FORESTRY IDEAS, 2010, vol. 16, No 2 (40)

EXCHANGES OF CO_2 THROUGH THE SOIL-ATMOSPHERE INTERPHASE IN BROADLEAF AUTOCHTHONOUS FORESTS FROM THE NW OF SPAIN (*QUERCUS ROBUR* L. OR *BETULA ALBA* L.): INTRA-ANNUAL VARIATIONS

Irene Fernandez, Beatriz Carrasco, and Ana Cabaneiro

Departamento de Bioquímica del Suelo, Instituto de Investigaciones Agrobiológicas de Galicia, Consejo Superior de Investigaciones Científicas (CSIC), Apartado 122, E-15780 Santiago de Compostela, Spain. E-mail: ifernandez@iiag.csic.es

UDC 574.4

Received 13 August 2010
Accepted 01 June 2011

Abstract

It is widely accepted that increasing concentrations of "greenhouse gases" will raise the temperatures of the Earth's atmosphere and oceans. By acting as C sinks, forest ecosystems can store significant amounts of CO_2. There is, therefore, a growing need to evaluate the C cycle in forest ecosystems. Quatification of the C stored in forests, both in plants and soils (global balance between CO_2 fixation and CO_2 emission), and the knowledge of the main factors affecting net C fluxes in these ecosystems are basic and essential tools to control this environmental problem. This research work encompasses the study of the seasonal variations of the CO_2 emissions from soils of two different types of deciduous forests of the temperate-humid zone (*Quercus robur* L. or *Betula alba* L.) located in Galicia (Northwestern Spain). With this objective, permanent forest plots were established and *in situ* determinations of soil CO_2 effluxes were assessed using a portable infrared gas analyser. The determinations of the exchanges of this gas through the soil-atmosphere interphase were periodically carried out during a whole year (winter, spring, summer and autumn) in order to quantify the seasonal variations of these soil emissions. The significance of the seasonal variations observed for both types of forests and the implications of the results obtained in the global warming mitigation strategies, as well as the relation of these CO_2 effluxes with soil temperature, are discussed.

Key words: *Betula alba*, greenhouse gases, *Quercus robur*, seasonal fluctuations, soil CO_2 effluxes, soil organic matter, terrestrial C cycle.

Introduction

Decidous forests are part of the European cultural heritage and are a key component of Galician landscapes. By amplifying parent material alteration with the development of fine and coarse tree roots, these kinds of ecosystems contribute to soil depth increase, to preserve fertility, productivity as well as C fixation and to prevent soil erosion. Since both the biosphere and the edaphosphere of these forests are important organic matter reservoirs, their degradation could generate considerable emissions of greenhouse gases (GHG) due to biomass decomposition and soil organic matter mineralization. For this reason, adequate silvicultural managements are necessary to keep their C retention capacity and to avoid the convertion of these forests into a possible source of CO_2 that could contribute to global warming.

It has been reported that the CO_2 concentration in the air is responsible for more than 70% of the greenhouse effect (Lashof and Ahuja 1990) and some authors predict that CO_2 emissions to the atmosphere could increase from 7.4 GtC.year^{-1} in 1997 to approximately 26 GtC.year^{-1} in 2100 (Houghton et al. 1996). Nowadays, considering absorptions by natural sinks and emissions by CO_2 sources, the net balance of total emissions towards the atmosphere amounts to 3 GtC.year^{-1}. As a result of this excess of CO_2, the greenhouse effect have been increased, raising the mean temperature of the atmosphere by 0.7ºC since the industrial period commencement. Although the effects of elevated CO_2 concentration in the ecosystem functioning are uncertain, many scientist state that doubling CO_2 atmospheric concentrations could produce serious environmental consequences (Lindzen 1994, Adams et al. 1999), with biological, economical and edaphic negative effects.

Although some authors indicate that the soil respiration rate is scarcely sensitive to the environmental temperature, it is widely acepted that a global increase of the temperature can cause soil C losses if the soil have enough moisture (Leirós et al. 1999, Gallardo and Merino 2007). For this reason, the evaluation of the C effluxes and the knowledge of the main factors affecting their intensity could be basic and essential tools to control this environmental problem.

Therefore, the aim of this research is to quantify the CO_2 exchanges in the soil-atmosphere interphase in *Quercus robur* L. or *Betula alba* L. ecosystems located in Galicia (Northwestern Spain). This research work also encompasses the study of the seasonal variations of the soil CO_2 emissions during a whole year, in order to enhance the knowledge of the C cycle in these types of broadleaf autochthonous ecosystems.

Methods and Study Area

Deciduous species such as oak and birch are the natural forests in the NW of Spain (Galicia). This geographic area is located in the temperate-humid climate zone and the main meteorological records corresponding to the period of study (temperature and rainfall values during the year 2009) are included in Fig. 1. The forest plots studied were located throughout this region and were selected to represent the whole range of stand densities, undergrowth types and growing conditions in Galician forests for these two tree species. None or scarce silvicultural treatments were applied to the forests selected for this study and the spatial distribution of the different plots is represented on the regional map included in Fig. 1.

To monitor soil CO_2 effluxes, 12 oak and 12 birch permanent forest plots (around 1000 m^2) were established, in order to determine the intra-annual variation of the CO_2 exchanges through the soil-atmosphere interphase in this type of broadleaf autochthonous ecosystems. In all permanent plots, *in situ*

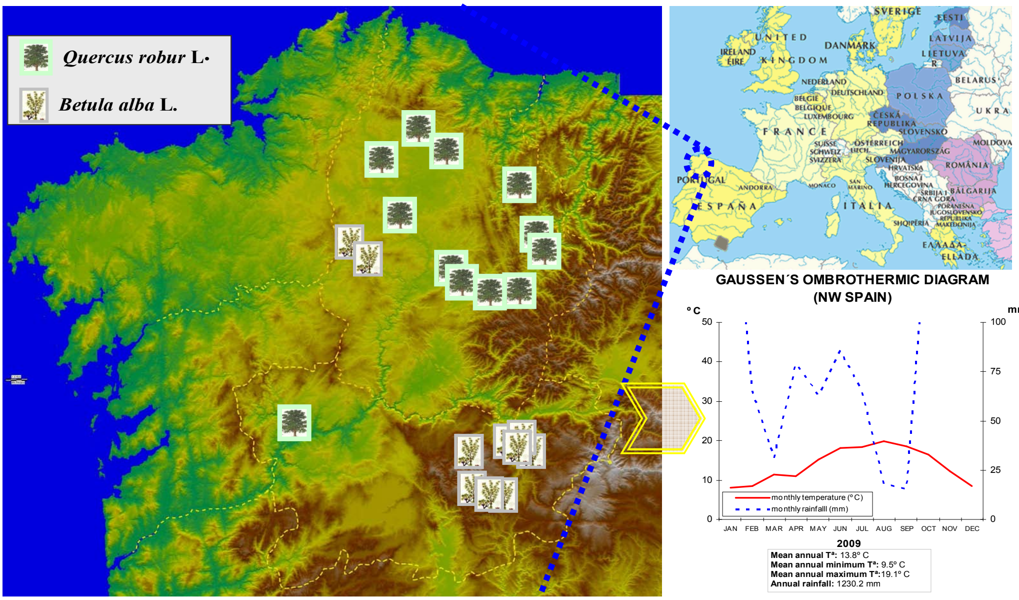

Fig. 1. Geografic distribution of the selected oak and birch forest plots and general climatic conditions of the Galician region during the studied period.

measurements of soil C effluxes were assessed using a portable infrared gas analyser (EGM-4, PP Systems) and expressed as g CO_2.m^{-2}.h^{-1}. For each forest plot a squared pattern (4 rows and 6 columns) was established and 24 punctual determinations of the soil CO_2 emissions were periodically carried out during the 4 seasons of the year (winter, spring, summer and autumn'2009) in order to quantify the seasonal variations of the edaphic releases to the atmosphere. Simultaneously in each measurement point, a 10 cm probe was introduced into the forest floor to register the subsurface soil temperature.

After the removal of the litter and the duff, a representative soil sample (composed by mixing 24 subsamples regularly taken following the previously indicated squared pattern) from the upper layer of the A horizon (0–15 cm) were collected in winter to determine the main soil caracteristics. The soil pH was measured using a 1:2.5 soil:water ratio. Organic C was determined by dry combustion in a Carmhograph 12 (Whostoff, Germany), with primary and secondary ovens at 90ºC and 400ºC, respectively. Total soil C content, expressed as kgC.m^{-2}, was estimated by considering only the 0–15 cm depth layer and a soil density of 1000 kg.m^{-3}. Statistical analyses were performed using the computer software SPSS 15.0 (2006). ANOVA test was applied to analyse the possible variations between oak and birch soils.

Results and Discussion

For both types of ecosystems, all the selected forest plots exhibited acidic and highly organic soils, with soil pH values around 4.5 and averaged soil C contents always surpassing the 6.5% for *Betula alba* L. and the 8.5% for *Quercus robur* L. Thus, within this temperate-humid zone, oak forests seem to exhibit a significantly higher soil C content ($P<0.05$) than birch plantations. The values found in these soils are in agreement with the results obtained for different types of forest soils of this region (Sánchez-Rodríguez et al. 2002; Fernandez et al. 2004; Diaz-Maroto et al. 2005, 2007; Fernandez et al. 2006) and also with soils from other countries of similar latitudes (Mansson and Falkengren-Grerup 2003).

Annual soil CO_2 emissions to the atmosphere from oak forests were slightly lower than effluxes from birch plantations (Table 1). The annual mean value of the soil CO_2 emissions exhibited a significant negative correlation with the total soil C content (Fig. 2a) and, despite the scarce variability of the soil pH, a significant positive correlation with this edaphic parameter (Fig. 2b) and, due to this, the quantity of C released to the atmosphere was lower for more organic and acidic soils.

The values of the averaged annual soil CO_2 emissions found for these broadleaf autochthonous tree species are slightly higher than the results found for coniferous forests from the same area (Carrasco 2008).

When the results obtained for each season of the year were considered, a similar trend in both types of ecosystems was observed along the whole studied period, clear seasonal variations being revealed. Although intra- and interspecific differences were found, minimum values of the mean soil CO_2 emissions to the atmosphere were always observed during the winter season for both birch and oak ecosystems, these values differing significantly (ANOVA, $P<0.05$, $n=12$) from spring, summer and autumn emissions (Fig. 3). In all cases, maximum values of the mean soil CO_2 emissions were measured in the hotter seasons, particularly in the summer with values surpassing twice the soil C emissions observed during the winter (Table 1).

Furthermore, a very similar pattern was observed when values of the sub-

Table 1. Averaged values (mean ± standard deviation) of some edaphic parameters related to the soil C cycle for oak and birch forest ecosystems.

Parameters		***Quercus robur* L.** $n=12$	***Betula alba* L.** $n=12$
pH		4.65 ± 0.36	4.56 ± 0.29
Soil organic carbon (0-15 cm depth), kg C.m^{-2}		13.02 ± 3.35	9.89 ± 3.79
Soil CO_2 emissions (annual mean), g CO_2.m^{-2} h^{-1}		1.11 ± 0.25	1.24 ± 0.31
Seasonal soil CO_2 emissions, g CO_2.m^{-2} h^{-1}	**WINTER**	0.67 ± 0.27	0.61 ± 0.19
	SPRING	1.30 ± 0.34	1.46 ± 0.49
	SUMMER	1.39 ± 0.44	1.72 ± 0.55
	AUTUMN	1.07 ± 0.42	1.18 ± 0.62

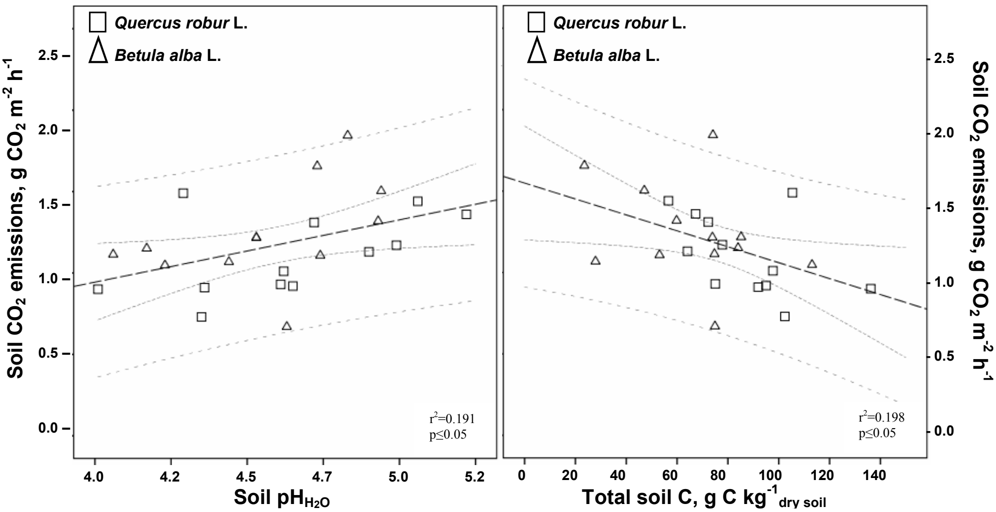

Fig. 2. Relationship between the annual averaged soil CO_2 emission rates and some edaphic characteristics.

surface edaphic temperature were analysed (Fig. 4), since soil CO_2 emission rates significantly correlated with this instant edaphic temperature, for both *Betula alba* or *Quercus robur* ecosystems (Fig. 5), this correlation being even slightly stronger in *B. alba* plots. Other authors also found a similar relation between these two parameters, the soil temperature and CO_2 exchange rates (Asensio et al. 2007, Shi et al. 2009).

Conclusions

Based on the experimental results obtained in this study, the following conclusions can be drawn:

– The tree species determines the total soil C content, oak forests normally exhibiting more organic soils than birch ecosystems.

– Significant seasonal variations of soil CO_2 emission rates were observed in both types of deciduous ecosystems.

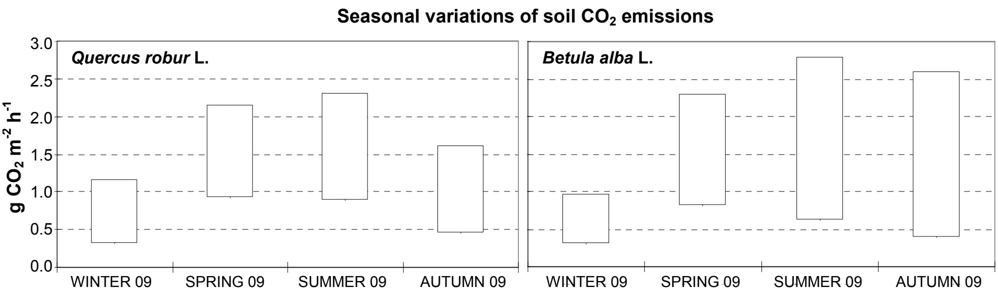

Fig. 3. Range of the soil CO_2 emissions in oak and birch ecosystems for the different seasons of the year.

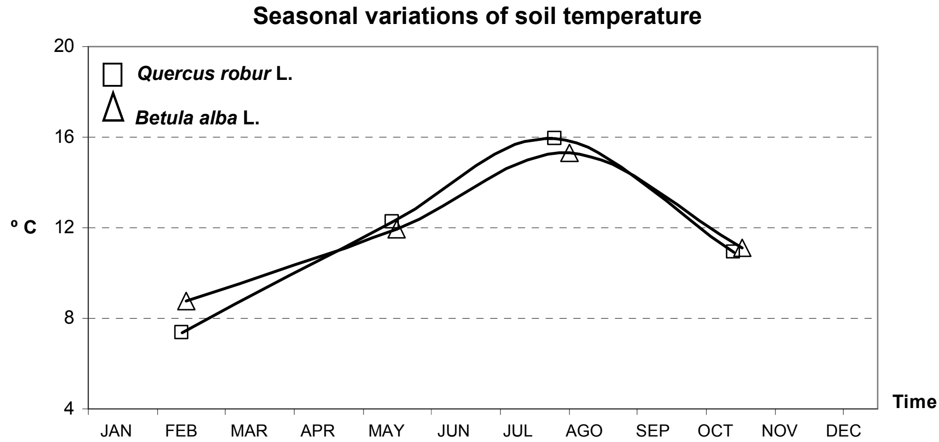

Fig. 4. Averaged subsurface edaphic temperature (°C) in oak and birch forests obtained simultaneously to the determination of the seasonal soil CO_2 emission rates.

– Edaphic emissions were slightly lower in oak woodlands as compared with birch forests and in both tree species the soil pH have a significant influence on the edaphic C effluxes.

– A significant correlation between the soil CO_2 emission rate and the edaphic temperature were observed in the two types of ecosystems considered.

– These results can be used as a tool for forest management and they can contribute not only to quantify the total CO_2 released to the atmosphere in the

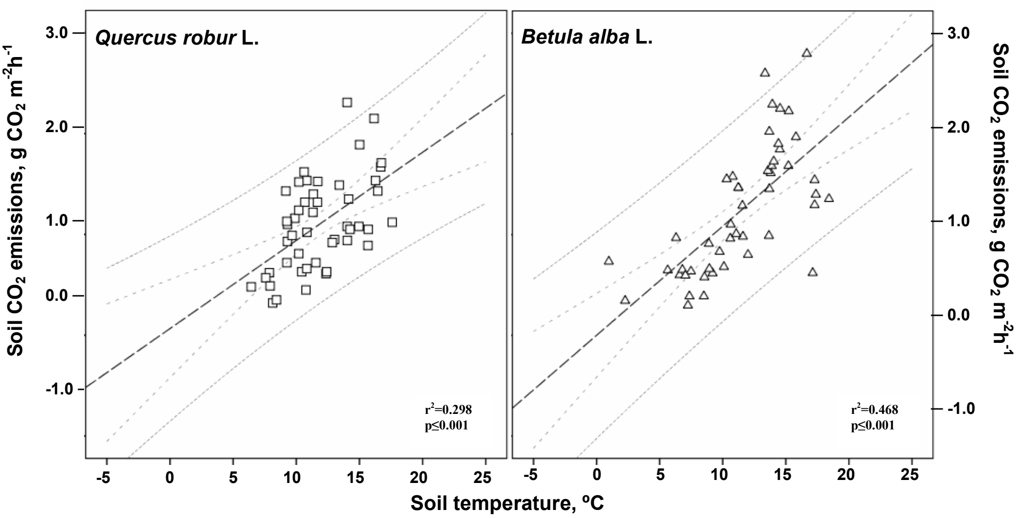

Fig. 5. Relationship between the averaged soil CO_2 emission rate and the subsurface soil temperature seasonally determined in oak and birch forests.

contemporary climatic conditions but also to evaluate the role of these deciduous forests in the global terrestrial C cycle.

Acknowledgements

This research was conducted as a part to the project No AGL2007-66739-C02-02 financed by the Spanish Government (MEC) and the European Commission. We thank the departments of "Ingenería Agroforestal" and "Producción Vegetal" of the University of Santiago de Compostela for their invaluable assistance in plot selection and site index calculation. We also wish to thank Esteban Gómez, Samuel Porto and Horacio Ferradás for their help in the field. Finally, we thank Ana Argibay, César González and Tamara Miguéns for their technical assistance in the laboratory and fieldwork, as well as Dr. Antonio de María Angulo, president of Silvanus, for showing interest in this reseach.

References

Adams R.M., Hurd B.H., Reilly J. 1999. Agriculture and global climate change: A Review of Impacts to U.S. Agricultural Resources. The Pew Center on Global Climate Change, Arlington, VA.

Asensio D., Peñuelas J., Ogaya R., Llusiá J. 2007. Seasonal soil and leaf CO_2 exchange rates in a Mediterranean holm oak forest and their response to drought conditions. Atmospheric Environment 41: 2447–2455.

Carrasco B. 2008. Efecto del tratamiento silvícola sobre la dinámica de la materia orgánica edáfica. Implicaciones en el cambio global. Dissertation Degree, University of Santiago de Compostela, 113 p.

Diaz-Maroto I.J., Vila-Lameiro P., Silva-Pando F.J. 2005. Autoécologie des chênaies de *Quercus robur* L. en Galice (Espagne). Annalls of Forest Science 62: 737–749.

Díaz-Maroto I.J., Fernández-Parajes J., Vila-Lameiro P. 2007. Chemical Properties and Edaphic Nutrients Content in Natural Stands of *Quercus pyrenaica* Will in Galicia, Spain. Eurasian Soil Science 40: 522–531.

Fernandez I., Cabaneiro A., González-Prieto S. 2004. The use of isotopic tracer (^{13}C) to monitor soil organic matter transformations caused by heating. Rapid communications in Mass Spectrometry 18: 435–442.

Fernandez I., Cabaneiro A., González-Prieto S. 2006. Partitioning CO_2 Effluxes from an Atlantic Pine Forest Soil between Endogenous Soil Organic Matter and Recently Incorporated ^{13}C-Enriched Plant Material. Environmental Science & Technology 40: 2552–2558.

Gallardo J.F., Merino A. 2007. El ciclo del carbono y la dinámica de los sistemas forestales. In: El papel de los bosques españoles en la mitigacion del cambio climático (Bravo F., Ed.). Fundación Gas Natural, Spain.

Houghton J.T., Meira Filho L.G., Callander B.A., Harris N., Kattenberg A., Maskell K. 1996. Climate change 1995: The Science of Climate Change: Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K.

Lashof D.A., Ahuja D.R. 1990. Relative Contribution of Greenhouse Emissions to Global Warming. Nature 344: 529–531.

Leirós M.C., Trasar-Cepeda C., Seone S., Gil-Sotres F. 1999. Dependence of mineralization of soil organic matter on temperature and moisture. Soil Biology and Biochemistry 31: 327–335.

Lindzen R.S. 1994. On the scientific basis for global warming scenarios. Environmental Pollution 83: 125–134.

Mansson K.F., Falkengren-Grerup U. 2003. The effect of nitrogen deposition on nitrification, C and nitrogen mineralization and litter C:N ratios in oak (*Q. robur*) forests. Forest Ecology and Management 179: 455–467.

Sánchez-Rodríguez F., López C., Rodríguez-Soalleiro R., Español E., Merino A. 2002. Influence of edaphic factors on the productivity of *Pinus radiata* D. Don plantations in NW Spain. Forest Ecology and Management 171: 181–189.

Shi A., Li Y., Wang S., Wang G., Ruan H., He R., Tang Y., Zhang Z. 2009. Accelerated soil CO_2 efflux after conversion from secondary oak forest to pine plantation in southeastern China. Ecological Research 24 (6): 1257-1265.