

This discussion paper is/has been under review for the journal Biogeosciences (BG).
Please refer to the corresponding final paper in BG if available.

Interdependencies between temperature and moisture sensitivities of CO₂ emissions in European land ecosystems

C. Gritsch, M. Zimmermann, and S. Zechmeister-Boltenstern

Department of Forest and Soil Sciences, Institute of Soil Research, University of Natural Resources and Life Sciences, Vienna, Austria

Received: 2 February 2015 – Accepted: 8 February 2015 – Published: 16 March 2015

Correspondence to: C. Gritsch (christine.gritsch@boku.ac.at)

Published by Copernicus Publications on behalf of the European Geosciences Union.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



Abstract

Soil respiration is one of the largest terrestrial fluxes of carbon dioxide (CO₂) to the atmosphere. Hence, small changes in soil respiration rates could have large effects on atmospheric CO₂. In order to assess CO₂ emissions from diverse European soils under different land-use and climate (soil moisture and temperature) we conducted a laboratory incubation experiment.

Emission measurements of carbon dioxide under controlled conditions were conducted using soil monoliths of nine sites from the ÉCLAIRE flux network. Sites are located all over Europe; from the UK in the west to the Ukraine in the east; Italy in the south to Finland in the north and can be separated according to four land-uses (forests, grasslands, arable lands and one peatland). Intact soil cores were incubated in the laboratory at the temperatures 5, 10, 15, 20, and 25 °C in a two factorial design of five soil moisture levels (5, 20, 40, 60, 80 (100) % water filled pore space, WFPS), before analysed for CO₂ fluxes with an automated laboratory incubation measurement system.

Land-use generally had a substantial influence on carbon dioxide fluxes, with the order of CO₂ emission rates of the different land-uses being grassland > peatland > forest/arable land ($P < 0.001$). CO₂ efflux responded strongly to varying temperature and moisture content with optimum moisture contents for CO₂ emissions between 40–70 % WFPS and a positive relationship between CO₂ emissions and temperature. The relationship between temperature and CO₂ emissions could be well described by a Gaussian model. Q_{10} values ranged between 0.86–10.85 and were negatively related to temperature for most of the moisture contents and sites investigated. At higher temperatures the effect of water and temperature on Q_{10} was very low. In addition under cold temperatures Q_{10} varied with moisture contents indicating a stronger prospective effect of rain events in cold areas on temperature sensitivity. We found at both coniferous forest sites a strong increase of the temperature sensitivity at a moisture range between 20–40 % WFPS.

Emissions in European land ecosystems

C. Gritsch et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



In our study moisture sensitivity (MS) of CO₂ efflux was calculated as the slope of a polynomial function of second degree. Moisture sensitivities were highest under dry and wet conditions. In addition we found a positive relationship between MS of CO₂ efflux and temperature for both arable lands.

1 Introduction

Most reported impacts of climate change are attributed to warming and/or to shifts in precipitation patterns (IPCC, 2014) which are known to be key drivers for ecosystem functioning and biochemical cycles (Larsen et al., 2011). The temperature sensitivity of organic matter decomposition is of considerable eco-physiological importance, especially in the context of possible climate-change feedback effects (Kirschbaum, 2006). Disagreement exists if carbon stored belowground is transferred via CO₂ emissions to the atmosphere by a warming-induced acceleration of its decomposition (positive feedback to climate change) or if increases of plant-derived carbon inputs to soils exceed increases in decomposition (negative feedback to climate change) (Davidson and Janssens, 2006).

The production of CO₂ in non-calcareous soils originates almost entirely from autotrophic (root respiration) and heterotrophic respiration (microbial decomposition of soil organic matter, SOM). Like all chemical and biochemical reactions, these processes are temperature dependent (Wu et al., 2010) and subject to water content (Davidson and Janssens, 2006; Suseela et al., 2012). Because root respiration has its own short-term temperature dependence (over periods of more than a few hours root respiration can become relatively insensitive to climate, Atkin et al., 2000) it is necessary to separate autotrophic and heterotrophic soil respiration when investigating the effect of temperature and moisture on ecosystem functioning (Baggs, 2006; Kirschbaum, 2006).

The effects of soil temperature on heterotrophic soil respiration are mostly direct and entail a positive correlation between temperature and CO₂ emissions as long as

BGD

12, 4433–4464, 2015

Emissions in European land ecosystems

C. Gritsch et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Emissions in European land ecosystems

C. Gritsch et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



To describe the effect of moisture on soil microbial activity quadratic functions are common (Moyano et al., 2013; Rodrigo et al., 1997). Moyano et al. (2012) calculated moisture sensitivity as the proportional response of soil microbial respiration to a 0.01 increase in soil moisture of a certain unit. Moisture sensitivity showed highest values at dry conditions decreasing progressively with increasing moisture content.

Janssens and Pilegaard (2003) and Qi et al. (2002) expect a positive relationship between temperature sensitivity and moisture content due to the assumption that the effects of soil temperature and moisture are negatively correlated. Thus, soil moisture would be positively correlated with the temperature sensitivity of soil respiration. While Mäkiranta et al. (2009) and Gaumont-Guay et al. (2006) found an actual positive relationship between temperature sensitivity and soil moisture content in their field measurements Peng et al. (2009) describes in a review of 52 papers (all field measurements) a negative correlation between Q_{10} values and mean annual precipitation. However, Curiel Yuste et al. (2004) presented a case study of how the seasonal Q_{10} of soil respiration calculated from field measurements can be decoupled from the temperature sensitivity of heterotrophic soil respiration indicating that the large differences in seasonal Q_{10} do not represent differences in the temperature sensitivity of the soil microbial metabolism.

Land use influences the production and consumption of soil CO_2 emissions through vegetation type (Raich and Tufekciogul, 2000), root density, N input (Skiba et al., 1998) and management (Flechard et al., 2005). Peng et al. (2009) even found differences of Q_{10} values between ecosystem types by comparing field measurements.

In field studies the seasonal development of soil temperature and soil moisture usually is reflected in the seasonal course of soil gas emissions (Schaufler et al., 2010). Authors describe difficulties when investigating the influence of a single climate parameter from seasonal field measurements because confounding factors like N deposition, litterfall and nitrogen availability (Davidson et al., 2000; Pilegaard et al., 2006) co-vary or interact. With these confounding factors, measurements under natural field conditions cannot provide an unbiased estimate of the temperature sensitivity of SOM de-

composition (Kirschbaum, 1995). For field soil CO₂ fluxes, further complications arise from the contribution of autotrophic soil respiration (Schaufler et al., 2010). Laboratory incubations provide the best and least biased basis for estimating the temperature dependence of SOM decomposition (Kirschbaum, 2006). This assumption can be extended to the assessment of soil moisture dependence of heterotrophic soil respiration (Schaufler et al., 2010). The combined effects of temperature and moisture changes are not necessarily additive (Beierkuhnlein et al., 2011; Larsen et al., 2011; Leuzinger et al., 2011). A two-factorial incubation design provides the opportunity to assess temperature and moisture effects independently and to investigate how the two climatic factors affect each other (Schaufler et al., 2010).

To investigate the combined effects of soil temperature and moisture on heterotrophic soil respiration from different land-use types, intact soil cores were taken from four representative land-use types from the ÉCLAIRE flux network, Europe and incubated in the laboratory under varying soil temperature and moisture levels. The main objectives of this study were (1) to determine the influence of soil temperature and moisture on CO₂ efflux, (2) to calculate temperature and moisture sensitivities of CO₂ efflux coming from different land-use types, (3) to investigate the influence of moisture and land-use on temperature sensitivity of CO₂ efflux, and (4) to investigate the influence of temperature and land-use on moisture sensitivity of CO₂ efflux.

2 Material and methods

2.1 Study sites

Emission measurements of carbon dioxide under controlled conditions were conducted using soil monoliths from nine sites from the ÉCLAIRE flux network. Sites are located all over Europe; from the UK in the west to the Ukraine in the east; Italy in the south to Finland in the north. A list of all sites including relevant site information can be found in Table 1. The sites can be separated according to four land-use types (forests,

BGD

12, 4433–4464, 2015

Emissions in European land ecosystems

C. Gritsch et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



grasslands, arable lands and one peatland). Relevant soil characteristics are given in Table 2.

2.2 Sampling and experimental layout

Thirty-three undisturbed soil cores were collected at each of the investigation sites in spring 2012 after weekly-averaged soil temperatures reached 8 °C. This was done to provide comparable conditions across sites with respect to sampling conditions. Soil cores were collected at 6 randomly distributed plots of approximately 10 m² within an overall area of approximately 50 m × 50 m at each site. Six soil samples were collected from each 10 m² plot at 6 spots. The upper 6 cm of the soil was collected in stainless steel cylinders (diameter, 7.2 cm; height, 7 cm). Soil cores were capped and sealed in plastic bags to ensure original conditions and shipped in insulated coolers equipped with ice cartridges to our laboratory in Austria, where they were stored at 4 °C before being used for CO₂ flux measurements. 3 soil cores were used to determine gravimetric water contents. The gravimetric water content was determined for mineral soil by oven drying at 103 °C for three days to a constant weight. These water contents were assumed to be representative for the rest of the soil samples from the same location, so that different water contents for the gas measurements could be established. The real gravimetric water content for each core was determined after gas flux measurements were completed.

Intact soil cores were incubated in the laboratory for 22 h at the temperatures 5, 10, 15, 20, and 25 °C in a two factorial design of five soil moisture levels (5, 20, 40, 60, 80 % water filled pore space, WFPS), before analysed for CO₂ fluxes. To design the experiment realistically moisture levels for the peatland site (UK-AMo) were set between 20–100 % WFPS. To reach the required moisture contents, distilled water was either added to too dry samples, or too moist samples were dried at 4 °C until they reached the required moisture content. The lowest possible moisture content was 5 to 15 % WFPS for soil samples when drying at 4 °C. The second variable, soil temperature, was set by controlling the incubator to the desired temperature. Starting with 5 °C

the temperature was increased every day in 5 °C steps up to an end temperature of 25 °C. We used 6 replicates for each moisture content in a complete factorial design in which each of the moisture contents was matched with each of the temperatures for all soil cores investigated.

5 From three remaining cores soil characteristics (Table 2) were analyzed. Ammonium and nitrate was quantified according to Hood-Nowotny et al. (2010) using the ration 2.5 g soil : 25 ml KCL solution. Photometric analyses were conducted with a photometer from PerkinElmer® type 2300 EnSpire™. Conductivity was measured with a conducting meter 2F191 (WTW) and pH was measured in 0.01 mCaCl₂, using the ratio
10 10 g soil : 25 mL CaCl₂ solution. The contents of total soil carbon (C_t) and nitrogen (N_t) were determined with elemental analysis (NA-1500 Carlo Erba, Italy; ÖN1998).

2.3 Gas flux measurements

A fully automatic laboratory incubation system was used (Schindlbacher, 2004) to measure CO₂ flux rates. The system analysed CO₂ fluxes with an open flow system using
15 a PP SYSTEMS WMA-2 (Amesbury, MA, USA) infrared CO₂ analyser. Twenty-four modified Kilner jars were placed in a temperature-controlled incubator and connected to the instruments by Teflon tubes. Two of the chambers in the incubator were empty and served as control chambers for the gas measurements. The incubation chamber was flushed constantly with compressed ambient air (1.0 L min⁻¹). The air sampling
20 period in each test chamber was 6 min and of each reference chamber 4 min. A steady state was achieved after approximately 4 min in the test chambers and 2.5 min in the reference chambers (Schindlbacher, 2004). Gas flux rates were calculated based on gas concentration changes over time according to Schindlbacher (2004) and mean values are shown with standard errors (SE).

25 To examine the temperature and moisture sensitivity of heterotrophic soil respiration, regression analyses were conducted using the equations $R(T) = R_0 \cdot e^{aT + bT^2}$

BGD

12, 4433–4464, 2015

Emissions in European land ecosystems

C. Gritsch et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



(Tuomi et al., 2008) for temperature–CO₂ efflux relations and $R(M) = R_0 + aM + bM^2$ for moisture–CO₂ efflux relations.

To investigate how moisture content, temperature and land-use influence moisture sensitivity relative CO₂ values (relative to the CO₂ efflux of the lowest moisture content) were calculated to exclude the temperature contribution from the absolute CO₂ values. Moisture sensitivity was calculated as the slope of a polynomial function of second degree which was fitted over the relative CO₂ values. This has been done for each temperature and site investigated.

2.4 Statistical analysis

Statistical analyses were performed with R (version 3.0.2) and SigmaPlot (version 11.0). Data were tested for normal distribution with the Shapiro–Wilk normality test and for variance homogeneity with the Constant Variance test. For multiple comparisons, the ANOVA test was performed to analyse significant differences. Significance of all tests was accepted at P levels < 0.05 .

3 Results

Intact soil cores from nine sites of the ÉCLAIRE flux network were incubated in the laboratory at the temperatures 5, 10, 15, 20, and 25 °C in a two factorial design of five soil moisture levels (5, 20, 40, 60, 80 (100) % water filled pore space, WFPS) before analysed for CO₂ fluxes. Data were normally distributed (Shapiro–Wilk test) and showed homogeneity of variances (Constant Variance test). CO₂ emissions differed significantly among sites, temperatures and moisture contents (ANOVA). Comparison of CO₂ fluxes calculated as mean values over all temperature and moisture contents indicate that grassland sites showed the highest CO₂ emissions with 848.39 (± 87.81) and 420.70 (± 40.68) mg CO₂–C m⁻² h⁻¹ for CH-Po and HU-BU, respectively, followed

BGD

12, 4433–4464, 2015

Emissions in European land ecosystems

C. Gritsch et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



by the peatland site with $303.25 (\pm 26.16) \text{ mg CO}_2\text{-C m}^{-2} \text{ h}^{-1}$ for UK-AMo. Forests and arable sites ranged between $27.60 (\pm 1.69)$ and $126.00 (\pm 12.43) \text{ mg CO}_2\text{-C m}^{-2} \text{ h}^{-1}$.

Figure 1 shows absolute mean values of CO_2 emissions at each temperature and moisture content for all nine sites investigated. Highest CO_2 emissions occurred with intermediate moisture content (40–70 % WFPS) over all sites investigated except NL-Spe where no significant moisture optimum could be detected. Additionally, a positive relation between CO_2 emissions and temperature is clearly visible.

3.1 Temperature sensitivity

The relationship between CO_2 emissions and temperature could be well described by a Gaussian model with the equation $R(T) = R_0 \cdot e^{aT + bT^2}$ (Tuomi et al., 2008) for all sites investigated. Table 3 summarizes the fit of the Gaussian model for all sites investigated with all forest sites and the peatland site ranging between an R^2 of 0.990 and 1; grasslands between an R^2 of 0.871 and 1; and arable lands between an R^2 of 0.639 and 1. The temperature course of individual soil cores exhibited a good fit to the Gaussian model. As a result mean values of CO_2 fluxes for each of the five temperatures per moisture content and site were calculated to fit the equation. When taking all samples R^2 ranged between 0.019 (UA-Pet; 6 % WFPS) and 0.958 (NL-Spe; 30 % WFPS) due to the variability between soil cores.

Based on the Gaussian model temperature sensitivities were calculated as Q_{10} values from 5–15 °C for each moisture content and site investigated. Table 3 shows Q_{10} at the lowest and highest temperatures investigated, 5 and 15 °C. Q_{10} values of almost every moisture content and site showed that temperature sensitivity was negatively correlated to temperature (Q_{10} values were decreasing from 5 to 15 °C) for all sites investigated except one arable land (UA-Pet) which showed no distinct relationship between temperature sensitivity and temperature. Also IT-BFo at 26 % WFPS, NL-Spe at 18 % WFPS showed no relationship to temperature and CH-Po at 5 % WFPS and UK-AMo at 83 % WFPS showed a small increase of Q_{10} values with temperature. Additionally

BGD

12, 4433–4464, 2015

Emissions in European land ecosystems

C. Gritsch et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Q_{10} at 15 °C showed that temperature sensitivity converged towards 2 as temperature was increasing. There was no positive or negative relationship of temperature sensitivities to increasing moisture content. However, the variability between Q_{10} values of different moisture contents (highest Q_{10} value minus lowest Q_{10} value illustrated in Table 3 for 5 and 15 °C) at a certain temperature decreases with increasing temperature. Figure 2 shows Q_{10} values calculated from 5–15 °C for each of the 5 moisture contents investigated at the sites IT-IFo, NL-Spe, FI-Hyy, and UK-AMo. At both the coniferous forest sites (NL-Spe, FI-Hyy) results show a strong increase of temperature sensitivity at lower temperatures at a moisture range between 20–40 % WFPS (Q_{10} (5 °C) = 10.85 at NL-Spe, Q_{10} (5 °C) = 7.78 at FI-Hyy) which can also be seen in Table 3.

3.2 Moisture sensitivity

Moisture sensitivity (MS) was calculated as the slope of a quadratic function fitted over relative CO₂ values (to exclude the temperature contribution). Figure 3a shows relative values calculated for a deciduous forest in Italy (IT-IFo) and Fig. 3b shows the quadratic function fitted over relative CO₂ emissions for the same forest at 5 °C. Table 4 shows the fit of the regression analysis (polynomial function of second degree) to relative CO₂ values with R^2 ranging between 0.445–0.984 for forest sites; 0.840–0.927 for grassland and peatland sites; and 0.337–0.980 for arable sites. Using the quadratic function optimum moisture contents were calculated when moisture sensitivities reached zero which equals highest CO₂ values. Optimum moisture contents (MC_{Opt}) were ranging between 41–54 % WFPS for forest sites except for the coniferous site NL-Spe (38–74 % WFPS) which showed no significant moisture trend (Fig. 1); 53–59 % WFPS for the grassland site CH-Po; 44–54 % WFPS for the peatland site UK_AMo; and 43–54 % WFPS for the arable sites (Table 4). Relative values could not be calculated for HU-Bu because CO₂ values at lowest moisture contents were missing due to technical problems. Figure 4 shows calculated moisture sensitivities at all 5 temperatures investigated for a grassland site (CH-Po) and one arable land investigated (UA-Pet). Results showed that moisture sensitivities were highest at very wet and dry conditions. Addi-

tionally moisture sensitivities of CO₂ fluxes coming from arable lands showed a positive relationship to temperature which can be also seen in Table 4, namely that moisture sensitivities at 5 % WFPS increased with temperature for both arable lands, FR-Gri and UA-Pet.

4 Discussion

Land-use generally had a substantial influence on carbon dioxide fluxes, with the order of CO₂ emission rates of the different land-use being grassland > peatland > forest/arable land ($P < 0.001$) which is in line with observations by Schaufler et al. (2010); Raich and Tufekciogul (2000); Ambus and Robertson (2006). Heterotrophic soil respiration responded strongly to varying temperature and moisture content (Ferréa et al., 2012; Gasche and Papen, 1999; Papen and Butterbach-Bahl, 1999; Schindlbacher, 2004; Suseela et al., 2012; Wu et al., 2010). Optimum moisture contents for CO₂ emissions occurred with intermediate moisture content (Bowden et al., 1998; Schaufler et al., 2010; Suseela et al., 2012) over all sites investigated (except for the coniferous forest site NL-Spe where no significant moisture optimum could be detected). Possible explanations for a decline of CO₂ emissions at dry and wet conditions according to literature are (1) limiting diffusivity of air at wet conditions, and (2) osmotic stress of soil microbial communities at dry conditions (Smith et al., 2003) which means a thinner film of water coats the soil particles, slowing the diffusion of labile substrates and reducing the activity of exo-enzymes needed for the decomposition of organic matter (Stark and Firestone, 1995). Additionally results showed a positive correlation between CO₂ emissions and temperature (Davidson et al., 1998; Luo et al., 2012; Wang et al., 2006; Wu et al., 2010). In agreement with other studies the relationship between CO₂ emissions and temperature could be well described by a Gaussian model with the equation

$$R(T) = R_0 \cdot e^{aT + bT^2} \quad (\text{Tuomi et al., 2008; Vanhala et al., 2008}).$$

BGD

12, 4433–4464, 2015

Emissions in European land ecosystems

C. Gritsch et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



4.1 Temperature sensitivity

Q_{10} values were calculated based on the Gaussian model equation for the whole temperature range between 5–15 °C for each moisture content and site investigated and were ranging between 0.86–10.85 which is in agreement with the estimation (2.0– 6.3) of European and North American forest ecosystems (Davidson et al., 1998; Peng et al., 2009) and Janssens and Pilegaard (2003) who found Q_{10} values up to 16, and also with results for temperate grasslands by Wu et al. (2010). Our findings confirm results from previous studies (Kirschbaum, 1995; Lloyd and Taylor, 1994; Luo et al., 2001) that temperature sensitivity is negatively correlated to temperature which was true for most of the moisture contents and sites investigated (except one arable land UA-Pet and IT-BFo at 26 % WFPS, NL-Spe at 18 % WFPS; CH-Po at 5 % WFPS and UK-AMo at 83 % WFPS). Additionally temperature sensitivity converged towards 2 as temperature increased for all moisture contents at all sites investigated. We found that precipitation can influence temperature sensitivity of CO₂ efflux due to the decrease of the variability between Q_{10} values of different moisture contents (highest Q_{10} value minus lowest Q_{10} value) at each moisture point with increasing temperature. At low temperatures Q_{10} values vary more between dry and wet conditions. At higher temperatures the effect of water and temperature on Q_{10} is very low as Q_{10} converges towards 2. Additionally to the Gaussian model equation we applied the Arrhenius function ($R(T) = R_0 \cdot e^{aT^{-1}}$) to our results which showed similar trends but unrealistic Q_{10} values at temperatures below 8 °C (Q_{10} ranging between 20 and 2000).

Our results showed that no distinct relationship (neither positive nor negative) could be found between temperature sensitivity and moisture content at any of the investigated sites. Janssens and Pilegaard (2003) and Qi et al. (2002) expected a positive relationship between temperature sensitivity and moisture content due to the assumption that the effects of soil temperature and moisture are negatively correlated. Thus, soil moisture would be positively correlated with the temperature sensitivity of soil respiration. While Mäkiranta et al. (2009) and Gaumont-Guay et al. (2006) found an actual

BGD

12, 4433–4464, 2015

Emissions in European land ecosystems

C. Gritsch et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Emissions in European land ecosystems

C. Gritsch et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



positive relationship between temperature sensitivity and soil moisture content in their field measurements. Peng et al. (2009) described in a review of 52 papers a negative correlation between Q_{10} values and mean annual precipitation. However, all these conclusions were achieved through seasonal field measurements at which derivation of the influence of a single climate parameter is difficult, because of incorporated seasonal changes in root biomass, litter inputs, microbial population, nitrogen availability and other seasonally fluctuating processes and conditions, and thus reflect community responses, which may differ from temperature and moisture responses of the respiratory processes (Davidson et al., 2000; Janssens and Pilegaard, 2003; Pilegaard et al., 2006) and can even be partly decoupled from actual soil temperature and moisture (Curiel Yuste et al., 2004; Schaufler et al., 2010). Also most of the studies did not separate autotrophic from heterotrophic soil respiration. Curiel Yuste et al. (2004) presented a case study of how the seasonal Q_{10} of soil respiration can be decoupled from the temperature sensitivity of soil respiration indicating that the large differences in seasonal Q_{10} do not represent differences in the temperature sensitivity of the soil metabolism. Kirschbaum (2006) and Lützow and Kögel-Knabner (2009) considered that laboratory incubations provide the best and least biased basis for estimating the temperature sensitivity of organic matter decomposition. This assumption can be extended to the assessment of soil moisture sensitivity of organic matter decomposition (Schaufler et al., 2010). Another laboratory incubation study by Schindlbacher et al. (2007) showed that different soil moisture contents of trenched and control plots affected rates of heterotrophic soil respiration, but did not affect the temperature sensitivity of heterotrophic respiration which is in agreement with our results.

We found at both the coniferous forest sites a strong increase of the temperature sensitivity at a moisture range between 20–40 % WFPS. At coniferous sites the amount of recalcitrant material is higher (Landsberg and Gower, 1997; Wang et al., 2006) than at all other sites investigated. Temperature sensitivity of soil respiration increases with substrate recalcitrance as long as environmental constraints are not limiting decomposition (Conant et al., 2008; Hartley and Ineson, 2008; Karhu et al., 2010; Lützow and

Emissions in European land ecosystems

C. Gritsch et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

Many articles can be found on the topic of temperature sensitivity. However, much fewer articles calculate moisture sensitivities. Our results indicate that moisture sensitivity is highest at very dry and wet conditions. Results by Moyano et al. (2012) indicate that moisture sensitivity is negatively correlated to soil moisture. However, Moyano et al. (2012) calculated moisture sensitivity as the proportional response of soil microbial respiration to a 0.01 increase in soil moisture of a certain unit. As CO₂ values decline after a moisture optimum this mathematical approach results in moisture sensitivities showing highest values at dry conditions decreasing progressively with increasing moisture content until converging to a certain value. Our approach to calculate moisture sensitivities indicates that moisture sensitivities decrease until reaching the moisture optimum and increase again after that (negative values after reaching the optimum moisture content (MC_{opt}) only indicate a decrease of CO₂ emissions with increasing moisture content; positive values indicate an increase of CO₂ emissions with increasing moisture content). Therefore we can show that changing moisture content has a higher impact on CO₂ emissions at dry and wet conditions than at intermediate moisture conditions.

No relationship between moisture sensitivity and temperature could be found for forests, grasslands and peatlands. However, moisture sensitivity was positively correlated with temperature for both arable lands which both showed the highest bulk densities of all sites ($> 1.00 \text{ g m}^{-3}$; Table 2). Moyano et al. (2012) found that bulk density influences moisture sensitivity but did not investigate the influence of temperature. Also tillage can change physical protection of organic matter, diffusivity as well as improve the exchange with deeper soil layers (Davidson and Janssens, 2006). There are several characteristics in which arable lands differ from other ecosystems with respect to carbon-cycle responses to climate change. Cropland systems are entirely managed and the soil–vegetation system can be reset regularly through harvest and agricultural management such as tillage, manure/residue management and irrigation. Consequently, the response to climate is highly modulated by human intervention both immediately and over longer periods (Reichstein et al., 2013).

5 Conclusions

Our experiments showed that under cold temperatures temperature sensitivities of CO₂ emission were highest which means that in cold areas (e.g. northern latitudes or mountain areas) warming will have a larger impact on CO₂ emissions. In addition Q_{10} values varied strongly under cold temperatures with moisture content indicating an effect of rain events in cold areas on temperature sensitivity.

Moisture sensitivity was prominent under dry or wet conditions, which indicates that increased moisture in dry areas or drying of wet areas will largely promote CO₂ emissions. Moisture sensitivities of CO₂ emissions from cropland soils were positively related to temperature; hence irrigation of arable lands might have a higher impact on CO₂ emissions in warmer regions in the South of Europe than in the North.

Acknowledgements. The authors thank their colleagues Florian Egger, Christian Holtermann, Angelica Patterson and Barbara Kitzler for continuing support and discussion.

References

- Ågren, G. I. and Wetterstedt, J. Å. M.: What determines the temperature response of soil organic matter decomposition?, *Soil Biol. Biochem.*, 39, 1794–1798, 2007.
- Ambus, P. and Robertson, G. P.: The effect of increased N deposition on nitrous oxide, methane and carbon dioxide fluxes from unmanaged forest and grassland communities in Michigan, *Biogeochemistry*, 79, 315–337, 2006.
- Atkin, O. K., Edwards, E. J., and Loveys, B. R.: Response of root respiration to changes in temperature and its relevance to global warming, *New Phytol.*, 147, 141–154, 2000.
- Baggs, E. M.: Partitioning the components of soil respiration: a research challenge, *Plant Soil*, 284, 1–5, 2006.
- Beierkuhnlein, C., Thiel, D., Jentsch, A., Willner, E., and Kreyling, J.: Ecotypes of European grass species respond differently to warming and extreme drought, *J. Ecol.*, 99, 703–713, 2011.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Emissions in European land ecosystems

C. Gritsch et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



- Bowden, R. D., Newkirk, K. M., and Rullo, G. M.: Carbon dioxide and methane fluxes by a forest soil under laboratory-controlled moisture and temperature conditions, *Soil Biol. Biochem.*, 30, 1591–1597, 1998.
- Conant, R. T., Drijber, R. A., Haddix, M. L., Parton, W. J., Paul, E. A., Plante, A. F., Six, J., and Steinweg, J. M.: Sensitivity of organic matter decomposition to warming varies with its quality, *Glob. Change Biol.*, 14, 868–877, 2008.
- Curiel Yuste, J., Janssens, I. A., Carrara, A., and Ceulemans, R.: Annual Q_{10} of soil respiration reflects plant phenological patterns as well as temperature sensitivity, *Glob. Change Biol.*, 10, 161–169, 2004.
- Davidson, E. A. and Janssens, I. A.: Temperature sensitivity of soil carbon decomposition and feedbacks to climate change, *Nature*, 440, 165–173, 2006.
- Davidson, E. A., Belk, E., and Boone, R. D.: Soil water content and temperature as independent or confounded factors controlling soil respiration in a temperate mixed hardwood forest, *Glob. Change Biol.*, 4, 217–227, 1998.
- Davidson, E. A., Keller, M., Erickson, H. E., Verchot, L. V., and Veldkamp, E.: Testing a conceptual model of soil emissions of nitrous and nitric oxides: using two functions based on soil nitrogen availability and soil water content, the hole-in-the-pipe model characterizes a large fraction of the observed variation of nitric oxide and nitrous oxide emissions from soils, *Biol. Science*, 50, 667–680, 2000.
- Ferréa, C., Zenone, T., Comolli, R., and Seufert, G.: Estimating heterotrophic and autotrophic soil respiration in a semi-natural forest of Lombardy, Italy, *Pedobiologia*, 55, 285–294, 2012.
- Flechard, C. R., Neftel, A., Jocher, M., Ammann, C., and Fuhrer, J.: Bi-directional soil/atmosphere N_2O exchange over two mown grassland systems with contrasting management practices, *Glob. Change Biol.*, 11, 2114–2127, 2005.
- Garten, C. T., Classen, A. T., and Norby, R. J.: Soil moisture surpasses elevated CO_2 and temperature as a control on soil carbon dynamics in a multi-factor climate change experiment, *Plant Soil*, 319, 85–94, 2008.
- Gasche, R. and Papen, H.: A 3 year continuous record of nitrogen trace gas fluxes from untreated and limed soil of a N-saturated spruce and beech forest ecosystem in Germany, 2, NO and NO_2 fluxes, *J. Geophys. Res.-Atmos.*, 104, 18505–18520, 1999.
- Gaumont-Guay, D., Black, T. A., Griffis, T. J., Barr, A. G., Jassal, R. S., and Nescic, Z.: Interpreting the dependence of soil respiration on soil temperature and water content in a boreal aspen stand, *Agr. Forest Meteorol.*, 140, 220–235, 2006.

Emissions in European land ecosystems

C. Gritsch et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



- Hartley, I. P. and Ineson, P.: Substrate quality and the temperature sensitivity of soil organic matter decomposition, *Soil Biol. Biochem.*, 40, 1567–1574, 2008.
- Hood-Nowotny, R., Umana, N. H.-N., Inselbacher, E., Oswald-Lachouani, P., and Wanek, W.: Alternative methods for measuring inorganic, organic, and total dissolved nitrogen in soil, *Soil Sci. Soc. Am. J.*, 74, 1018–1027, 2010.
- Janssens, I. A. and Pilegaard, K. I. M.: Large seasonal changes in Q_{10} of soil respiration in a beech forest, *Glob. Change Biol.*, 9, 911–918, 2003.
- Karhu, K., Fritze, H., Tuomi, M., Vanhala, P., Spetz, P., Kitunen, V., and Liski, J.: Temperature sensitivity of organic matter decomposition in two boreal forest soil profiles, *Soil Biol. Biochem.*, 42, 72–82, 2010.
- Kirschbaum, M.: The temperature dependence of organic-matter decomposition – still a topic of debate, *Soil Biol. Biochem.*, 38, 2510–2518, 2006.
- Kirschbaum, M. U. F.: The temperature dependence of soil organic matter decomposition, and the effect of global warming on soil organic C storage, *Soil Biol. Biochem.*, 27, 753–760, 1995.
- Landsberg, J. J. and Gower, S. T.: Applications of physiological ecology to forest management, *Physiol. Ecol.*, ISBN-9780080527383, 161–184, 1997.
- Larsen, K. S., Andresen, L. C., Beier, C., Jonasson, S., Albert, K. R., Ambus, P. E. R., Arndal, M. F., Carter, M. S., Christensen, S., Holmstrup, M., Ibrom, A., Kongstad, J., Van Der Linden, L., Maraldo, K., Michelsen, A., Mikkelsen, T. N., Pilegaard, K. I. M., Priemé, A., Røpoulsen, H., Schmidt, I. K., Selsted, M. B., and Stevnbak, K.: Reduced N cycling in response to elevated CO_2 , warming, and drought in a Danish heathland: synthesizing results of the CLIMATE project after two years of treatments, *Glob. Change Biol.*, 17, 1884–1899, 2011.
- Leuzinger, S., Luo, Y., Beier, C., Dieleman, W., Vicca, S., and Körner, C.: Do global change experiments overestimate impacts on terrestrial ecosystems?, *Trends Ecol. Evol.*, 26, 236–241, 2011.
- Lloyd, J. and Taylor, J.: On the temperature dependence of soil respiration, *Funct. Ecol.*, 8, 315–323, 1994.
- Luo, G. J., Brüggemann, N., Wolf, B., Gasche, R., Grote, R., and Butterbach-Bahl, K.: Decadal variability of soil CO_2 , NO , N_2O , and CH_4 fluxes at the Höglwald Forest, Germany, *Biogeochemistry*, 9, 1741–1763, doi:10.5194/bg-9-1741-2012, 2012.
- Luo, Y., Wan, S., Hui, D., and Wallace, L. L.: Acclimatization of soil respiration to warming in a tall grass prairie, *Nature*, 413, 622–625, 2001.

Emissions in European land ecosystems

C. Gritsch et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



- Lützw, M. and Kögel-Knabner, I.: Temperature sensitivity of soil organic matter decomposition – what do we know?, *Biol. Fert. Soils*, 46, 1–15, 2009.
- Mäkiranta, P., Laiho, R., Fritze, H., Hytönen, J., Laine, J., and Minkinen, K.: Indirect regulation of heterotrophic peat soil respiration by water level via microbial community structure and temperature sensitivity, *Soil Biol. Biochem.*, 41, 695–703, 2009.
- Meixner, F. X.: Biogenic emissions of nitric oxide and nitrous oxide from arid and semi-arid land, in: *Dryland Ecohydrology*, Springer, Netherlands, 233–255, 2006.
- Moyano, F. E., Vasilyeva, N., Bouckaert, L., Cook, F., Craine, J., Curiel Yuste, J., Don, A., Epron, D., Formanek, P., Franzluebbers, A., Ilstedt, U., Kätterer, T., Orchard, V., Reichstein, M., Rey, A., Ruamps, L., Subke, J. A., Thomsen, I. K., and Chenu, C.: The moisture response of soil heterotrophic respiration: interaction with soil properties, *Biogeosciences*, 9, 1173–1182, doi:10.5194/bg-9-1173-2012, 2012.
- Moyano, F. E., Manzoni, S., and Chenu, C.: Responses of soil heterotrophic respiration to moisture availability: an exploration of processes and models, *Soil Biol. Biochem.*, 59, 72–85, 2013.
- Papen, H. and Butterbach-Bahl, K.: A 3 year continuous record of nitrogen trace gas fluxes from untreated and limed soil of a N-saturated spruce and beech forest ecosystem in Germany, 1, N₂O emissions, *J. Geophys. Res.*, 104, 18487, doi:10.1029/1999JD900293, 1999.
- Peng, S., Piao, S., Wang, T., Sun, J., and Shen, Z.: Temperature sensitivity of soil respiration in different ecosystems in China, *Soil Biol. Biochem.*, 41, 1008–1014, 2009.
- Pilegaard, K., Skiba, U., Ambus, P., Beier, C., Brüggemann, N., Butterbach-Bahl, K., Dick, J., Dorsey, J., Duyzer, J., and Gallagher, M.: Factors controlling regional differences in forest soil emission of nitrogen oxides (NO and N₂O), *Biogeosciences*, 3, 651–661, doi:10.5194/bg-3-651-2006, 2006.
- Qi, Y., Xu, M., and Wu, J.: Temperature sensitivity of soil respiration and its effects on ecosystem carbon budget: nonlinearity begets surprises, *Ecol. Model.*, 153, 131–142, 2002.
- Raich, J. and Tufekciogul, A.: Vegetation and soil respiration: correlations and controls, *Biogeochemistry*, 48, 71–90, 2000.
- Reichstein, M., Bahn, M., Ciais, P., Frank, D., Mahecha, M. D., Seneviratne, S. I., Zscheischler, J., Beer, C., Buchmann, N., Frank, D. C., Papale, D., Rammig, A., Smith, P., Thonicke, K., van der Velde, M., Vicca, S., Walz, A., and Wattenbach, M.: Climate extremes and the carbon cycle, *Nature*, 500, 287–295, 2013.

Emissions in European land ecosystems

C. Gritsch et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



- Rodrigo, A., Recous, S., Neel, C., and Mary, B.: Modelling temperature and moisture effects on C–N transformations in soils: comparison of nine models, *Ecol. Model.*, 102, 325–339, 1997.
- Schaufler, G., Kitzler, B., Schindlbacher, A., Skiba, U., Sutton, M. A., and Zechmeister-Boltenstern, S.: Greenhouse gas emissions from European soils under different land use: effects of soil moisture and temperature, *Eur. J. Soil Sci.*, 61, 683–696, 2010.
- Schindlbacher, A.: Effects of soil moisture and temperature on NO, NO₂, and N₂O emissions from European forest soils, *J. Geophys. Res.*, 109, D17302, doi:10.1029/2004JD004590, 2004.
- Schindlbacher, A., Zechmeister-Boltenstern, S., Kitzler, B., and Jandl, R.: Experimental forest soil warming: response of autotrophic and heterotrophic soil respiration to a short-term 10 °C temperature rise, *Plant Soil*, 303, 323–330, 2007.
- Schindlbacher, A., Zechmeister-Boltenstern, S., and Jandl, R.: Carbon losses due to soil warming: do autotrophic and heterotrophic soil respiration respond equally?, *Glob. Change Biol.*, 15, 901–913, 2009.
- Shrestha, B. M., Sitaula, B. K., Singh, B. R., and Bajracharya, R. M.: Fluxes of CO₂ and CH₄ in soil profiles of a mountainous watershed of Nepal as influenced by land use, temperature, moisture and substrate addition, *Nutr. Cycl. Agroecosys.*, 68, 155–164, 2004.
- Skiba, U. M., Sheppard, L. J., Macdonald, J., and Fowler, D.: Some key environmental variables controlling nitrous oxide emissions from agricultural and semi-natural soils in Scotland, *Atmos. Environ.*, 32, 3311–3320, 1998.
- Smith, K. A., Ball, T., Conen, F., Dobbie, K. E., Massheder, J., and Rey, A.: Exchange of greenhouse gases between soil and atmosphere: interactions of soil physical factors and biological processes, *Eur. J. Soil Sci.*, 54, 779–791, 2003.
- Stark, J. M. and Firestone, M. K.: Mechanisms for soil moisture effects on activity of nitrifying bacteria, *Appl. Environ. Microbiol.*, 61, 218–221, 1995.
- Suseela, V., Conant, R. T., Wallenstein, M. D., and Dukes, J. S.: Effects of soil moisture on the temperature sensitivity of heterotrophic respiration vary seasonally in an old-field climate change experiment, *Glob. Change Biol.*, 18, 336–348, 2012.
- Teepe, R., Vor, A., Beese, F., and Ludwig, B.: Emissions of N₂O from soils during cycles of freezing and thawing and the effects of soil water, texture and duration of freezing, *Eur. J. Soil Sci.*, 55, 357–365, 2004.

**Emissions in
European land
ecosystems**

C. Gritsch et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

- Thornley, J. H. M. and Cannell, M. G. R.: Soil Carbon Storage Response to Temperature: an Hypothesis, *Ann. Bot.-London*, 87, 591–598, 2001.
- Tuomi, M., Vanhala, P., Karhu, K., Fritze, H., and Liski, J.: Heterotrophic soil respiration – comparison of different models describing its temperature dependence, *Ecol. Model.*, 211, 182–190, 2008.
- 5 Vanhala, P., Karhu, K., Tuomi, M., Björklöf, K., Fritze, H., and Liski, J.: Temperature sensitivity of soil organic matter decomposition in southern and northern areas of the boreal forest zone, *Soil Biol. Biochem.*, 40, 1758–1764, 2008.
- Wang, C., Yang, J., and Zhang, Q.: Soil respiration in six temperate forests in China, *Glob. Change Biol.*, 12, 2103–2114, 2006.
- 10 Wang, W. and Fang, J.: Soil respiration and human effects on global grasslands, *Global Planet. Change*, 67, 20–28, 2009.
- Wu, X., Yao, Z., Brüggemann, N., Shen, Z. Y., Wolf, B., Dannenmann, M., Zheng, X., and Butterbach-Bahl, K.: Effects of soil moisture and temperature on CO₂ and CH₄ soil–atmosphere exchange of various land use/cover types in a semi-arid grassland in Inner Mongolia, China, *Soil Biol. Biochem.*, 42, 773–787, 2010.
- 15 Zimmermann, M. and Bird, M. I.: Temperature sensitivity of tropical forest soil respiration increase along an altitudinal gradient with ongoing decomposition, *Geoderma*, 187–188, 8–15, 2012.

Emissions in
European land
ecosystems

C. Gritsch et al.

Table 2. Soil characteristics of the 9 sampling sites. Indicated soil textures are loamy sand (LS), sandy loam (SL), sandy clay (SC), Silt loam (SiL), and clay (C).

| Landuse | Site | Ammonium [NH ₄ ⁺ -N μg g ⁻¹] | Nitrate [NO ₃ ⁻ -N μg g ⁻¹] | Bulk density [g cm ⁻³] | Conductivity [μS] | pH | Texture | C/N |
|-----------|--------|---|--|---------------------------------------|----------------------|-----|---------|------|
| Forest | IT-IFo | 38.0 | 21.0 | 0.46 | 37.0 | 3.4 | LS | 19.6 |
| Forest | IT-BFo | 32.5 | 26.0 | 0.68 | 53.4 | 4.0 | SL | 17.8 |
| Forest | NL-Spe | 13.9 | 17.5 | 0.89 | 34.8 | 2.9 | LS | 32.7 |
| Forest | FI-Hyy | 23.0 | 17.5 | 0.61 | 20.9 | 3.1 | LS | 42.1 |
| Grassland | CH-Po | 5.7 | 28.2 | 0.77 | 100.4 | 6.7 | SC | 12.9 |
| Grassland | HU-Bu | 79.3 | 155.3 | 0.70 | 91.1 | 6.9 | LS | 13.0 |
| Peatland | UK-AMo | 42.9 | 29.1 | 0.12 | 38.9 | 3.2 | organic | 23.7 |
| Arable | FR-Gri | 1.9 | 21.5 | 1.11 | 65.5 | 6.8 | SiL | 13.3 |
| Arable | UA-Pet | 1.7 | 20.0 | 0.99 | 29.3 | 6.5 | C | 16.4 |

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Emissions in
European land
ecosystems

C. Gritsch et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Table 3. Regression analysis of temperature relationship of heterotrophic soil respiration at all moisture contents (MC; shown in real values) investigated (Gaussian model equation); determination coefficient R^2 , Standard Error of Estimate, significance level P , and number of observations n (mean values over 6 replicants); Q_{10} values at 5 and 15 °C for all moisture contents and all sites investigated; and variability (Var) at 5 and 15 °C. Variability was calculated as the highest Q_{10} value at a certain temperature minus the lowest Q_{10} value at a certain temperature ($Q_{10\text{Max}} - Q_{10\text{Min}}$).

| Site | MC [% WFPS] | n | R^2 | P | Q_{10} (5 °C) | Q_{10} (15 °C) | Var(5 °C) | Var(15 °C) |
|--------|-------------|-----|-------|---------|-----------------|------------------|-----------|------------|
| IT-IFo | 13 | 5 | 1.00 | < 0.001 | 3.8 | 2.7 | 1.1 | 0.6 |
| IT-IFo | 27 | 5 | 0.99 | 0.008 | 3.9 | 2.0 | | |
| IT-IFo | 44 | 5 | 1.00 | 0.001 | 4.4 | 2.5 | | |
| IT-IFo | 65 | 5 | 1.00 | < 0.001 | 3.9 | 2.3 | | |
| IT-IFo | 84 | 5 | 0.99 | 0.007 | 4.9 | 2.6 | | |
| IT-BFo | 13 | 4 | 1.00 | 0.026 | 3.8 | 2.8 | 2.1 | 0.9 |
| IT-BFo | 26 | 4 | 1.00 | 0.004 | 2.9 | 3.0 | | |
| IT-BFo | 46 | 4 | 1.00 | 0.021 | 3.3 | 3.1 | | |
| IT-BFo | 65 | 4 | 0.99 | 0.089 | 4.3 | 2.7 | | |
| IT-BFo | 84 | 4 | 1.00 | 0.005 | 2.3 | 2.2 | | |
| NL-Spe | 18 | 5 | 0.99 | 0.010 | 3.7 | 3.8 | 7.5 | 1.3 |
| NL-Spe | 30 | 5 | 0.99 | 0.006 | 10.9 | 4.3 | | |
| NL-Spe | 42 | 5 | 0.99 | 0.007 | 8.6 | 3.9 | | |
| NL-Spe | 55 | 5 | 1.00 | 0.003 | 3.4 | 3.0 | | |
| NL-Spe | 74 | 5 | 1.00 | < 0.001 | 4.3 | 3.0 | | |
| FI-Hyy | 15 | 5 | 1.00 | 0.005 | 2.9 | 2.7 | 4.9 | 0.3 |
| FI-Hyy | 22 | 5 | 0.99 | 0.009 | 7.8 | 2.5 | | |
| FI-Hyy | 45 | 5 | 0.99 | 0.009 | 3.1 | 2.4 | | |
| FI-Hyy | 65 | 5 | 1.00 | < 0.001 | 3.5 | 2.5 | | |
| FI-Hyy | 83 | 5 | 1.00 | < 0.001 | 3.5 | 2.7 | | |
| CH-Po | 5 | 5 | 1.00 | 0.001 | 2.1 | 2.3 | 1.3 | 1.2 |
| CH-Po | 18 | 5 | 1.00 | 0.002 | 3.1 | 2.1 | | |

Emissions in
European land
ecosystems

C. Gritsch et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Table 3. Continued.

| Site | MC [% WFPS] | <i>n</i> | <i>R</i> ² | <i>P</i> | <i>Q</i> ₁₀ (5 °C) | <i>Q</i> ₁₀ (15 °C) | Var(5 °C) | Var(15 °C) |
|--------|-------------|----------|-----------------------|----------|-------------------------------|--------------------------------|-----------|------------|
| CH-Po | 45 | 5 | 0.95 | 0.046 | 3.1 | 1.7 | | |
| CH-Po | 59 | 5 | 0.89 | 0.105 | 2.9 | 1.2 | | |
| CH-Po | 86 | 5 | 0.87 | 0.129 | 3.4 | 1.1 | | |
| HU-Bu | 5 | 3 | na | na | na | na | 2.1 | 0.5 |
| HU-Bu | 19 | 5 | 0.99 | 0.007 | 4.9 | 2.5 | | |
| HU-Bu | 36 | 5 | 0.96 | 0.037 | 5.2 | 2.5 | | |
| HU-Bu | 57 | 5 | 0.96 | 0.041 | 5.3 | 2.3 | | |
| HU-Bu | 77 | 5 | 0.98 | 0.020 | 3.2 | 2.0 | | |
| UK-AMo | 22 | 5 | 1.00 | < 0.001 | 3.8 | 2.8 | 1.5 | 0.6 |
| UK-AMo | 41 | 5 | 1.00 | < 0.001 | 2.8 | 2.5 | | |
| UK-AMo | 59 | 5 | 1.00 | < 0.001 | 3.4 | 2.5 | | |
| UK-AMo | 83 | 5 | 0.99 | 0.010 | 2.3 | 2.9 | | |
| UK-AMo | 101 | 5 | 1.00 | 0.003 | 3.3 | 2.3 | | |
| FR-Gri | 5 | 5 | 0.94 | 0.062 | 1.3 | 1.1 | 3.5 | 1.6 |
| FR-Gri | 21 | 5 | 1.00 | < 0.001 | 3.2 | 2.7 | | |
| FR-Gri | 40 | 5 | 0.99 | 0.013 | 4.8 | 1.6 | | |
| FR-Gri | 60 | 5 | 0.99 | 0.007 | 4.5 | 1.8 | | |
| FR-Gri | 80 | 5 | 0.96 | 0.036 | 3.5 | 1.8 | | |
| UA-Pet | 6 | 5 | 0.64 | 0.361 | 1.1 | 0.9 | 1.1 | 1.5 |
| UA-Pet | 19 | 5 | 0.98 | 0.017 | 1.6 | 1.9 | | |
| UA-Pet | 40 | 5 | 0.99 | 0.006 | 2.0 | 2.4 | | |
| UA-Pet | 63 | 5 | 1.00 | < 0.001 | 2.2 | 2.3 | | |
| UA-Pet | 83 | 5 | 1.00 | 0.005 | 1.7 | 1.8 | | |

Emissions in
European land
ecosystems

C. Gritsch et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Table 4. Regression analysis of moisture relationship of heterotrophic soil respiration at all temperatures investigated (Polynomial second degree); determination coefficient R^2 , Standard Error of Estimate, significance level P , and number of observations n (mean values over 6 replicants; relative values). Calculated moisture content (MC_{Opt}), where CO_2 emissions show their optimum and calculated moisture sensitivity (MS) at 5 % WFPS.

| Site | T [°C] | n | R^2 | P | MC_{Opt} [%WFPS] | MS (5 %WFPS) |
|--------|----------|-----|-------|-------|--------------------|--------------|
| IT-IFo | 5 | 5 | 0.66 | 0.338 | 49 | 3.6 |
| IT-IFo | 10 | 5 | 0.80 | 0.202 | 41 | 3.1 |
| IT-IFo | 15 | 5 | 0.99 | 0.007 | 43 | 3.7 |
| IT-IFo | 20 | 5 | 0.98 | 0.016 | 45 | 3.0 |
| IT-IFo | 25 | 5 | 0.90 | 0.102 | 42 | 2.3 |
| IT-BFo | 5 | 5 | 0.87 | 0.132 | 52 | 12.4 |
| IT-BFo | 10 | 5 | 0.80 | 0.199 | 50 | 8.6 |
| IT-BFo | 15 | 5 | 0.70 | 0.304 | 50 | 11.5 |
| IT-BFo | 20 | 5 | 0.85 | 0.148 | 49 | 11.8 |
| IT-BFo | 25 | 5 | – | – | – | – |
| NL-Spe | 5 | 5 | 0.89 | 0.106 | 74 | 0.2 |
| NL-Spe | 10 | 5 | 0.89 | 0.106 | 75 | 3.7 |
| NL-Spe | 15 | 5 | 0.45 | 0.555 | 46 | –4.5 |
| NL-Spe | 20 | 5 | 0.76 | 0.241 | 38 | –2.5 |
| NL-Spe | 25 | 5 | 0.90 | 0.101 | 45 | –2.2 |
| FI-Hyy | 5 | 5 | 0.87 | 0.134 | 54 | 9.3 |
| FI-Hyy | 10 | 5 | 0.93 | 0.069 | 53 | 20.3 |
| FI-Hyy | 15 | 5 | 0.98 | 0.018 | 52 | 20.6 |
| FI-Hyy | 20 | 5 | 0.83 | 0.174 | 53 | 15.2 |
| FI-Hyy | 25 | 5 | 0.92 | 0.080 | 54 | 15.6 |
| CH-Po | 5 | 5 | 0.91 | 0.091 | 57 | 55.4 |
| CH-Po | 10 | 5 | 0.89 | 0.106 | 59 | 127.7 |
| CH-Po | 15 | 5 | 0.93 | 0.074 | 58 | 96.9 |

Emissions in
European land
ecosystems

C. Gritsch et al.

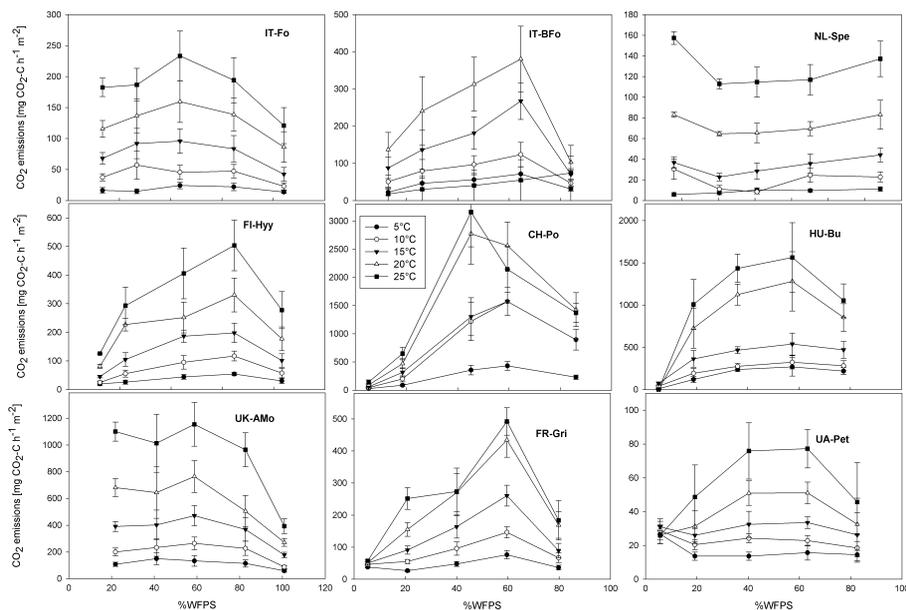


Figure 1. Mean CO_2 flux rates measured at 5 temperatures and 5 moistures contents (real values) from the 9 study sites, starting with the deciduous forests (IT-IFo, IT-BFo) followed by the coniferous forests (NL-Spe, FI-Hyy), grasslands (CH-Po, HU-Bu), the peatland site (UK-AMo) and the arable lands (FR-Gri, UA-Pet).

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Emissions in
European land
ecosystems

C. Gritsch et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

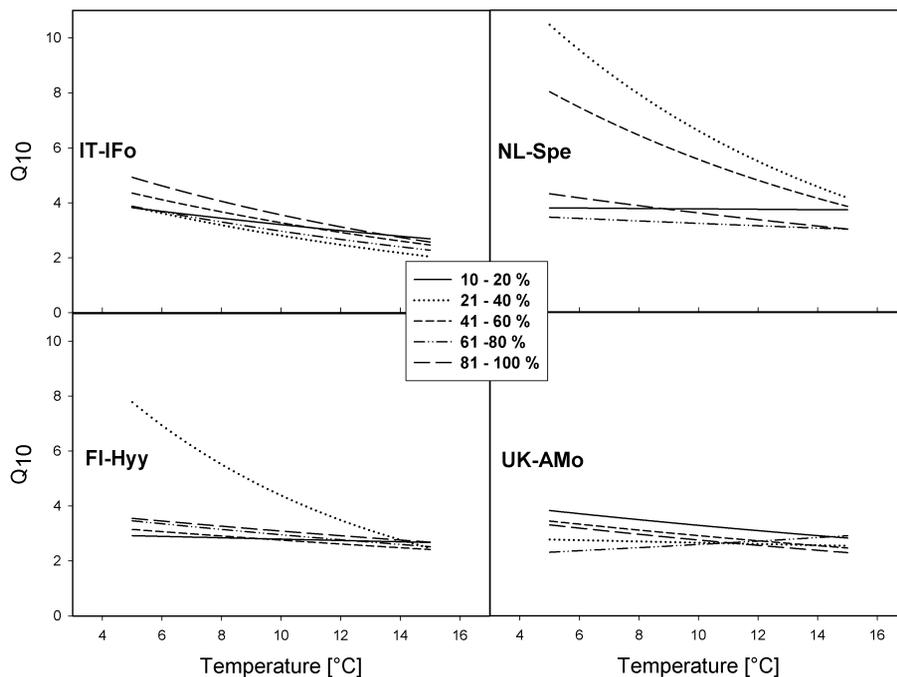


Figure 2. Calculated Q_{10} values of CO_2 efflux derived from the Gaussian model as a function of temperature for each of the investigated moisture contents here shown for the deciduous forest IT-IFo, the 2 coniferous forests NL-Spe and FI-Hyy and the peatland site UK-AMo.

Emissions in
European land
ecosystems

C. Gritsch et al.

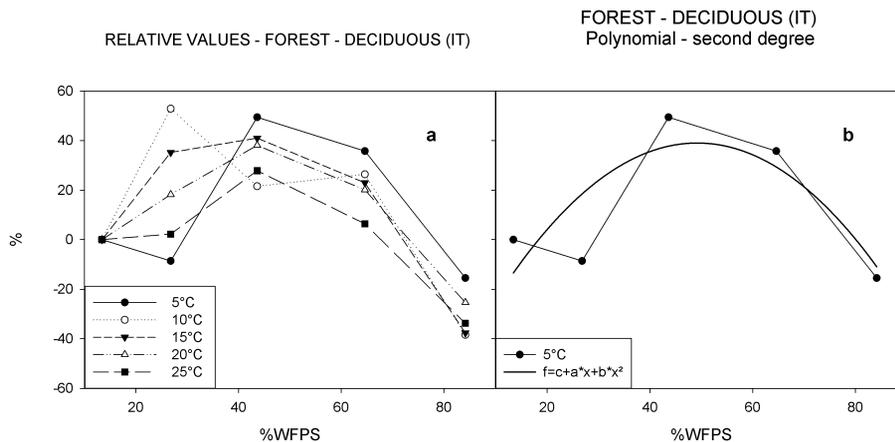


Figure 3. (a) Relative CO₂ flux rates measured at 5 temperatures and 5 moisture contents (real values) from the deciduous forest IT-IFo; (b) Polynomial function of second degree fitted of the moisture relationship of relative CO₂ values at 5°C.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Emissions in
European land
ecosystems

C. Gritsch et al.

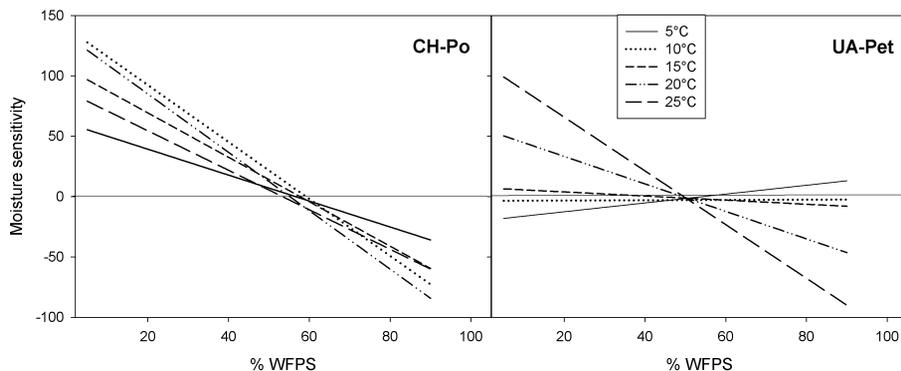


Figure 4. Illustrated moisture sensitivity (MS) of relative CO₂ efflux in relations to soil moisture content. MS was calculated as the slope of a polynomial function of second degree for each of the 5 temperatures investigated here shown for the grassland site CH-Po and the arable site UA-Pet. Cutpoint on *x* axis indicates optimum moisture content for CO₂ emissions at respective temperature. Negative values of moisture sensitivity after reaching the optimum moisture content (MC_{Opt}) indicate a decrease of CO₂ emissions with increasing moisture content; positive values indicate an increase of CO₂ emissions with increasing moisture content.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

