Soil & Tillage Research 150 (2015) 30–42

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Soil respiration after tillage under different fertiliser treatments – implications for modelling and balancing

Sebastian Rainer Fiedler [a,*], Uwe Buczko [a], Gerald Jurasinski [a], Stephan Glatzel [a,1]

[a] University of Rostock, Faculty of Agricultural and Environmental Sciences, Justus-von-Liebig-Weg 6, 18059 Rostock, Germany

ARTICLE INFO

Article history:
Received 25 April 2014
Received in revised form 8 December 2014
Accepted 24 December 2014

Keywords:
Soil respiration
Soil organic carbon
Soil CO_2 flux modeling
Tillage
Hot-water extraction
Biogas residues

ABSTRACT

Temperature-driven models of soil respiration (SR) are crucial for estimating C-balances of arable soils. However, model construction may be severely influenced by tillage operations. The impact of tillage on the temperature dependence of SR was studied to reveal the temporal patterns of model quality of temperature-driven SR-models. To obtain SR, CO_2 fluxes were measured with a dynamic chamber technique in treatments of an energy crop rotation amended with biogas residues (BR) and mineral fertiliser (MF). Measurements were performed with short intervals during the first three days after tillage operations, then with extending intervals between measurements up to 35 days after tillage. Additionally, soil concentrations of hot-water extractable organic carbon (HWC) were determined before and during the experiment. Overall, in all treatments individual CO_2 fluxes were affected by the extent of soil disturbance and fertiliser treatment. The highest tillage-induced fluxes where observed after disking in MF treatment. Tillage also induced an immediate increase of HWC, indicating additional labile C and a fast response of microbial activity. However, the change of HWC lasted only one day and approximated the pre-tillage values within a week. Even though BR soil had a higher HWC content, the increased C mineralisation in one repetition of MF suggests that buried plant residues might have a higher influence on SR after tillage than the type of fertiliser. Directly after soil disturbance by tillage it was impossible to construct temperature-driven models for SR in all treatments. Assuming that the coefficient of determination is appropriate with $R^2 \geq 0.5$ and the model quality is good with NRMSE ≤ 0.15, the qualities of the models increased continuously with time, but were unsatisfying for at least two weeks. During this time, SR showed a high sensitivity to changing environmental influences like precipitation and soil moisture or available C for microbial turnover, rather than temperature. The treatment BR showed a less sensitive pattern, which might be attributed to an altered soil structure and microbial activity of soil after long-term application of an organic fertiliser like BR. Therefore, temperature-driven models for the prediction of soil derived CO_2 emissions should be applied carefully for the days and weeks after tillage and verification by measurements in shorter intervals is advisable.

1. Introduction

Soil respiration (SR) is an essential part of the terrestrial carbon cycle. As a large component of ecosystem respiration, SR is the main process of carbon transport from terrestrial ecosystems to the atmosphere (Bond-Lamberty and Thomson, 2010; Chen et al., 2011; Ryan and Law, 2005; Schlesinger and Andrews, 2000). In 2011, 37.8% of the global land area was used for agriculture (FAOSTAT, 2011). Thus, a large part of global SR is affected by agricultural land use (5.2 Mg C ha^{-1} yr^{-1}) (Chen et al., 2010; Raich and Schlesinger, 1992). In general, the composition and mass of three main C-pools control SR: (1) soil organic matter (SOM), (2) dead plant residues and (3) organic substances released by living roots (Kuzyakov, 2006). The contributions of these sources vary throughout the year (Atarashi-Andoh et al., 2012), depending mainly on soil temperature and moisture (Lloyd and Taylor, 1994; Raich and Schlesinger, 1992; Wang et al., 2000), affecting microbial activity (Álvaro-Fuentes et al., 2007; Borken et al., 2003; Kim et al., 2012).

In the long term, SR equals the total CO_2 efflux from biogenic sources in bare soils which is measured at the soil surface (Kuzyakov, 2006; Raich and Schlesinger, 1992). However, when short time intervals are considered, total CO_2 efflux may be much larger than SR,

* Corresponding author. Tel.: +49 381 4983228; fax: +49 381 498 3222.
E-mail addresses: sebastian.fiedler@uni-rostock.de (S.R. Fiedler), uwe.buczko@uni-rostock.de (U. Buczko), gerald.jurasinski@uni-rostock.de (G. Jurasinski), stephan.glatzel@univie.ac.at (S. Glatzel).
[1] Now at University of Vienna, Department of Geography and Regional Research, Althanstr. 14, Vienna 1090, Austria.

http://dx.doi.org/10.1016/j.still.2014.12.015
0167-1987/

e.g., due to short-term physical CO_2 release induced by management activities like tillage (Calderon and Jackson, 2002; Jackson et al., 2003; Rochette and Angers, 1999). Here, we will use the terms "CO_2 efflux" and "SR" to distinguish between the tillage-induced CO_2 emission and the permanent CO_2 emission that is largely constituted by SR. The CO_2 efflux of agricultural soils is influenced by various management factors, such as type and amount of fertilizer (Rochette and Gregorich, 1998; Sänger et al., 2010), cropping system (Ceschia et al., 2010; Osborne et al., 2010), tillage system (Ciais et al., 2010; Lopez-Garrido et al., 2009; Reicosky, 1997) and individual tillage operations (Osborne et al., 2010; Reicosky and Archer, 2007). Agricultural tillage operations enhance to a large extent CO_2 emissions from soils (Reicosky et al., 1997; Reicosky and Archer, 2007). Immediately after tillage, there is a sharp increase in soil CO_2 efflux due to the physical release of CO_2, followed by a rapid decrease after a few hours (Álvaro-Fuentes et al., 2007; Calderon and Jackson, 2002; Morell et al., 2010; Reicosky et al., 1997). This instantaneous CO_2 release is caused by gas accumulations in soil clods and aggregates, which are broken up by the tillage operation. After this first degassing, the increase of oxygen availability in the tilled soil promotes microbial activity, resulting in enhanced SR. In contrast to the first instantaneous degassing, the CO_2 efflux resulting from this aerobic microbial activity declines much slower with time (Ellert and Janzen, 1999; Jackson et al., 2003; Reicosky and Archer, 2007). In general, in temperate climate zones the tillage-induced CO_2 release from soil ends after a few days (Ellert and Janzen, 1999; Rochette and Angers, 1999).

Since the decay of SOM and organic residues is the only source of SR on bare soils (Kuzyakov, 2006), the temporal changes of SOC fractions are relevant when considering SR after tillage (Dungait et al., 2012). As carbohydrates like simple sugars and starch are the most easily biodegradable SOC fractions (Dungait et al., 2012; Kalbitz and Kaiser, 2008; Yano et al., 1998), it is supposed that tillage has an impact on the relationship between availability of these fractions and respiration. An appropriate approach to quantify labile C, especially carbohydrates like pentoses, hexoses and polysaccharides, in soil is hot-water extraction (Ghani et al., 2003; Leinweber et al., 1995; Sparling et al., 1998).

Precise information about the impact of management activities on soil CO_2 efflux is needed to estimate carbon budgets and greenhouse gas inventories (Ceschia et al., 2010; Lehuger et al., 2011). This applies especially to agricultural land, due to its diversity in terms of crops grown, rotation, management, soil types, and climatic conditions (Osborne et al., 2010; Smith et al., 2010). Soil CO_2 efflux is commonly measured using chamber-based methods (Gesch et al., 2007; Pumpanen et al., 2004). Measured fluxes are then used to construct models that allow for the estimation of soil CO_2 efflux for the periods between measurement dates (Beetz et al., 2013; Elsgaard et al., 2012). A common approach for modelling soil CO_2 efflux is the use of an exponential function describing its relationship with soil temperature (Lloyd and Taylor, 1994). From a biogeochemical perspective this approach is only valid when the soil CO_2 efflux represents pure SR. The temperature model has to be calibrated against site-specific conditions. This is commonly done using continuous data of temperature and soil CO_2 efflux for the full range of one day, encompassing the lowest and highest soil and air temperatures during the day. However, this approach is feasible only for undisturbed site conditions (especially regarding temperature, soil moisture, and developmental stage of crops). Thus, directly after disturbance of the soil by tillage, a relationship between temperature and soil CO_2 efflux cannot be established using this approach and consequently, the temperature models for soil CO_2 efflux, which are based on data recorded on undisturbed soils, cannot be applied immediately after tillage operations. Thus, the altered CO_2 fluxes increase the uncertainty in the modelling of the overall CO_2 balance of crop rotations (Osborne et al., 2010; Zhang et al., 2011a). Until now, some basic approaches have been proposed to quantify the effect of tillage on soil CO_2 efflux. In such models a correlation of SOC decay and SR is assumed and both are modeled using a first order kinetic approach (Ellert and Janzen, 1999; La Scala et al., 2008, 2009; Teixeira et al., 2010). However, the parameters needed for such models are soil and site specific and are a priori unknown for a given site. This hampers the application of such approaches for in situ observations.

It is of great practical significance to know the duration of the "disturbed" state with CO_2 effluxes governed by the soil tillage operation in order to (1) estimate the amount of CO_2 that is released after the tillage operation, and (2) determine when the estimation of CO_2 efflux with a temperature-driven model can be resumed after tillage. The use of different fertiliser types with their different proportions of organic matter leads to different emissions from soil. The emissions arising from the use of novel fertilisers like biogas residues (BR) are of particular interest (Eugster et al., 2010; Sänger et al., 2010). This may also affect the emissions after tillage. We are not aware of any studies dealing (1) with tillage induced CO_2 emissions from arable fields fertilised with BR and (2) with the recalibration of temperature driven models of SR after soil disturbance. To overcome this shortage, we investigated the extent and temporal evolution of CO_2 emissions under different fertiliser regimes as affected by tillage operations. This is important in order to establish and to (re-) calibrate models of SR to obtain carbon balances of agricultural sites.

2. Material and methods

2.1. Study site

The study site is located in northeast Germany's terminal moraine of the Weichselian glacial period at 53°48′35″N and 12°4′20″E (elevation 10 m) within a gently rolling relief. The soil is a stagnic luvisol (IUSS Working Group WRB, 2006) with loamy sand texture overlying bedrock of till. According to our own measurements the top soil (0–30 cm) had an organic carbon content of 1.02% (measured with CN-analyser "vario MAX", Elemtar, Hanau, Germany), pH of 6.8 (measured in H_2O with pH meter "CX-401", Elmetron, Zabrze, Poland) and bulk density of 1.45 g cm^{-3} (measured on 250 cm^3 soil cores). The climate is characterized by maritime influence with an annual average temperature of 8.5° C and an annual total precipitation of 569.4 mm for the 30 year period from 1982 until 2011 (LFA 2012). The experiment was conducted on a field which had been cultivated with a rotation of energy crops for the past seven years. The crop rotation consisted of maize (*Zea mays* L.), rye (*Secale cereale* L.), sorghum (*Sorghum bicolor* (L.) Moench), winter triticale (× *Triticosecale* Wittm.), ryegrass (*Lolium perenne* L.) and winter wheat (*Triticum aestivum* L.) and was cultivated to produce feedstock for biogas production. The size of the experimental plots was 4.5 by 22.5 m.

Five days following the whole-plant harvest of winter wheat (27 July 2012), the field site was prepared for mustard as catch crop with the following management measures: liming (1 t CaO ha^{-1}) and deep loosening with deep loosener "Amazone TL" (40 cm depth) plus disking with disk harrow "Väderstad Carrier 300" (up to 10 cm depth) on the first day (1 Aug 2012). On the second day (2 Aug 2012), the preparation was continued with mouldboard ploughing and packing with reversible plough "Överum CX 490" plus packer (30 cm depth). Subsequently, drilling of mustard as catch crop with seedbed combination "Lemken System-Kompaktor S" (8 cm depth) concluded the tillage (Table 1). The mustard emerged on 8 Sep 2012.

Three fertiliser treatments were compared: (1) mineral fertiliser (MF), (2) biogas residue (BR) and (3) a mixture of 50%