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Spatial and seasonal variations in soil respiration in a temperate deciduous forest with fluctuating water table

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Abstract

Our objectives were to determine both spatial and temporal variations in soil respiration of a mixed deciduous forest, with soils exhibiting contrasting levels of hydromorphy. Soil respiration (R_S) showed a clear seasonal trend that reflected those of soil temperature (T_S) and soil water content (W_S), especially during summer drought. Using a bivariate model (RMSE = 1.03), both optimal soil water content for soil respiration (W_{SO}) and soil respiration at both 10 °C and optimal soil water content (R_{S10}) varied among plots, ranging, respectively, from 0.25 to 0.40 and from 2.30 to 3.60 μmol m^{-2} s^{-1}. Spatial variation in W_{SO} was related to bulk density and to topsoil N content, while spatial variation in R_{S10} was related to basal area and the difference in pH measured in water or KCl suspensions. These results offer promising perspectives for spatializing ecosystem carbon budget at the regional scale.

Keywords: Soil respiration; Soil temperature; Soil water content; Forest soils; Waterlogging; Seasonal variations; Spatial variability

1. Introduction

The evaluation of biospheric fluxes of carbon is of major importance in the context of increasing CO_2 concentration in the atmosphere and the related potential change in climate. Soil respiration is one of the main fluxes in the global carbon cycle, second in magnitude after gross primary production (Raich and Schlesinger, 1992, Schlesinger and Andrews, 2000). Forests are particularly important in the carbon cycle, since they contain, respectively, 80% and 40% of the aboveground and belowground global carbon stocks (Dixon et al., 1994). Carbon sequestration in forested ecosystems often results from a small difference between photosynthetic carbon fixation and ecosystem respiration (Granier et al., 2000, Valentini et al., 2000) and soil respiration in temperate forests represents about 70% of total ecosystem respiration (Granier et al., 2000). Soil respiration corresponds to the efflux of CO_2 at the soil–atmosphere interface. Soil CO_2 efflux depends on biological activities in soil and gas diffusion in the soil pores, and biological activities and gas diffusion may both be influenced by soil and vegetation properties. Respiration of roots and rhizosphere microorganisms (i.e. autotrophic components) is one of the two main CO_2 sources in soil. The second one is microbial and microfaunal activities (i.e. heterotrophic components) associated with the decomposition of both above and below ground litter (leaves, woody debris and roots) and the mineralization of soil organic matter (Hanson et al., 2000).

Soil respiration is known to be highly variable, both in time and space, at different scales. Temporal variations have been described at various time scales, from diurnal to interannual variations (Rayment and Jarvis, 2000; Savage and Davidson, 2001; Subke et al., 2003; Epron et al., 2004a; Scott et al., 2004). The seasonal variability is mostly explained by soil temperature and soil water content in temperate ecosystems (Epron et al., 1999; Buchmann,

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2000). Litter moisture (Keith et al., 1997), rain events (Sotta et al., 2004) and soil rewetting after a drought period (Borken et al., 1999) are among factors that may explain short-term temporal variability of soil respiration.

Large spatial variability has been reported in several studies, which may be explained by biotic and abiotic factors. Biotic factors involved are root density or biomass (Janssens et al., 1998), quantity and quality of organic matter (Rayment and Jarvis, 2000, Epron et al., 2004b), microbial biomass (Lee and Jose, 2003) or vegetation characteristics (Law et al., 2001). Soil texture or porosity may also play a role, by affecting gas diffusion and biological activity (Dilustro et al., 2005).

The effects of the water table fluctuations on both spatial and temporal variability in soil respiration have been poorly documented. Yet, waterlogging of lowland or poorly drained temperate forests may become more abundant because of more abundant precipitation at the high latitudes (IPCC, 2001). Soils that are regularly flooded are known as hydromorphic. About one third of the forested area in France occurs on soil exhibiting water saturation during winter and early spring due to high water table and pronounced decrease in soil water content from last spring to autumn because of summer drought (Levy and Lefèvre, 2001). The physical transport of gas in the soil is modified during and after waterlogging, either because air is replaced by water in the soil pores or because the soil structure is damaged (Baize and Girard, 1995). This limits soil and roots oxygenation, and therefore biological activities, as well as CO_2 diffusion (Dreyer, 1994). In addition, hypoxic and anoxic conditions are thought to favour solubilization of some metal ions up to toxic levels that would also affect biological activities (Pezeshki, 2001). Differences in soil water regimes (depth and duration of waterlogging) among sites may lead to an important spatial variability of soil respiration (Davidson et al., 1998).

The first objective of the present paper was to determine both spatial and temporal variations in soil respiration on nine plots of a mixed deciduous forest, with soils exhibiting contrasting levels of hydromorphy. Two plot-dependent parameters (i.e. optimal soil water content for soil respiration, W_{SO}, and soil respiration at both 10 °C and optimal soil water content, R_{S10}) were computed from an 18-month field experiment during which soil temperature, soil water content and soil respiration were recorded. This study also attempted to identify the underlying determinants of spatial variations in soil respiration in a poorly drained forest. Relationships between the two plot dependent parameters and either biological or physico-chemical characteristics of the plots were assessed.

2. Materials and methods

2.1. Studied area and experimental plots

The study was conducted in a temperate forest (state forest of Chaux, Jura country, Eastern France, 47°07′N; 5°42′E, mean elevation 250 m). A mixed broadleaved mature forest of about 205 km^2 is situated on acidic and hydromorphic soils developed on alluvial stones covered with a fragipan, forming a waterproof layer. Average annual precipitation and air temperature are 950 mm and 10.3°C over the past 30 years, and there are an average of 95 days with daily minimum temperatures below freezing (0 °C) (data Météo France).The main trees species are *Quercus petraea* and *Quercus robur*, *Carpinus betulus*, *Fagus sylvatica*, *Betulus verrucosus*, *Populus tremula*. Acidophilic mosses, like *Leucobrium glaucum*, and swamp herbaceous species like *Ranunculus flammula*, *Deschampia cespitosa* or *Molinia caerulea* are well represented in the understorey vegetation. The understorey vegetation is, however, rather sparse.

Table 1
Depths of the transitional zone (cm) between two successive soil horizons in the nine studied plots as observed from 1 m depth soil cores

Plot	P1	P2	P3	P4	P5	P6	P7	P8	P9
A11-A12	4	5	5	4	3	3	5	5	2
A12-E	10	19	15	10	11	9	12	18	7
E-Btg	38	39	31	28	31	23	26	35	27
Rust-blue grey coloured mottled zones	56	64	50	50	63	40	46	48	50

Nine plots (4 m × 4 m) were delimited within an area of 230 ha. The forest floors and the soils were similar in all plots with their humus layers classified as eumull to mesomull and the soils classified as pseudogleyic luvisol according to the F.A.O. classification (World Reference Base for Soil Resources, FAO WRB, 1994). At the end of the study (November 2004), a 1-m deep soil core was excavated from the middle of each plot for soil profiles description. Plots differed in the thickness of the A11 horizon (from 2 to 5 cm) and in the depth of the transitional zone among successive horizons (from 9 to 19 cm for the A12-E transition and from 23 to 39 cm for the E—Btg transition, Table 1). Within the Btg horizon, transitions depth between a rust-coloured mottled zone and a blue-grey one ranged from 35 to 63 cm.

The level of the water table was monitored twice a month during 2 years using two piezometer tubes (0.5 m depth and 1 m depth, respectively) that were installed in three of the nine plots. Tubes were slotted the whole length.

2.2. Soil temperature, water content and respiration

Soil respiration (R_S) was measured by a closed dynamic system, composed from a portable infrared gas analyser (EGM4, PPsystems, Hitchin, UK), connected to a soil respiration chamber (SRC1, PPsystems, Hitchin, UK). Measurements were conducted during the day, from about 08:00 to 17:00, with a time lag of 56 to 72 s for each measurement. The problem due to uneven ventilation in the chamber that was previously reported (Le Dantec et al.,