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What actually controls the minute to hour changes in soil carbon dioxide concentrations?

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ABSTRACT

The monitoring of carbon dioxide (CO_2) in anthrosol showed CO_2 concentrations ($[CO_2]$) up to 10,000 ppmv in dependence on external conditions. During dry season, $[CO_2]$ oscillated in a diurnal cycle with mean amplitude about 1520 ppmv. $[CO_2]$ was strongly positively correlated with soil temperature, $T_{(soil)}$, (correlation coefficient $r \sim 0.92$). However, $T_{(soil)}$ lagged behind $[CO_2]$ by 55 min. Due to the phase shift, the $[CO_2]/T_{(soil)}$ dependence showed typical hysteresis loop with a counterclockwise rotation. A simple model of two oscillating signals indicates that this direction of rotation would mean violation of causality. The lag of $T_{(soil)}$ behind $[CO_2]$ would be conceivable if heat and CO_2 were transported to the point of measuring from soil top layer and the CO_2 transport was faster than heat transport. An effect of photosynthesis on $[CO_2]$ via root respiration is not too probable at dry season because it works on a longer time scale. Nevertheless, the correlation of $[CO_2]$ with the illumination (IL) in spectral range of 380–720 nm did not rule out such possibility (correlation coefficient $r = 0.63$ at 4-hour lag of $[CO_2]$ behind IL).

Wet season was simulated by artificial soil sprinkling: adding water to soil induced the strong/immediate increase of $[CO_2]$ which was attributed to enhanced heterotrophic respiration. The dependence $[CO_2] = f(WEx)$ where WEx is water excess in L m^{-2} was almost linear, but its slope increases exponentially with temperature. Based on this finding, the relation $S_H(z) = b_1 \times \exp(b_2 \times T_{(soil)}(z) / T_0) \times (\theta(z) / \Phi) + b_3$ (where $S_H(z)$ is heterotrophic respiration [mol m^{-3} s^{-1}], $T_{(soil)}(z)$ is soil temperature [K], T_0 is standard temperature [K], $\theta(z)$ is moisture [m^3 m^{-3}], Φ is soil total porosity [m^3 m^{-3}], z is vertical coordinate, b_1, b_2, b_3 are parameters) was proposed. A participation of root respiration on immediate fluctuation of $[CO_2]$ is less probable. This would be possible only in case of pressure propagation through plant xylem/phloem system.

1. Introduction

Soil carbon dioxide (CO_2) is an important component of carbon cycle (e.g., Xu and Shang, 2016). The CO_2 itself is frequently associated with current climate changes (Davidson and Janssens, 2006; Smith, 2012). In this context, the effluxes of CO_2 from soils into external atmosphere are broadly investigated (e.g., Maier et al., 2011; Oertel et al., 2016). However, the CO_2 concentrations in soil air are equally important. In addition to constituting the concentration gradient driving the efflux, CO_2 partial pressures (P_{CO2}) control the hydrochemistry of percolating waters. Soil air P_{CO2} increases the water aggressiveness and contributes to rock weathering that represents a significant sink of atmospheric/soil CO_2 (Suchet et al., 2003; Moquet et al., 2011). Limestone karstification plays an especial role (Faimon et al., 2012; Pracný et al., 2016; Zeng et al., 2016). Five main sources of the soil CO_2 may be distinguished: (1) root respiration, (2) rhizomicrobial respiration, (3) microbial respiration of dead plant residues, (4) basal respiration by microbial decomposition of soil organic matter (SOM), and (5) additional CO_2 derived from SOM (so called rhizosphere priming effect) (e.g., Kuzyakov and Gavrichkova, 2010). Whereas the first source represents a respiration of autotrophs, the remaining four sources are linked to a respiration of heterotrophs (microbial respiration). The studies on partitioning of soil respiration showed that the contribution of root and rhizomicrobial respiration (root-derived CO_2) represent 10–90% of the total CO_2 efflux into exterior depending on studies and ecosystems (Hanson et al., 2000). Whereas the soil heterotrophic organisms' activity is proportionate to the decomposition of soil C, the CO_2 resulting from root and rhizosphere corresponds to consumption of assimilates supplied by above ground plants' organs (Horwath et al., 1994). It is believed that soil CO_2 concentrations and respiration are controlled by temperature and moisture if considering abiotic variables (e.g., Davidson et al., 1998; Jassal et al., 2005; Chang et al., 2014).

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However, there is growing evidence that soil CO_2 is at least partly controlled by photosynthesis (e.g., Tang et al., 2005; Bahn et al., 2009; Kuzyakov and Gavrichkova, 2010; Han et al., 2014).

The purpose of the article was to summarize current knowledge, to critically evaluate the influence of the individual variables generally believed to be controlling or to point out some contradictions in generally accepted interpretations. The work itself has focused on (1) the effects of relevant variables on diurnal variations in soil CO_2 concentrations during dry periods and (2) the impact of water on CO_2 fluctuations during wet period (simulated by artificial sprinkling of soil surface). We believe that the new data resulting from detailed monitoring with extremely short logging step followed by an extensive discussion based on an advanced conceptual model could bring a better insight into the problem of soil CO_2.

2. Methods

2.1. Site of study

The site of study (Central Europe, Czech Republic, South-Moravian region, 49°20′19″N 16°39′60″E) belongs to temperate climate zone. In the region, the long-term average of annual temperatures is 8.3 °C (CHMI, 2016a); the long-term average of annual precipitations is 543 mm (CHMI, 2016b). The study site was chosen for favorable local and logistic conditions. It represents a 15 × 25 m flat open area overgrown with grass.

2.2. The soils

The soil was plaggic anthrosol (IUSS Working Group WRB, 2015) that were formed from a natural soil modified by cultivating (tilling) 30–35 years ago. The original soil-forming substrate was regolith of underlying granitic rock (biotite to hornblende-biotite granodiorite of Brno Massif, type Blansko). Depth of the soil profile ranged from 20 to 30 cm. The soil texture was sandy loam (USDA soil taxonomy) consisting of 0.2 to 0.9% clay (below 2 μm), 9.6 to 24.4% silt (2–50 μm), and 55.1 to 67.8% sand (50–2000 μm). The soil organic carbon ranged from 57.7 to 65.8 g kg^{-1} as estimated from the loss on ignition at 550 °C for 7 h, (see, Schnitzer and Hoffman, 1966). The soil bulk density ranged from 1.11 to 1.37 g cm^{-3}. The soil did not contain any carbonates. Anthrosol shows some advantages for CO_2 study: it is relative homogenous across the soil profile and has reproducible properties and behavior.

2.3. Vegetation

The vegetation covering the studied site consisted of grasses/herbs. There were identified: *Festuca* L., *Taraxacum* L., *Bellis* L., *Poa* L., *Achillea millefolium* L., *Plantago major* L., *Plantago lanceolata* L., *Trifolium repens* L., *Geranium* L., *Oxalis corniculata* L., *Glechoma hederacea* L., *Malva neglecta* L., and *Potentilla reptans* L. Besides the grasses/herbs, various mosses covered soil surface.

2.4. Monitoring

2.4.1. Monitoring campaigns – schedule

Totally five short monitoring campaigns were conducted at the top of growing cycle in the period from July 20 to October 2, 2016. During this period, the local mean external temperature was 17.4 °C (31 °C maximum, 3 °C minimum) and total precipitation was 80 mm. The campaign #1 focused on CO_2 diurnal variations during 23–28 August 2016. The campaigns #2 and #3 aimed on detailed patterns of the variations were implemented during 21–24 July 2016 and 28–30 September 2016, respectively. The campaigns #4 and #5, respectively, accomplished during 9 September 2016 and 1–2 October 2016 were directed to water impact study.

2.4.2. Monitored variables

Some variables (CO_2 concentrations, temperature/humidity, and barometric pressure) were monitored directly in the soil profile air, in probe holes (ø 2 cm) drilled through the soil profile up to the basement rock (up to 30 cm). Measuring equipment consisted of external data-logger (ALMEMO 2290–4 V5, Ahlborn, Germany) and individual sensors. Geometry of the sensors allowed their placement directly into drill-hole air; into the same depth of 15 cm below the surface. Before the measurement, the sensors were carefully seated in the holes and

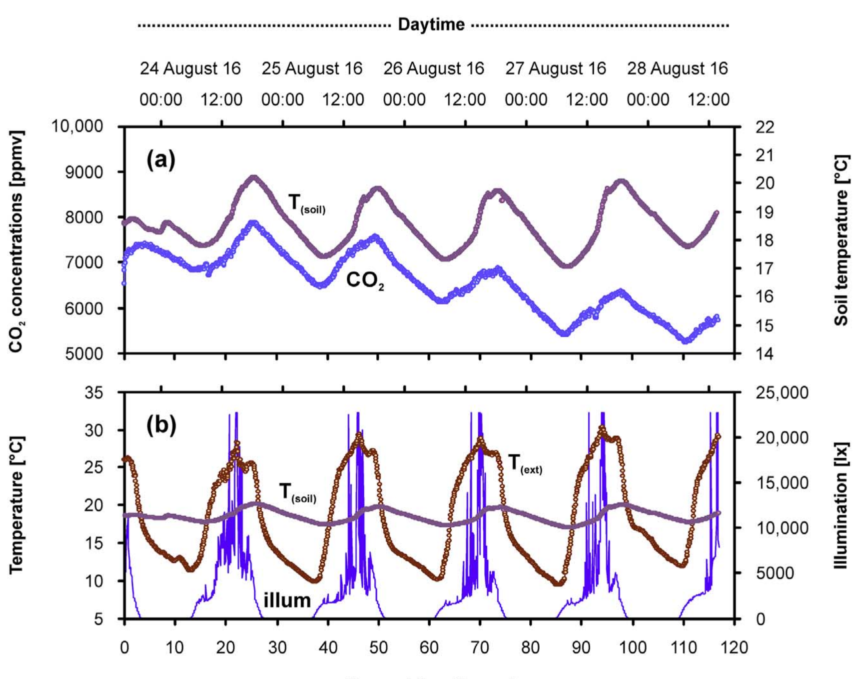

Fig. 1. Diurnal variations (the campaign #1 implemented during 23–28 August 2016): CO_2 concentrations and soil temperature in the soil air (a); soil/external air temperature and illumination (b).