2011-2012

MASTER FAGE
Biologie et Ecologie pour la Forêt, l'Agronomie et l'Environnement

Spécialité
FGE

The influence of spring geophytes on soil CO_2 efflux in a Common beech forest

Laura Heid

Mémoire de stage, soutenu à Nancy le 03/09/2012

Tuteur de stage: Stephan Glatzel, Professor

Responsable universitaire : Bernard Amiaud, Lecturer

Structure d'accueil :
Chair for Landscape Ecology and Site Evaluation
University of Rostock
Justus-von-Liebig Weg 6, Rostock, Germany

Traditio et Innovatio

Acknowledgement

First of all I wanted to thank Pr. Stephan Glatzel who welcomed me into his unit and allowed me to expand my vision of the scientific world. Thank to him and Dr. Gerald Jurasinski for giving me such an interesting subject. Thanks for your (R-) help, advice, reading, correction,… Thanks for giving me the opportunity to improve (myself) and to get to see what it means to be a scientist!

I want to thank particularly Franziska Koebsch who helped me survive in Rostock, in nearly every aspect of my life there (scientific or not), thanks for all your advice and for our (always) serious talks, and of course I could not thank you enough for having showed me the joy of your field work! A big thank to Sascha Beetz for his unbelievable patience with me and my several EGM and electrical problems and for his interest in my results. And thanks to Marian Koch for his implication in my study and his help when I thought it started to get unmanageable and hopeless (and for correction, motivation and tons of other things)! As promised back then to you two Marian and Sascha, thanks for helping setting up the site!

Thanks to all of the Ph.D. students (German or Taiwanese) for their help on practical problem, on lending soil probe, digging soil profiles,…

And thanks again to all the member of the chair that I (probably) bothered during their work several time, thanks a lot for your help (on scientific or administrative matter)! And thanks to all the people who have contributed to this study (without forgetting the students of the Master program “Environmental Engineering” for their hard work)!

I wish you all the best!

Table of Contents

Abbreviations

C: Carbon
C:N ratio: Ratio between the Carbon and Nitrogen content
dbh: Diameter at Breast Height
FRB: Fine Root Biomass
G: Geophytes
GHG: Greenhouse Gases
GIS: Geographic Information System
GPP: Gross Primary Production
IRGA: Infra-Red Gas Analyzer
N: Nitrogen
NEE: Net Ecosystem Exchange
NG: Non-Geophytes
PCC: Pearson's correlation coefficient
R_{eco}: Ecosystem respiration
R_s: Soil respiration
rFRB: relative fine root biomass
RSS: Residual Sum of Square
ST: Soil Temperature
SWC: Soil Water Content

Figures and tables

Introduction

The faculty of Agricultural and Environmental Sciences, founded in 1942, is one of the nine faculties of the University of Rostock, Germany. Among the 20 chairs, stand the Landscape Ecology and Site Evaluation where I have done my training. The goal of this chair is to try to understand to what extent the matter and greenhouse gas balance of a site, an ecosystem or a landscape is driven by vegetation and/or soil and other environmental parameters.

It has been shown that the CO_2 concentrations have increased in the atmosphere since the beginning of industrialization (IPCC, 2007; Revelle *et al.,* 1957). CO_2 acts as a greenhouse gas (GHG) and because its release has increase dramatically it is the principal driver of global warming (Cox *et al.,* 2000). In the context of global change and climate warming it is important to better understand the carbon cycle and the rate of exchange of carbon in every ecosystem. Some ecosystems are described as 'carbon sinks' because they keep more carbon than they release. That is why the carbon increase in the atmosphere could be limited by storage in these ecosystems.

Vegetation is an important terrestrial carbon sink, thanks to photosynthesis. The carbon is stored in the plant until either the leaves fall or a part of the plant dies. Then the plant matter is decomposed to CO_2 or partially passed into the soil. Forests are among the important terrestrial carbon sinks; they store 30% of the GHG emitted worldwide (Service de l'observation et des statistiques, 2011). Therefore, in recent years researchers focused on widening our understanding of the carbon cycle and on quantifying the actual carbon balance (Figure 1) in terrestrial ecosystems.

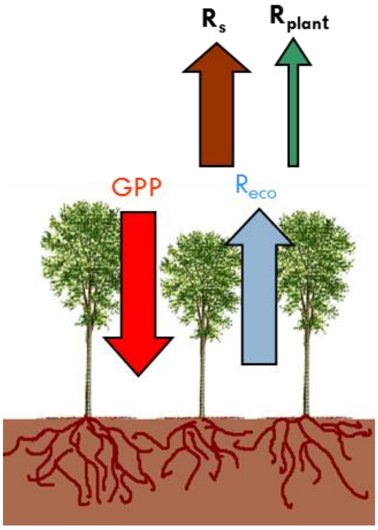

Figure 1: The carbon balance of a forest is the result from the difference between GPP (Photosynthesis) and R_{eco} (carbon release or respiration). R_{eco} is made up of two terms, plant respiration (R_{plant}) and soil respiration (R_s)

Soil respiration is the most important term of ecosystem respiration. It has been shown that it can amount to up to 70% of R_{eco} in European broad-leaved forest (Granier *et* *al.,* 2000; Valentini *et al*., 2000). R_S can be divided further into autotrophic and heterotrophic respiration. Autotrophic (or root) respiration is realized by living roots and the associated microorganismic respiration whereas heterotrophic (or microbial) respiration stems from microorganisms that live directly in the soil. But the separation between the two is challenging. The available methods to do so (trenching, girdling) considerably modify the environmental properties (Epron *et al,* 1999b; Hanson *et al.,* 2000). After all, root respiration seems to represent an important part of soil respiration, but available studies show great variation. Hanson *et al*. reviewed the literature in this regard and report shares of root respiration on soil respiration from 10% to 90%. In a beech forest in north east France (Epron *et al*., 1999b and 2001) about 60% of the total soil respiration came from roots.

The problem for share studies is that soil respiration varies considerably in space and time. This variability depends on three groups of factors: edaphic factors like soil's texture and structure; biological factors like vegetation type, litter's quality and quantity (Longdoz *et al*., 2000; Fang *et al.*, 1998), and climatic factors like temperature (Longdoz *et al*., 2000) and soil humidity (Epron *et al.,* 1999a). Several authors have therefore tried to model soil respiration using these factors.

Jurasinski *et al*. (2012), used tree fine root biomass (FRB) as a proxy in the modeling of soil respiration patterns. The estimated FRB of Ash (*Fraxinus excelsior*) explained some variation in measured CO_2-efflux of an old-growth forest in Central Germany. Yet, the modeled tree FRB from other species (*Fagus sylvatica* for example) could not be used to model soil respiration. A possible explanation was that the activity of spring geophytes might mask the direct effect of the tree fine roots, due to high springtime heterotrophic respiration.

Geophytes are plants able to survive the cold season thanks to their perennating buds that lay in underground storage organs (bulb, rhizome...) (Dafni *et al.,* 1981). Thanks to this specificity, geophytes develop themselves as soon as the conditions (light, temperature, humidity) are propitious again after the dormant season. They are present in a large panel of habitat, from grasslands (like *Muscari tenuiflorum*) to forests (*Anemone nemorosa* for example) where they are the first to bloom, forming a grassy expanse on the forest's soil. Depending on biom and species, they grow in different seasons (early spring, summer...).

Geophytes constitute an important floristic element of European beech forests (Ellenberg and Leuschner, 2010). They are generally found in forests on soils with intermediate pH and nitrogen availabilities, mild temperatures and medium humidity (Hermy *et al*., 1999; Morschhauser *et al.*, 2009; Hermann *et al.,* 2005). They typically grow in patches. The conditions for their presence are not yet well known. Morschhauser *et al.*, (2009) suggested that the establishment of *Allium ursinum* depends on the neighbor density; more precisely the establishment was better in stands of intermediate plant density. However, despite their importance on the forest floor, little is known about their possible impact on soil respiration.

During my internship, I studied both the role of springtime geophytes on the soil respiration in a beech forest and the possible correlation of soil CO_2 efflux with the modeled relative FRB using the model described in Jurasinski *et al*, (2012) work. The main purpose was to see whether the geophytes could modify the soil properties and the soil CO_2 efflux behavior of the forest.

Carbon turnover was expected to be faster during spring and early summer in parts of the ground where geophytes grow, leading to an increase in soil CO_2 efflux. I tested the hypothesis that soil respiration is higher in geophyte spots than in spots without visible geophytes but with similar environmental characteristics.

Material and methods

Site description:

The research has been carried in the “Rostocker Heide”; more precisely in the forest district Schnatermann, located in the North-East of Rostock (Germany; Figure 2). The forest in the study site is mainly composed of European beech (*Fagus sylvatica*). Other important species are Hornbeam (*Carpinus betulus*), European Ash (*Fraxinus excelsior*) and Sycamore maple (*Acer pseudoplatanus*). During the measurement period the ground vegetation consisted mainly of geophytes, particularly *Anemone nemorosa* and *Ranunculus ficaria* at the beginning of the study, and *Galium odoratum* in late spring. The soil at the study site is a Humic gleysol or an Umbrisol according to the F.A.O classification.

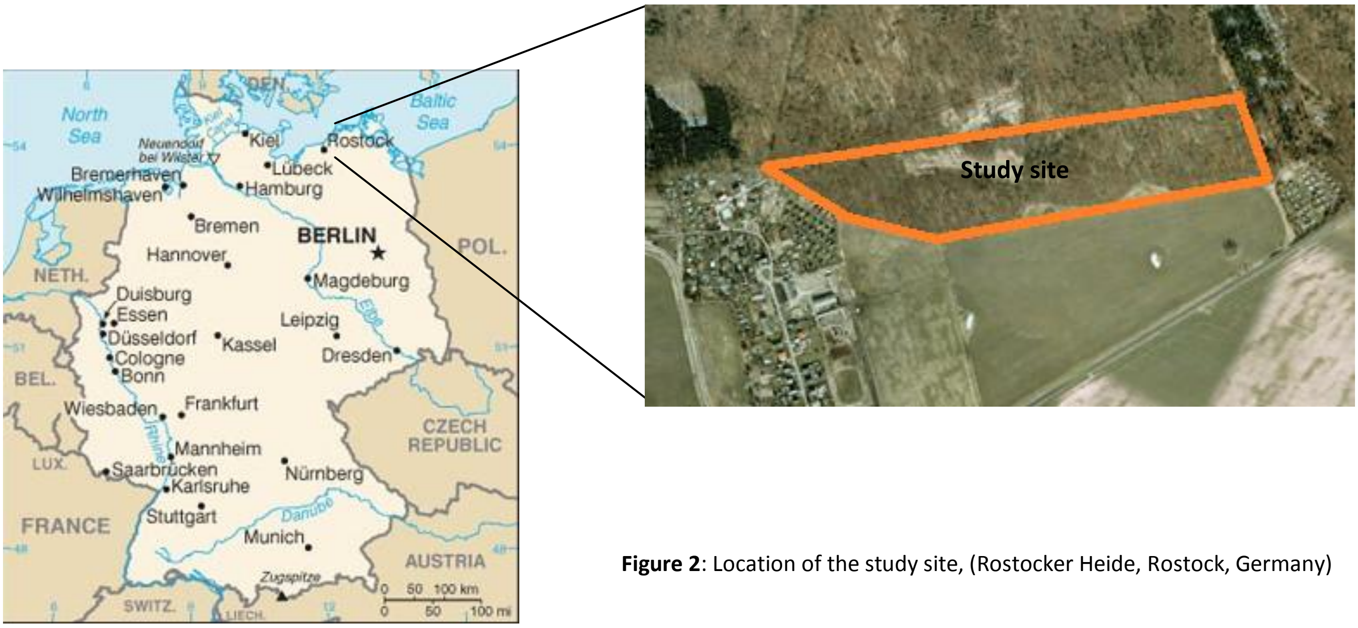

Figure 2: Location of the study site, (Rostocker Heide, Rostock, Germany)

Soil CO_2 efflux:

Soil CO_2 efflux was measured from February to end of June, at least once every week. The 60 measurement locations (spots in the following) were arranged along 12 transects. Each of the 30 m long transects had 5 measurement locations equally. The spots were marked by permanently installed collars (diameter = 10 cm; height = 7cm). The collars were installed some weeks before the measurements started to avoid perturbation of the soil during measurements. We planned to set up the single transects in a specific position and direction so that each transect should stretch from inside a geophyte patch to adjacent, geophyte free areas of the forest floor while keeping soil environmental conditions similar and having the transects run in different, random directions to avoid bias from micro-climatic forces (see Figure 3). One transect was set up in a part of the forest where trees were cut recently.
However, the site was set up in early February. Therefore, the geophyte patches were not easy to distinguish and when spring arrived it was clear that not all transect covered geophytes/non-geophytes as planned. Finally, a spot was considered as a geophyte (G) spot when there were geophytes growing inside the collar (36 spots) and as non-geophyte (NG) spot when there weren't any geophytes growing inside the collar (24 spots). The collars were secured with 3 tent pegs to avoid removal by animals.

Soil respiration was measured with a portable, dynamic closed chamber system (SRC-1) equipped with an infra-red gas analyzer (IRGA, EGM4, both the chamber and the IRGA by PP-Systems, Hitchin, UK).

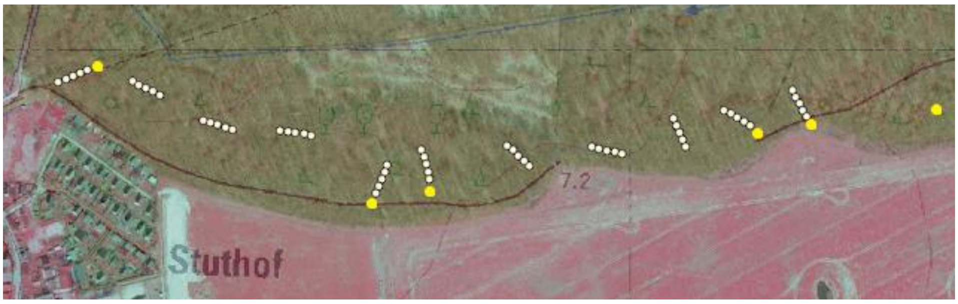

Figure 3: Dispersion and orientation of the transects. The white dots represent the collars and the yellow ones the localization of the temperature logger

Additional measurements:

Soil climatic related parameters

Soil temperature was measured using 6 HOBO Data Loggers (Pendant temp/light, UA-002-64, Onset Computer Corp., Bourne, MA) placed near some of the transects (Figure 3) at 10 cm depth. They recorded temperature continuously during the length of the experiment, from the 18/02/2012 to 17/07/2012 and stored half hourly means. Additionally, during soil CO_2 efflux measurement campaigns, at each spot I measured soil temperature at different depths (2, 5 and 10 cm) and soil moisture with frequency domain reflectometry using a

ThetaProbe Soil Moisture Sensor Type ML-2x and a Soil Moisture Meter-HH2 (AT-Delta-T Devices Ltd., Cambridge, UK).

Soil study

Two soil profiles have been dug on the site, one inside a patch and the other outside. The location was decided randomly on the site. Soil samples were taken once near each collar using a core cutter of known volume (100mL) by students from the University during a field course in the Master program "Environmental Engineering". A cube of soil from the A horizon (after removing litter) of approximately 20 cm edge length was taken out with a spade and one core cutter sample was taken from the top (0-10 cm) and another was taken from the bottom (10-20 cm) of that cube. The core cutter samples were weighed, and then dried for 24 hours at 105°C in a drying oven (Binder, Tuttlingen, Germany). This allowed for calculating the soil bulk density at each collar, knowing the volume of soil that was taken. Then the total carbon and nitrogen contents of the samples were measured using an Elementar Analyzer (VarioMAX; Elementar Analysensystem Gmbh, Hanau, Germany). From C_{tot} and N_{tot} the C:N ratio of the samples was calculated giving an idea of the speed of organic matter decomposition and of the quality of the soil.

Vegetation survey and plot localization:

The vegetation was surveyed at the end of May by students of the University of Rostock during a field course in the Master program "Environmental Engineering". Within one meter radius around the spot centre, all species and their respective cover were recorded. Further, the locations (x, y, z) of all collars and all trees in the vicinity of the transects were recorded using a tachymeter/total station (Leica TC600; Leica Geosystems, Munich, Germany). Further, the tree species and the dbh (diameter at breast height) of each tree were recorded.

Relative fine root biomass

Relative fine root biomass (rFRB) at each transect has been estimated using a heuristic model from Ammer and Wagner (2005) adapted to broad leaved tree species by Jurasinski *et al*. (2012). This model is, for any point in a system of x-y-coordinates, based on only two parameters: the distance from that point to a surrounding tree and its diameter at breast height (dbh). There are several assumptions for that model:

- The maximum extension of fine roots away from the trunk depends on the dimensions of the tree and exceeds the crown-covered area.
- The FRB decreases with the distance from the trunk
- The FRB increases with dbh
- The maximum FRB can be found at a specific distance from the trunk.

To develop their model, Jurasinski *et al*. followed model A from Ammer and Wagner (2005) as the fit to measured FRB was better.

To calculate the rFRB the following equations have been used:

- If $D \geq RD_3$, rFRB=0

If D<RD$_3$, rFRB of a tree at point x,y is calculated

$$h = \mathrm{RD}_2 - \mathrm{RD}_1$$
$$b_0 = \mathrm{rFRB}_0$$
$$b_1 = \frac{(\mathrm{rFRB}_1 - \mathrm{rFRB}_0)}{1!\,h}$$
$$b_2 = \frac{((\mathrm{rFRB}_2 - \mathrm{rFRB}_1) - (\mathrm{rFRB}_1 - \mathrm{rFRB}_0))}{2!\,h_2}$$
$$b_3 = \frac{((\mathrm{rFRB}_3 - \mathrm{rFRB}_2) - (\mathrm{rFRB}_2 - \mathrm{rFRB}_1) - (\mathrm{rFRB}_1 - \mathrm{rFRB}_0))}{3!\,h_3}$$
$$\mathrm{rFRB}_{x,y} = b_0 + b_1(D - \mathrm{RD}_0) + b_2(D - \mathrm{RD}_0)(D - \mathrm{RD}_1) + b_3(D - \mathrm{RD}_0)(D - \mathrm{RD}_1)(D - \mathrm{RD}_2)$$

With: *D* the distance between the tree's trunk and the position of the respective point*,* RD$_3$=dbh/6; the maximum distance in meters, RD$_2$ and RD$_1$ represent 2/3 and 1/3 respectively of RD$_3$, RD$_0$ marks the trunk. rFRB$_0$=dbh/40; rFRB$_1$=0.83*rFRB$_0$; rFRB$_2$=0.43*rFRB$_0$ and rFRB$_3$=0 where rFRB$_1$, rFRB$_2$ and rFRB$_3$ are rFRB at distance RD$_1$, RD$_2$ and RD$_3$ (Parameterization is for beech and was directly taken from Jurasinski *et al*. 2012).

Data management and Analysis:

Soil CO$_2$ efflux

The CO$_2$ efflux rate was calculated directly by the EGM-4, from the change of CO$_2$ concentration within the chamber. To avoid outliers, the first and last decile from the total dataset has been removed.

Soil CO$_2$ efflux modeling

It is current knowledge that soil CO$_2$ efflux has a strong relationship with temperature (particularly with the soil temperature at 10cm depth; Borken et *al.*, 2002), that's why the modeling has been based on this parameter. To find the best model fitting our data and their relationship to temperature, the function 'reco' (package '*flux*'; Jurasinski & Koebsch, 2012) was used. That function can test and fit the most R$_{eco}$ models (linear, exponential,…) used in literature. After trying out several models, the Arrhenius function (Lloyd&Taylor, 1994) has been selected. It showed the lowest Residual Sum of Squares (RSS) and Akaike information criterion of all compared models and so provided the best fit for the majority of the transects.

$$R = t_1 + \exp\,[E_0\left(\frac{1}{T_{Ref} - T_0} - \frac{1}{T - T_0}\right)] \qquad (\textit{Equation 1})$$

With: R the estimated soil CO$_2$ efflux at 10 cm depth (g m^{-2} h^{-1}), T the soil temperature at 10 cm (°C), t$_1$ a constant, E$_0$ the activation energy (J mol^{-1}), T$_{Ref}$ the reference value (set by default to 10°C) and T$_0$ the activation temperature (set by default to -46,02°C).

The model was fit to the soil CO_2 efflux and soil temperature data separated into geophyte and non-geophyte spots of each transect and the parameters t_1 and E_0 were determined. Thus, we ended up with 2 different sets of model parameters for each transect. Knowing the soil temperature at 10 cm (from the Hobo measurements, these have been synchronized to hourly values by averaging the two subsequent half-hourly values from the loggers), we were able to estimate the soil CO_2 efflux for each transect and each hour during the study period using the equation and the respective model parameters. Hobo measurements were always taken for the transect closest to the loggers. Data gaps in two loggers were closed by constructing a model with the best fitting other logger data with complete coverage and using these data to predict the missing data at the logger with the incomplete data series. "Seasonal" CO_2 emissions for the study period (February to June) were estimated by simply summing up the modeled hourly fluxes for each transect and treatment (geophytes / non-geophytes). The same method has been applied to soil CO_2 efflux data from each spot. In this case the models were constructed and the parameters were fit per spot.

Statistical analysis

We tested for statistical difference between G and NG spots for either the measured values using Man-Whitney's non parametrical test for two samples as the distribution of the measured soil CO_2 values wasn't normal. The variances between the modeled seasonal estimates of G and NG spots were tested with an ANOVA after checking for normality of the values.

To find a correlation between the soil C content, N content, C:N ratio and the soil CO_2 efflux, the Pearson's correlation coefficient (PCC)- that gives a measure (between -1 and 1, meaning negative or positive correlation) of the strength of linear dependence between two variables - was calculated. The significance of the difference between these characteristics and the geophytes presence in the spot was assessed with Kruskal-Wallis test.

The PCC between the rFRB and the soil CO_2 efflux (measured and estimated for the season) was calculated in order to find a correlation.

All statistical analyses were carried out in R (R Development Core Team, 2012).

Mapping

Several maps have been constructed with the free GIS software Quantum GIS 'Lisboa'. The map of the estimated seasonal CO_2 emissions at each collar was realized using the sum of the modeled values calculated for each days of the measurement period. An average of the measured value at each collar has been mapped too.

Results

Seasonal variation of the soil CO_2 efflux

From February to June, an evolution in soil CO_2 efflux, soil temperature (ST) and soil water content (SWC) has been observed (Figure 4). The daily average values of soil CO_2 efflux varied from 0.01 $g.m^{-2}.hr^{-1}$ (in March with a soil temperature at 10 cm of 4.35°C) to 0.91 $g.m^{-2}.hr^{-1}$ (in June, 9.15°C).

This change seems to follow the soil temperature evolution during the measurement campaign. We can see for example on May, 10th that the soil temperature reaches a maximum of around 10°C, followed on the 17th by a lower value of 8°C. And for the mean soil temperature, a peak of 0.37 $g.m^{-2}.hr^{-1}$ can be observed the 10th and then a lower value of 0.24 $g.m^{-2}.hr^{-1}$ the 17th following the change in soil temperature.

At the same time, the soil water content decreases continuously, from 0.7 in February to 0.4 at the last day of measurement. This variation can be related to soil temperature too. As a matter of fact, when focusing on some points, for example from May, 17th to May, 30th , the SWC decreases from 0.6 to 0.4 while the ST is increasing and then the temperature drops (on June, 1st) while the SWC shows a small increase (0.56). From our data we can see that there seem to be a negative influence of the SWC on soil CO_2 efflux. Unfortunately, a more precise correlation is difficult to make with these data because SWC couldn't be measured during some of the field campaigns because the measurement probe was not working properly. Therefore only the relationship between soil CO_2 efflux and soil temperature has been analysed.

For a more accurate model, the data were split between transects and therefore 23 different equations were obtained. All the factors and the RSS are shown in table 1 (Overall R^2=0,86). Comparing the RSS of the models made with all the collars with the RSS of the models arising from the separation between spots with geophytes and without justifies that decision. Indeed the RSS are generally lower for the models with separation than the ones made on the entire transect.

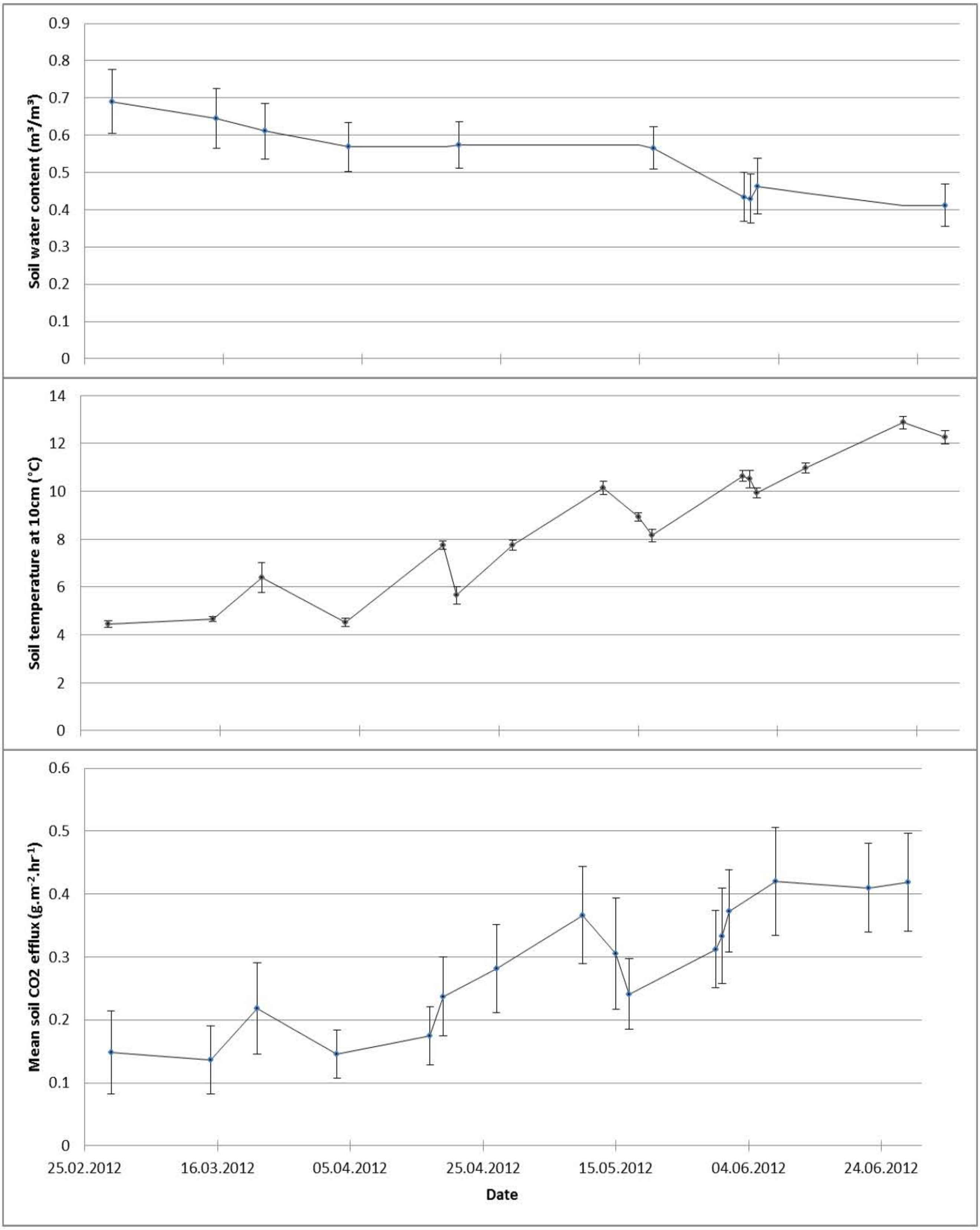

Figure 4: Temporal evolution of soil CO_2 efflux, soil temperature at 10 cm and soil water content at the study site. Dots represent overall means. Whiskers represent the standard deviation.

	Non-geophytes			Geophytes			All
transect	t_1	E_0	*RSS*	t_1	E_0	*RSS*	*RSS*
1	0.3632	191.9111	*0.1118*	0.3772	211.4181	*0.6769*	*0.7916*
2	-	-	-	0.3072	321.7038	*0.5391*	*0.5391*
3	0.3229	307.5893	*0.3242*	0.4241	432.4107	*0.4865*	*0.9722*
4	0.2812	329.5645	*0.04924*	0.286	385.327	*0.4809*	*0.532*
5	0.2746	421.5245	*0.4679*	0.5133	245.0063	*0.8182*	*2.17*
6	0.1841	407.7468	*0.1502*	0.3628	389.33	*1.223*	*1.897*
7	0.2587	453.2746	*0.5504*	0.2409	136.0445	*0.2804*	*0.9118*
8	0.4234	404.0946	*1.302*	0.281	321.18	*0.03772*	*1.556*
9	0.3333	400.0146	*0.8937*	0.2224	304.8865	*0.09445*	*1.158*
10	0.2945	368.1607	*0.3255*	0.3725	440.0119	*0.7019*	*1.116*
11	0.5164	251.1795	*1.329*	0.3308	225.6124	*1.002*	*2.861*
12	0.2646	412.0066	*0.1376*	0.3282	391.9376	*0.3574*	*0.5567*

Table 1: Values of the constant t_1, the activation energy (E_0) and the residuals sum of square (RSS) for all the transects and the RSS of the Arrhenius fit on each transect without separation between geophyte and non-geophyte collars

At the exception of transect 7, 8, 9 and 11, the estimated soil CO_2 efflux of the G spots is always higher than for the NG spots (Figure 5).

Spatial variation of the soil CO_2 efflux:

While mapping the result of either the seasonal estimation or the mean values of CO_2 efflux, a strong variation is noticeable (Figure 6) among transects. There is also considerable variation within some transects (for example in transects 5, 6 and 7). The geophytes and non-geophytes spots are represented as well. Generally the G spot have a higher value than NG spots, either when looking at all the study site or inside a transect.

	Modeled seasonal soil CO2 efflux		Measured
	g/m²		g/m²/hr
	per transect	per collar	
Geophytes	1214.3	1245.2	0.29
Non-geophytes	1056.9	1168	0.27

Table 2: Modeled seasonal coil CO_2 efflux mean values of geophytes and non-geophytes spots for the two ways of modeling and the measured soil CO_2 efflux mean

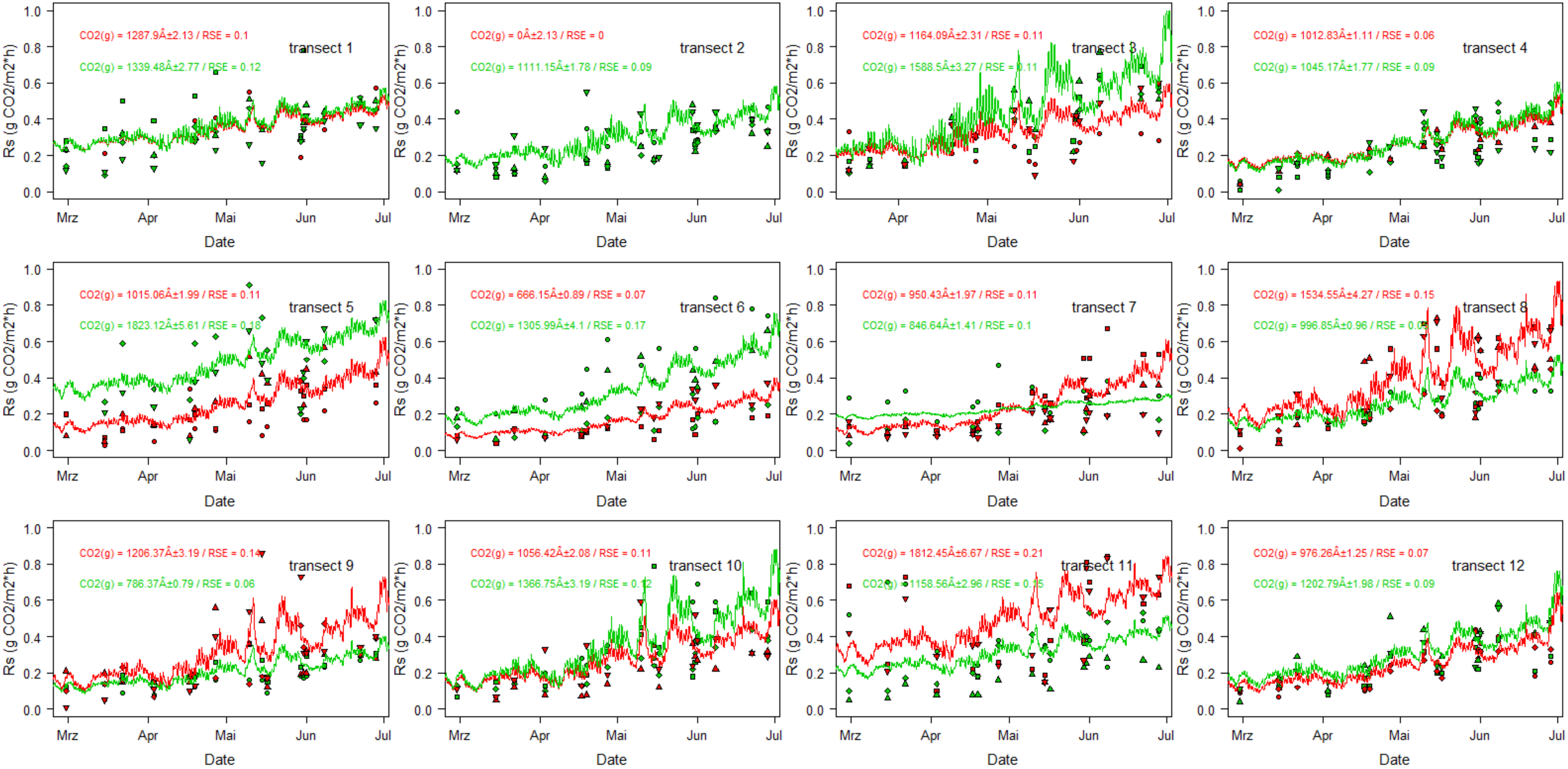

Figure 5: Soil CO_2 efflux per transect. The dots represent the measured values and the lines the results of the modeling (hourly values). Green color corresponds to geophyte spots and red to non-geophyte spots. On each graph the modeled soil seasonal CO_2 efflux in gram is given for the geophyte as well as for the non-geophyte parts of the transects.

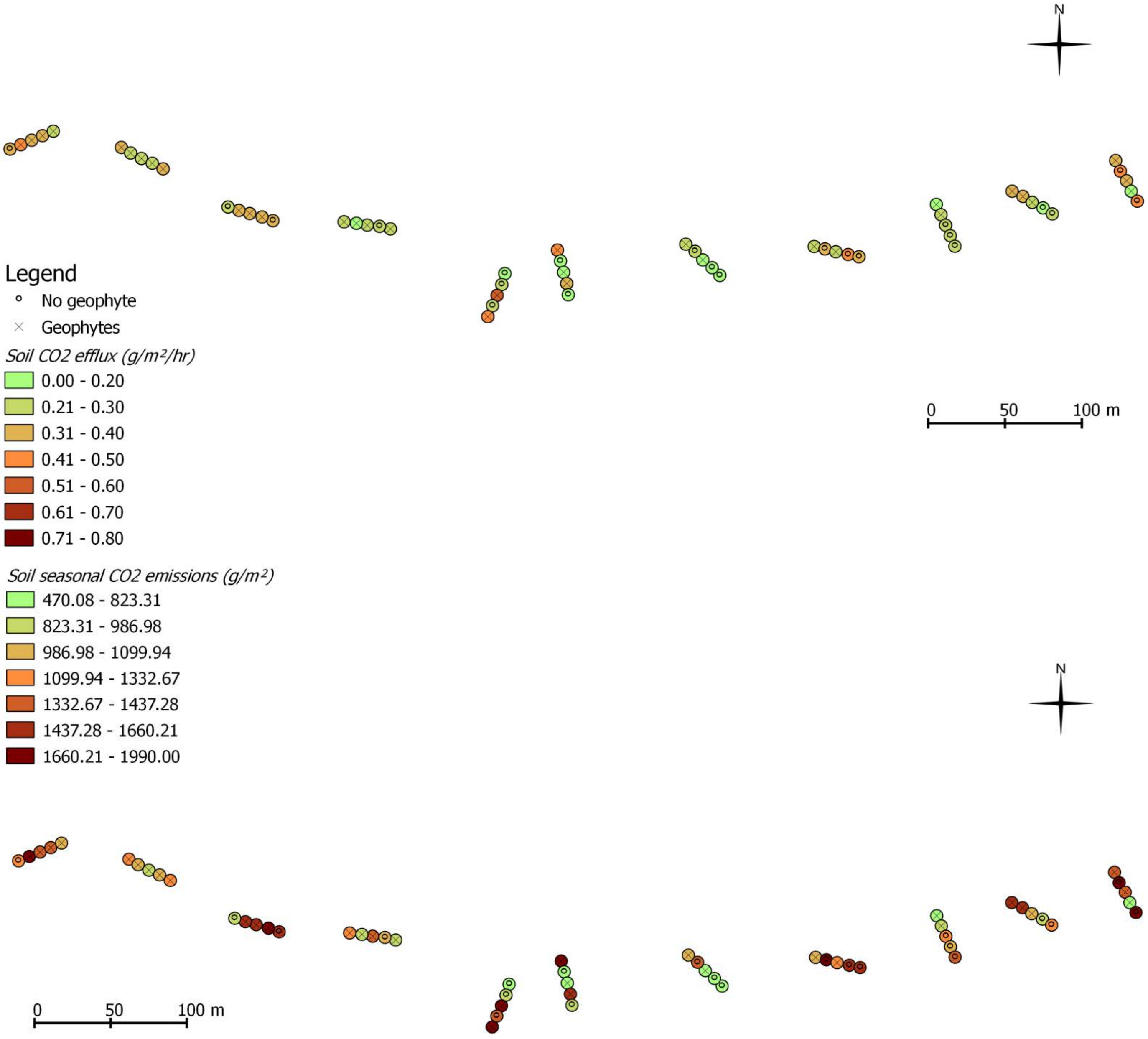

Figure 6: Maps of mean soil CO_2 efflux and seasonal modeled CO_2 emissions for transect 1 to 11 (from left to right)

Comparison between G spots and NG spots:

A comparison between G and NG spots was made using both the seasonal soil CO_2 emissions and the measured soil CO_2 effluxes. The mean values of modeled soil CO_2 efflux are always higher in geophyte spots compared to non-geophyte spots, independent of the aggregation scale (per transect/per spot) (Table 2). However, the difference is minor, as analyses of variance made for the modeled seasonal efflux didn't show any significant differences (per transect: F=1,04 and p=0,32>α ; per collar: F=0,63 and p=0,43>α). The test made on the measured values showed a significant difference (p<<0,05). Figure 7 gives a good overview of these results.

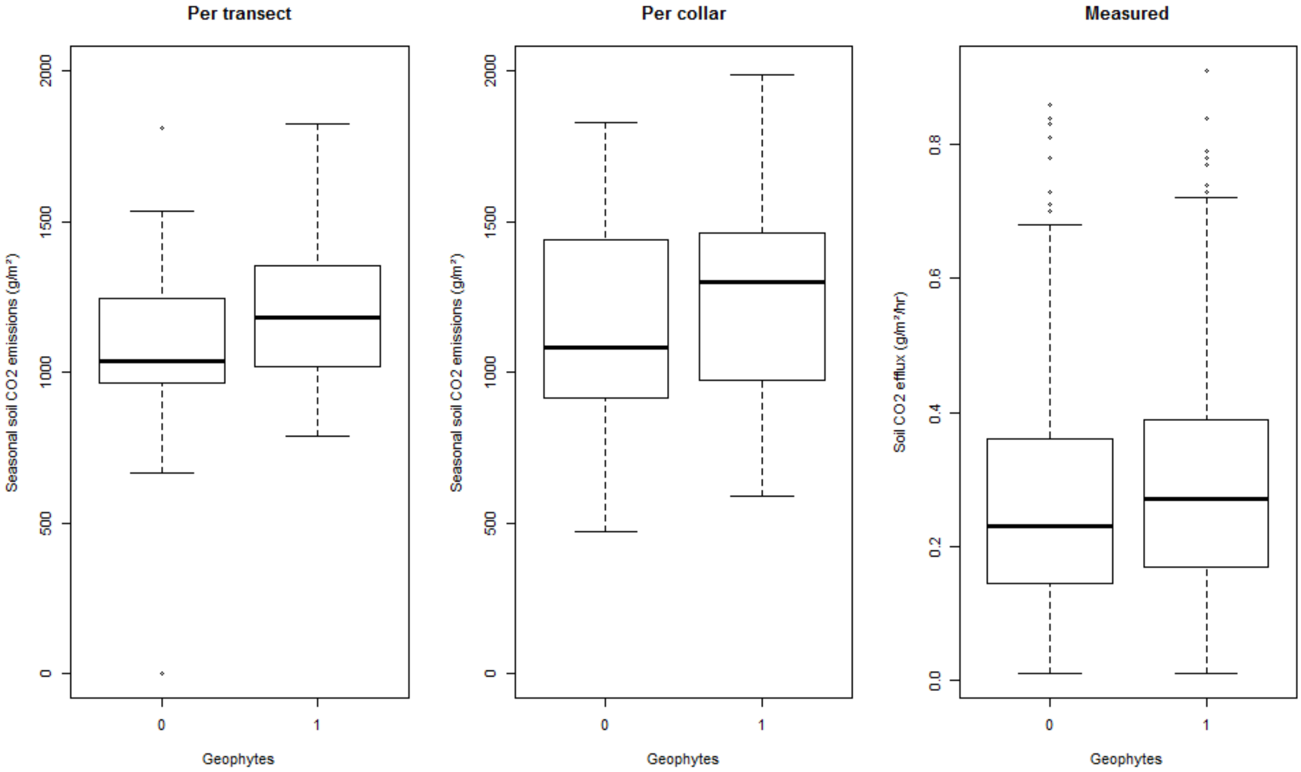

Figure 7: Difference between either the seasonal emissions modeled per transect or per collar or the mean soil efflux and the presence of Geophytes in the spots or not.

Geophytes, soil CO_2 efflux, soil carbon and nitrogen content and C:N ratio:

There isn't any correlation between C, N, C:N ratio and the soil CO_2 efflux in the site for neither of the horizons for which data was available (Figure 8). Nevertheless, there seems to be a small difference between geophytes and non-geophytes spots for the 0 to 10 cm layer of the top soil for both C and N content (Figure 9). But according to Kruskal-Wallis test, no significant differences between them have been enlightened.

.

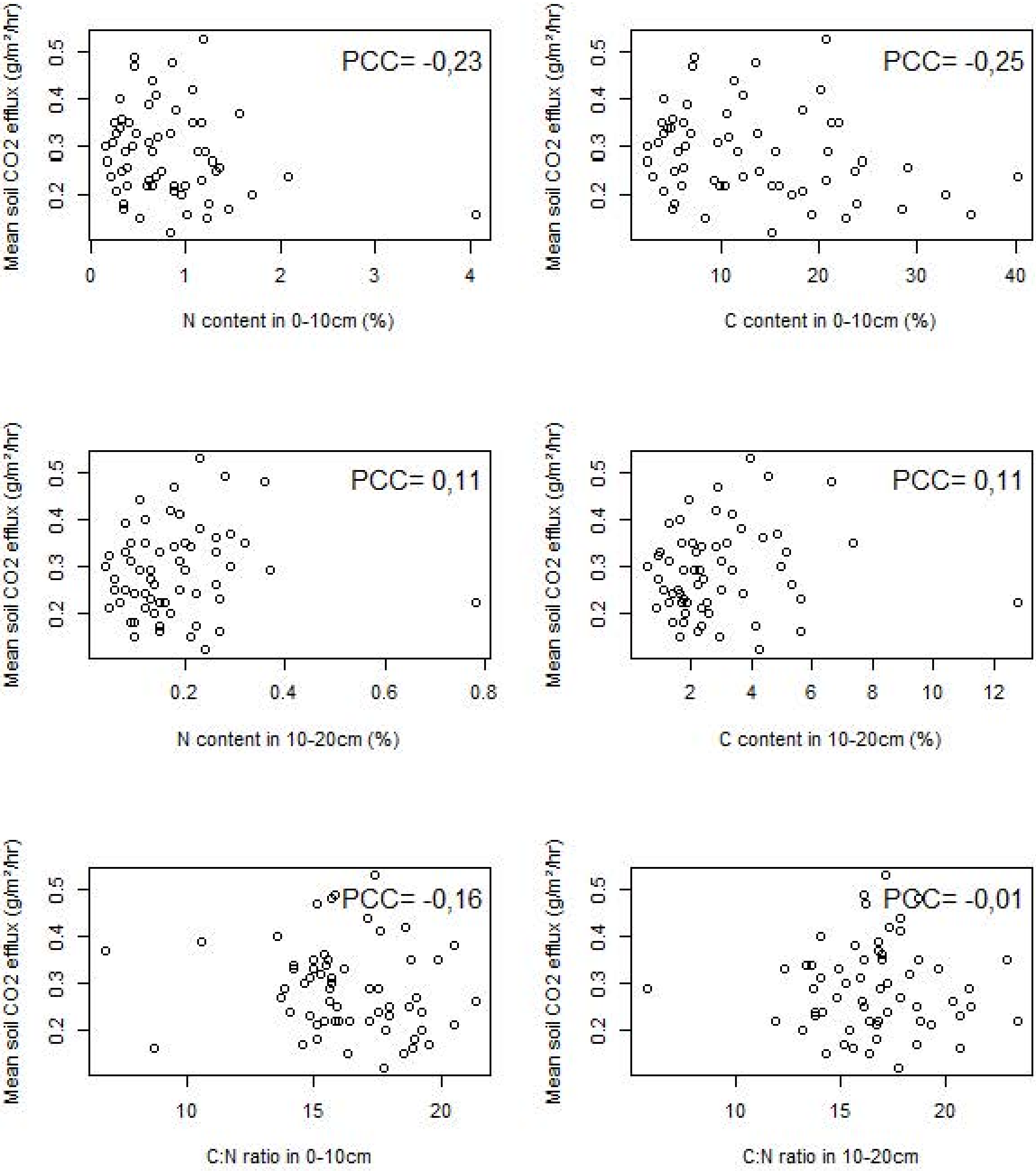

Figure 8: Correlation between N content, C content and C:N ratio at 0-10 cm and 10-20 cm and a mean value of the measured soil CO_2 value at each collars. PCC is Pearson's correlation coefficient for every plot.

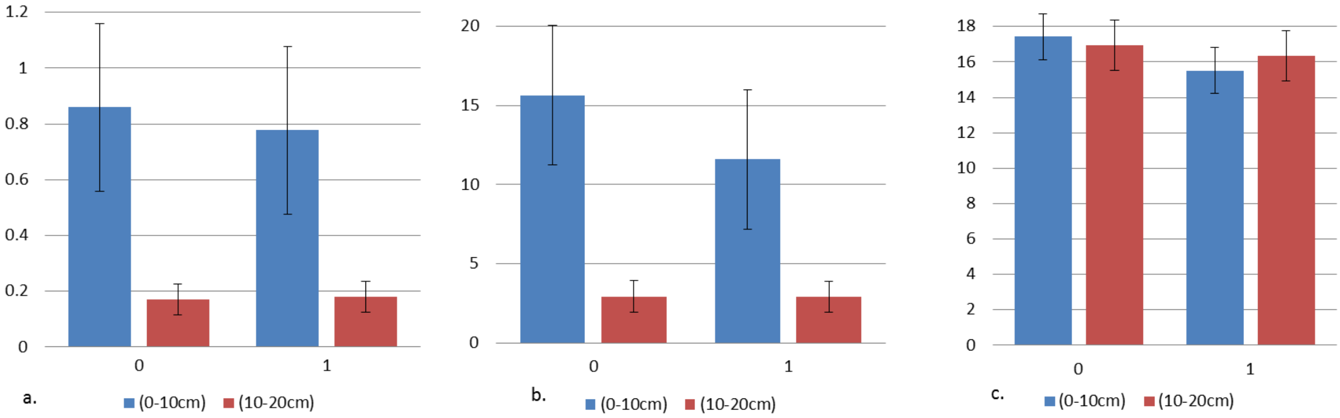

Figure 9: N content (a.) and C content (b.) in per cent and C:N ratio (c.) of the soil for geophytes (1; n=36) and non-geophytes (0; n=24) spot. Whiskers represent the standard deviation.

Soil CO2 efflux and rFRB:

Figure 10 shows that the soil CO_2 efflux and the rFRB calculated for each transects seem not to be related (Pearson's correlation coefficient of 0.02 with the mean soil CO_2 efflux and -0.02 with the seasonal soil CO_2 emissions).

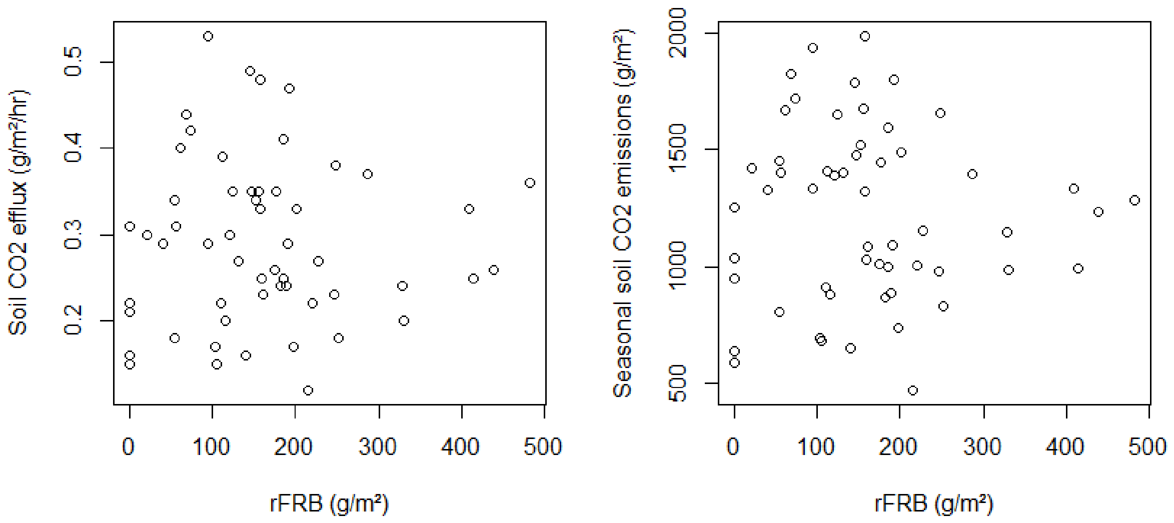

Figure 10: Mean soil CO_2 efflux and Seasonal soil emissions related to the rFRB at each collars

Discussion

Seasonal variation and relationship with soil temperature:

Authors	Type of vegetation	Min(gC/m²/hr)	Max(gC/m²/hr)
Longdoz *et al*. (2000)	Douglas	0.144	0.418
Davidson *et al.* (1998)	swamp site (peat)	0.010	0.200
Davidson *et al*. (1998)	well drained site	0.025	0.240
Davidson *et al*. (1998)	poorly drained site (hemlock/hardwood)	0.020	0.300
Epron *et al*. (1999)	beech (France)	0.063	0.649
Epron *et al.* (2001)	beech (France)	0.269	1.283
Borken *et al.* (2002)		0.100	0.125
Pilegaard *et al.*(2001)	beech	0.016	0.266
Janssens & Pilegaard (2003)	beech (Denmark)	0.016	0.760
Longdoz *et al*. (2000)	beech (Belgium)	0.150	0.927
Valentini *et al*. (2000)	beech	0.060	0.866
Singh & Gupta (1977)	generalization for temperate forest	0.095	0.507
Søe & Buchmann (2005)	beech- ash (Germany)	0.253	0.760
The present study	Beech (Germany)	0.010	0.910

Table 3: Soil CO_2 efflux range from other studies

With values between 0.01 and 0.91 $g.m^{-2}.h^{-1}$, the soil CO_2 efflux values we found are equivalent to the one found in other studies (see Table 3), from 0.016 to 0.760 $g.m^{-2}.hr^{-1}$ in a Danish beech forest (Janssens & Pilegaard, 2003) but rather in the lower end when compared to studies from French beech forests (Epron *et al*. 2001: 0.269 to 1.283 $g.m^{-2}.h^{-1}$).
The soil temperature at 10 cm explains 86% of the variation of soil CO_2 fluxes of the site, which is in the range of the results found by other studies based on exponential fit (around 80%; Davidson *et al*, 1998; Borken *et al*., 2002).
The predicted values are always above the measured one for the same temperature. A possible explanation is that our models are only based on soil temperature. Perrin *et al.* (2004) have shown that modeling only with temperature always overestimates the fluxes. Moreover the study site was a relatively wet site. Following the work of Perrin *et al.* (2004), above 0.27, the soil's pores are saturated and therefore the flux of carbon can decrease. And in our site, the SWC was nearly always above that value. Refining our model with the SWC could help getting a better fit and a better correlation.

Role of the geophytes:

We found that the RSS of the models were better when the spots with and without geophytes were separated, that implies the impact of the factor 'geophytes presence' on the model. That was a first clue on the possible impact of the plants. Seasonal estimates of soil

CO_2 fluxes were different between geophyte and non-geophyte spots, but these differences were not significant. Maybe the latter, is due to lack of precision of the model. This could well be the case, because when using the measured values, a small but significant difference between geophyte spots and non-geophyte spots was found. The mean soil CO_2 efflux is slightly higher on geophyte spots than on non-geophyte spots.

General evidence regarding the influence of forest understory vegetation on soil properties and/or soil CO_2 efflux is hard to find but differences between coniferous and broad-leaved forests or between forest ecosystems and grasslands are known (Raich & Tufekcioglu, 2000). Some studies showed that the vegetation had an impact on the soil CO_2 efflux by influencing several soil characteristics (quality of litter, C:N ratio, nutrient level, …) (Vincent G., 2006*;* Longdoz et al. 2000 ; Fang et al., 1998). In our site, there weren't any correlations between C:N ratio and soil CO_2 efflux independent of geophyte presence. It seems that the geophyte spots have a tendency to get a lower C and N content in the 0 to 10 cm soil layer but the difference to the non-geophytes spots was not significant.

Link between soil CO2 efflux and rFRB:

We found no correlation between soil CO_2 efflux and rFRB in our sites, even if roots are in general a major source of CO_2 in the soil and the FRB is one of the major components of belowground biomass (Tufekcioglu *et al.*, 1999). Jurasinski *et al*., (2012) found a good relation between the FRB and the rFRB (R^2=0,89) in the Hainich forest (Germany) at least for Ash roots. But they couldn't find the same for beech fine roots. In the light of the fact that beech is the constituting species in our site it is understandable that we did not find a good correlation. Further, one has to keep in mind that the model was calibrated for an unmanaged old forest of central Germany and was just adapted to the Stuthof' forest. Additionally we used the Jurasinski *et al*. (2012) beech model for all our species which might have introduced further bias.

Be it as it may, it is also worth to mention that rFRB may not be a good predictor for soil CO_2 efflux in general: In a recent study, Zhu *et al.*, (2009) found that the coarse root biomass was much more closely related to the soil CO_2 efflux in mixed forests than FRB.

Conclusion

By defining the geophyte spots as the spots having geophytes and the non-geophytes spots as spots without geophytes, a positive impact of the presence of geophytes on soil CO_2 efflux has been shown. However, we didn’t find any significant differences between soil carbon content, soil nitrogen content and C:N ratio between geophyte and non-geophyte spots, and so no visible impact from the geophytes on soil parameters. This implies that only the presence of the plant alters the soil CO_2 efflux. Still, it would be interesting to continue the research on that topic by changing the definition of geophytes spots and using geophyte cover instead to define them. Further, enhancing the acquisition soil parameters by including pH, root biomass, microbial biomass and microbial activity would be useful as they are important . It could help assessing if there really aren’t any change in the soil where the geophytes grow, and so knowing precisely if and on which parameter the geophytes have an impact and use the result to improve the model.

The absence of correlation between rFRB and soil CO_2 efflux could be overcome by calibrating the model specifically with the site data and by developing better models for the other species. In its current form the results are not convincing and given the fact that no relation was found in Jurasinski *et al*. (2012) for other trees than Ash shows that this subject is still ongoing research and the model results are not satisfying yet.

It would be also interesting to include the factor ‘geophyte’ directly into the soil CO_2 modeling, by looking more precisely on how it impacts the soil CO_2 efflux. Thus, it should be possible to integrate the different parameters that are influenced by geophyte presence in a model. This can only be fruitful if the definition of geophyte spots has been refined (see Appendix).

Bibliography

Ammer, Ch., S. Wagner. « An approach for modelling the mean fine-root biomass of Norway spruce stands ». *Trees - Structure and Function* 19, n°. 2 (2005): 145-153.

Borken, Werner, Yi-Jun Xu, Eric A. Davidson, Friedrich Beese. „Site and Temporal Variation of Soil Respiration in European Beech, Norway Spruce, and Scots Pine Forests“. *Global Change Biology* 8, Nr. 12 (2002): 1205–1216.

Cox P. M., Betts R.A., Jones C.D., Spall S.A., Totterdell I.J. Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. Nature 408, (2000): 184-187.

Dafni, A., C. Dan, I., Noy-Meir. « Life-cycle variation in geophytes ». *Annals of the Missouri Botanical Garden* (1981): 652.

Davidson EriC. A., Elizabeth Belk, Richard D. Boone. „Soil Water Content and Temperature as Independent or Confounded Factors Controlling Soil Respiration in a Temperate Mixed Hardwood Forest“. *Global Change Biology* 4, Nr. 2 (1998): 217–227.

Ellenberg H, Leuschner Ch. «Vegetation Mitteleuropas mit den Alpen». Ulmer Verlag, Stuttgart, (2010): 1334.

Epron, Daniel, L Farque, Eric Lucot, Pierre-Marie Badot. « Soil CO2 efflux in a beech forest: Dependence on soil temperature and soil water content ». *Annals of Forest Science* 56, n°. 3 (1999): 221-226.

Epron, Daniel, Laetitia Farque, Eric Lucot, Pierre-Marie Badot. « Soil CO2 efflux in a beech forest: the contribution of root respiration ». *Annals of Forest Science* 56, n°. 4 (1999): 7.

Epron, Daniel, Valerie Le Dantec, Eric Dufrene, Andre Granier. « Seasonal dynamics of soil carbon dioxide efflux and simulated rhizosphere respiration in a beech forest ». *Tree Physiology* 21, n°. 2-3 (2001): 145 -152.

Fang, C., John B. Moncrieff, Henry L. Gholz, Kenneth L. Clark. « Soil CO2 efflux and its spatial variation in a Florida slash pine plantation ». *Plant and Soil* 205, n°. 2 (1998): 135-146.

Granier, A., E. Ceschia, C. Damesin, E. Dufrêne, D. Epron, P. Gross, S. Lebaube, et al. « The Carbon Balance of a Young Beech Forest ». *Functional Ecology* 14, n°. 3 (2000): 312-325.

Hanson, P. J., Edwards, N. T., Garten, C. T., Andrews, J. A. « Separating root and soil microbial contributions to soil respiration: a review of methods and observations ». *Biogeochemistry* 48, n°. 1 (2000): 115–146.

Hermy, M., O. Honnay, L. Firbank, C. Grashof-Bokdam, J. E Lawesson. « An ecological comparison between ancient and other forest plant species of Europe, and the implications for forest conservation ». *Biological conservation* 91, n°. 1 (1999): 9–22.

Herrmann, N., G. Weiss, W. Durka. « Biological flora of Central Europe: Muscari tenuiflorum Tausch ». *Flora-Morphology, Distribution, Functional Ecology of Plants* 201, n°. 2 (2006): 81–101.

IPCC, Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Geneva, Switzerland. (2007): 104.

Janssens, Ivan A., Kim Pilegaard. „Large Seasonal Changes in Q10 of Soil Respiration in a Beech Forest“. *Global Change Biology* 9, Nr. 6 (2003): 911–918.

Jurasinski, G., Jordan A., Glatzel, S.« Mapping soil CO2 efflux in an old-growth forest using regression kriging with estimated fine root biomass as ancillary data ». *Forest ecology and management* 263, n°. 1 (2012): 101.

Lloyd J., Taylor J. A. „On the Temperature Dependence of Soil Respiration“. *Functional Ecology* 8, Nr. 3 (1994): 315–323.

Longdoz, B., M. Yernaux, M. Aubinet. « Soil CO2 Efflux Measurements in a Mixed Forest: Impact of Chamber Disturbances, Spatial Variability and Seasonal Evolution ». *Global Change Biology* 6, n°. 8 (2000): 907-917.

Morschhauser, T., K. Rudolf, Z. Botta-Dukát, B. Oborny. « Density-dependence in the establishment of juvenile< i> Allium ursinum</i> individuals in a monodominant stand of conspecific adults ». *Acta Oecologica* 35, n°. 5 (2009): 621–629.

Perrin, Dominique, Éric Laitat, Michel Yernaux, Marc Aubinet. « Modélisation de la réponse des flux de respiration d'un sol forestier selon les principales variables climatiques ». *Biotechnoogy, Agronomy, Society and Environment* 8, n°. 1 (2004): 15-26.

Pilegaard, K, P Hummelshøj, N.O Jensen, Z Chen. „Two years of continuous CO2 eddy-flux measurements over a Danish beech forest“. *Agricultural and Forest Meteorology* 107, Nr. 1 (2001): 29–41.

Raich, J, W., Tufekciogul, A, „Vegetation and soil respiration: Correlations and controls“. Biogeochemistry 48, Nr. 1 (2000): 71–90.

Revelle, Roger, Hans E. Suess. « Carbon Dioxide Exchange Between Atmosphere and Ocean and the Question of an Increase of Atmospheric CO2 During the Past Decades ». Tellus 9, n°. 1 (1957): 18–27.

Service de l'observation et des statistiques (2011). Chiffres clés du climat, France et Monde. Repères – Janvier 2011

Singh, J., S. Gupta. „Plant decomposition and soil respiration in terrestrial ecosystems“. *The Botanical Review* 43, Nr. 4 (1977): 449–528.

Søe, Astrid R. B., Nina Buchmann. „Spatial and Temporal Variations in Soil Respiration in Relation to Stand Structure and Soil Parameters in an Unmanaged Beech Forest“. *Tree Physiology* 25, Nr. 11 (Januar 11, 2005): 1427–1436.

Tufekcioglu, A., J. Raich, T. Isenhart, R. Schultz. „Fine Root Dynamics, Coarse Root Biomass, Root Distribution, and Soil Respiration in a Multispecies Riparian Buffer in Central Iowa, USA“. Agroforestry Systems 44, Nr. 2 (1998): 163–174.

Valentini, R., G. Matteucci, A. J. Dolman, E.-D. Schulze, C. Rebmann, E. J. Moors, A. Granier, et al. « Respiration as the Main Determinant of Carbon Balance in European Forests ». Nature 404, n°. 6780 (avril 20, 2000): 861-865.

Vincent, G. « Etude de la variabilité spatiale et temporelle dela respiration de sols forestiers hydromorphes à ennoyage temporaire ». Science de la Vie, Université de Franche Comté, 2006. http://artur.univ-fcomte.fr/ST/BIOECO/these/vincent_gaelle.pdf.

Zhu, Jiaojun, Qiaoling Yan, A'nan Fan, Kai Yang, Zhibin Hu. „The role of environmental, root, and microbial biomass characteristics in soil respiration in temperate secondary forests of Northeast China“. Trees - Structure and Function 23, Nr. 1 (2009): 189–196.

Appendix: *Toward a definition of Geophytes spots*

Several definitions are possible to separate geophyte spots from non-geophyte spots. The one used throughout this work was to take the presence/absence of geophytes within the soil CO_2 efflux measurement collars. After analyzing the results of the vegetation survey we noticed that this definition might better be modified to one that uses the geophyte cover within the surroundings of the collar instead (see Table 4). Considering the percentage of cover of geophytes, the results differ considerably under different geophyte spot definitions (cover values ranging from above 30 to above 10%, see Figure 11) Using the cover separation method, for any percentage used, the non-geophyte spots have always a higher soil CO_2 efflux than the geophyte spot. This contradicts the result found using the 1st definition.

One reason might be that the vegetation survey has been made quite late during the season, so the results can be unreliable because some of the plants may already been dead and decayed. The first definition based on presence or absence of geophytes in the collars (decided throughout the measurement campaign) has been used for modeling and further analysis.

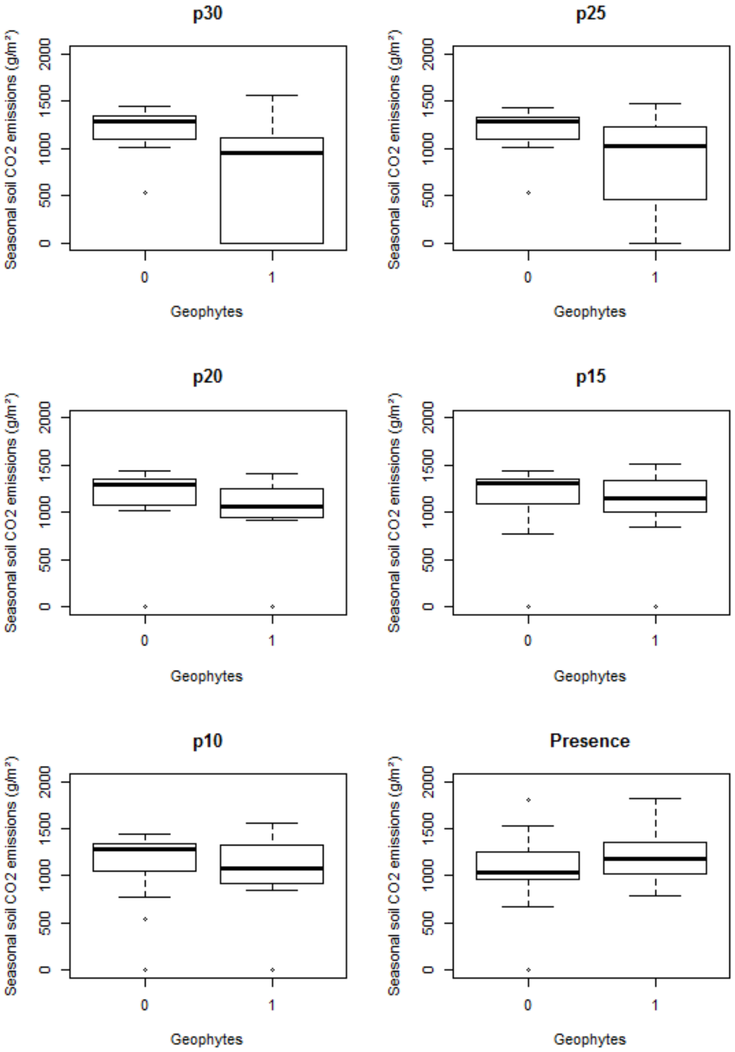

Figure 11: Difference between geophyte and non-geophyte spot according to the different definitions showed in Table 4.

Transect	Collars	p30	p25	p20	p15	p10	presence
1	1	0	0	0	0	0	0
	2	0	0	0	0	0	1
	3	0	0	0	0	0	1
	4	0	0	0	0	0	1
	5	0	0	0	0	0	1
2	6	1	1	1	1	1	1
	7	1	1	1	1	1	1
	8	1	1	1	1	1	1
	9	0	0	0	1	1	1
	10	0	0	0	0	1	1
3	11	0	0	0	0	1	0
	12	0	1	1	1	1	1
	13	0	0	0	0	0	1
	14	0	0	0	1	1	1
	15	0	0	1	1	1	0
4	16	0	0	0	0	0	1
	17	0	0	0	0	0	1
	18	0	0	1	1	1	1
	19	1	1	1	1	1	0
	20	1	1	1	1	1	1
5	21	0	0	0	1	1	0
	22	0	0	0	0	0	0
	23	0	0	0	1	1	1
	24	0	0	0	0	0	0
	25	0	0	0	0	0	1
6	26	1	1	1	1	1	1
	27	0	0	1	1	1	0
	28	1	1	1	1	1	1
	29	1	1	1	1	1	1
	30	1	1	1	1	1	0
7	31	1	1	1	1	1	1
	32	0	0	0	1	1	0
	33	0	0	0	0	1	1
	34	1	1	1	1	1	0
	35	0	0	0	0	0	0
8	36	0	1	1	1	1	1
	37	1	1	1	1	1	0
	38	0	0	0	0	0	1
	39	0	0	0	0	1	0
	40	0	0	0	0	1	0
9	41	0	0	0	1	1	1
	42	0	0	1	1	1	1
	43	0	0	0	0	0	0
	44	1	1	1	1	1	0
	45	0	0	0	0	0	0
10	46	0	0	0	1	1	1
	47	0	0	0	0	0	1
	48	0	0	0	0	0	1
	49	0	0	1	1	1	0
	50	0	0	1	1	1	0
11	51	0	1	1	1	1	1
	52	0	1	1	1	1	0
	53	0	0	0	0	1	1
	54	1	1	1	1	1	1
	55	1	1	1	1	1	0
12	56	0	0	0	0	0	0
	57	1	1	1	1	1	1
	58	1	1	1	1	1	0
	59	0	0	0	0	0	1
	60	0	0	1	1	1	1

Table 4: Different definitions for dividing the spot between geophytes or non-geophytes. Column p30 to p10 represent the collar where the geophytes cover more than 30 to 10 percent of the soil respectively, in the column presence a geophyte spot is a collar where geophytes grow inside.

Abstract

To define a forest as carbon sink or source the most important parameter is the soil carbon dioxide efflux (CO_2). Several studies have been made to assess more precisely the involved factors. The influence of soil temperature and humidity on soil CO_2 efflux has since long been known and both parameters are often included in current models. But there is still some variability that is more difficult to explain. Numerous factors, that have an effect on soil parameters, can impact the soil CO_2 efflux. Recent studies showed that the fine root biomass (FRB) of trees had an influence on this efflux. These studies have led to modeling of FRB for different tree species and their use in respiration models with more or less success.

A reason given to explain the lack of correlation between the modeled FRB (rFRB) was that the activity of spring geophytes could have an impact on the soil properties. Here, I show that the soil CO_2 efflux of geophyte spots (~0.29 $gC.m^{-2}.hr^{-1}$) was significantly higher than that of non-geophyte spots (~ 0.27 $gC.m^{-2}.hr^{-1}$). However, no impact of the presence of geophytes was found on soil carbon (C), nitrogen (N) content, or C:N.

Résumé

L’efflux de dioxyde de carbone (CO_2) du sol est le paramètre qui peut avoir le plus d’impact sur la détermination du rôle de puits ou de source de carbone d’une forêt. De nombreuses études ont été réalisées pour déterminer plus précisément les facteurs pouvant le faire varier. Si l’influence de la température ou encore de l’humidité du sol a été depuis longtemps mise en évidence et est bien prise en compte dans les modèles, il reste toujours une certaine variabilité qui est plus complexe à expliquer. En effet, de nombreux facteurs peuvent impacter cet efflux, notamment des facteurs ayant un impact sur les propriétés du sol. De récentes études ont montrés par exemple que la biomasse racinaire (FRB) des arbres avait une influence sur cet efflux de CO_2. Ces études ont ensuite aboutis sur des modèles de FRB pour les différentes espèces d’arbres et leur utilisation dans les modèles de respiration. Une raison avancée pour l’absence de corrélation entre la FRB modélisée et le flux de CO_2 du sol est que l’activité des géophytes au printemps peut impacter certaines propriétés du sol. Il a ici été mis en évidence que des points de mesures d’efflux du sol contenant des géophytes avait un efflux de CO_2 (~0.29 $gC.m^{-2}.hr^{-1}$) légèrement (mais significativement) plus important que ceux n’en ayant pas (~0.27 $gC.m^{-2}.hr^{-1}$). Aucun impact sur le contenu en carbone (C) ou en azote (N) du sol ainsi que sur le rapport C/N n’a pu être mis en évidence.