). This indicates that the black fallow reduces soil CO_2 flux, while fertilization with higher N quantities increases CO_2 flux. Statistical analyses determined that the same fertilization treatments significantly differed between studied years in I, II, IV, VI treatment. Soil CO_2 flux was higher on each treatment during the investigated 2012 compared to the 2016 growing season.

The effects of mineral and organic fertilization on CO_2 emission were studied by Mignon et al. (2011). Obtained results indicated a higher soil respiration rate in organically fertilized soil compared with mineral fertilized soil and control treatments where respiration was lower. After the disposals of organic wastes, increases in soil CO_2 fluxes in agricultural soils have been frequently observed by Ryals and Silver (2013). On the other hand, several studies showed that the replacement of the chemical fertilizer with the organic manure significantly decreased the emission of GHGs (Ryals and Silver, 2013; Liu et al., 2014), indicating the possibility that the organic farming can potentially reverse the agriculture ecosystem from a carbon source to a carbon sink. In this study case, the addition of organic manure had no significant impacts on the soil CO_2 flux in addition to the mineral fertilizers. Thus, the appropriate applications of farmland manure could potentially mitigate the soil CO_2 emissions.

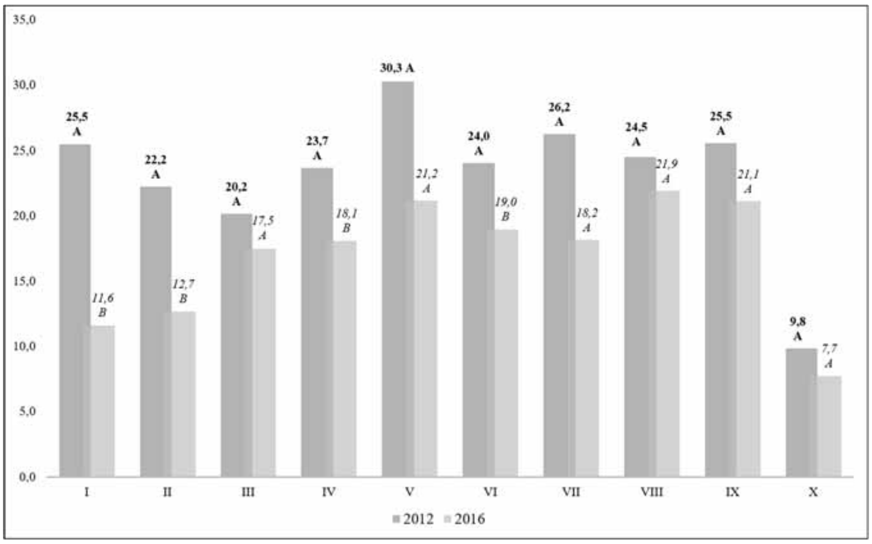

Figure 2. Average annual CO_2 flux (kg ha^{-1} day^{-1}) in 2012 and 2016 considering fertilization treatments *(Mean values marked with the same letter are not significantly different (SAS 9.1 $p < 0,05$)*

Conclusion

Intensification without suitable management and the use of chemical fertilizers has negative implications for the ecosystem and environment. Thus, the study was conducted to measure, analyze, and compare data of carbon dioxide emission from soil obtained in 2012 and 2016 during winter wheat vegetation, and to determine the relationships between soil CO_2 emissions, agro-ecological factors, and fertilization. The soil CO_2 emissions were higher in 2012 compared to 2016 due to the higher temperature during summer period in which the soil respiration is at its peak. The lower precipitation in 2012 did not reduce the soil respiration. The amount of the precipitation was sufficient to keep soil moisture at the level where soil microorganisms and roots can breathe. The soil CO_2 emissions are related to the agro-ecological factors like air temperature and precipitation as those factors are affecting the soil properties tied to soil respiration like soil moisture and temperature. The observed differences among treatments in soil CO_2 emissions show that the addition of N fertilizers increased soil respiration. The addition of solid farmyard mixed manure did not significantly impact the soil CO_2 flux as the manure was applied along with N fertilizer, which might have masked the impacts of the manure. Further research is needed in understanding the impacts of fertilizers on soil respiration in order to develop good agricultural practices that will reduce GHG emissions.

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Emisije ugljičnog dioksida iz tla u agroekosustavu ozime pšenice (*Triticum aestivum* L.)

Sažetak
Sve veće oslobađanje stakleničkih plinova iz tla u atmosferu važan je doprinos globalnim klimatskim promjenama. Istraživanje je provedeno u svrhu usporedbe podataka o emisiji ugljičnog dioksida iz tla tijekom vegetacije ozime pšenice 2012. i 2016. godine. Također, utvrđeni su odnosi između emisije CO_2 u tlu, agroekoloških čimbenika i N gnojidbe. Emisije CO_2 iz tla bile su veće u 2012. u odnosu na 2016. godinu zbog više temperature tijekom ljetnog razdoblja. Niže oborine u 2012. godini nisu umanjile disanje tla. Statističkim analizama utvrđeno je da se tretmani I, II, IV i VI međusobno značajno razlikuju između ispitivanih godina. Uočene razlike između tretmana u emisiji CO_2 iz tla pokazuju da je dodavanje N gnojiva povećalo disanje tla.

Ključne riječi: CO_2 fluks, temperature tla, vlaga tla, vegetacija