Final Report Summary - DIESEL (Developing Improved Estimations of Soil CO2 Effluxes at ecosystem Level)

The soil carbon dioxide (CO2) efflux is the second largest contributor to terrestrial CO2 exchanges, similar to uptake by terrestrial photosynthesis. Soil CO2 efflux (Fsoil) is commonly considered equal to soil CO2 respiration (Rsoil), and both terms are used interchangeably. However, in the short term Fsoil can deviate from instantaneous soil respiration whenever a change occurs in the amount of CO2 stored in soil pore spaces. Most often, Fsoil have been measured using manual or automated soil chambers. Manual chamber measurements have been frequently used due to their ease in deployment, but the sampling frequency is often low: normally weekly, monthly or seasonally and often only during the daytime and fair-weather conditions. Automated chamber systems are quickly gaining popularity as they allow continuous (~hourly) measurements of Fsoil over longer periods of time, but deployment of these systems is limited due to their higher costs. Additionally, although automated systems generate continuous estimation of Fsoil and improve temporal data coverage, data gaps due to instrument failures still must be filled to produce accurate seasonal to annual sums.

Gaps in Fsoil measurements usually are filled using the soil temperature as a predictor. The relationship between soil temperature and Fsoil has been defined using exponential functions, most commonly the Arrhenius function or Q10 models. However, growing evidence suggests that Fsoil does not always follow the expected Arrhenius or Q10 temperature response; rather, soil CO2 effluxes show a hysteretic response. This hysteretic response has generated a growing call for deeper understanding of different factors and processes limiting soil carbon metabolism and Fsoil. The main objective of this proposal is to use a combination of field and controlled-environment experiments to identify and quantify the causes and consequences of temperature hysteresis and soil CO2 storage with regard to the Fsoil, which will lead to improved ecosystem models for regional-to-global carbon cycle quantification.

During the three years of this project, we have worked both in natural ecosystems located in Tucson, USA and Granada, Spain and in controlled ecosystems located in the enormous facilities of Biosphere 2, USA and the Ecotron in France. The numerous technologies that have been used in this project have made it possible to answer the numerous questions related to the gaseous CO2 exchanges between soil, plant and atmosphere. The main work performed during this project has been:

- Measurements of diel Fsoil under grasses, mesquites and in inter-canopy soils: we use two measurement methods, 1) above ground, obtaining Fsoil from a multi-chamber monitoring system, and 2) underground, calculating Fsoil using Fick’s law of diffusion, using CO2 probes installed at different depths in conjunction with soil temperature and moisture probes.
- Development of a dynamic diffusivity algorithm, using the trace gas sulfahexafluoride (SF6), based on soil water content conditions and soil properties.
- Girdling a subset of mesquites to eliminate photosynthate delivery to soils.
- Using Sap flow sensors to determine the effect of hydraulic redistribution between trees and grasses.
- Identify the main drivers controlling CO2 storage and/or emission in the soil. Storage of CO2 in soil pore-space can be affected by abiotic processes like changes in soil water content or pressure pumping.
- Glasshouse experiments independently controlling above and belowground abiotic conditions.
• Measurements of CO2 exchange at leaf and ecosystem levels in an olive tree plantation.
• Measurements of diel $F_{soil}$ in an olive tree plantation both: above ground, using an automatic chamber, and underground, using measurements generated in four replicated horizontal CO2 profiles at 5cm depth. Each profile depth has 10 meters of high porosity PTFE tubing. A low-pressure pump circulates air through a closed system, which is measured by a CO2 sensor. Soil temperature and moisture also are registered.

The main results achieved are:
• We found that the wind can cause increases in CO2 in the shallow soil layer due to CO2 transport from the deep root zone toward the surface or maybe due to CO2 transport from deeper layers. But also, it can cause decreases in CO2 molar fraction, increasing the errors in $F_{soil}$ estimations using the gradient method (Sánchez-Cañete et al. 2016).
• Published diffusion models to obtain $F_{soil}$ using the gradient method, grossly underestimated cumulative $F_{soil}$. An in-situ diffusion model obtained by SF6 injection also did not generate accurate estimations in cumulative $F_{soil}$. Instead, we found great improvements by using the gradient method and chamber measurements to determine an empirical soil CO2 transfer coefficient in situ, which produced accurate cumulative $F_{soil}$ (Sánchez-Cañete et al. 2017).
• We investigated how patterns of hydraulic redistribution influence over- and understory ecophysiological function. The hydraulic redistribution regime was characterized predominantly by hydraulic descent relative to hydraulic lift. We found only a competitive interaction between the over- and understory, regardless of time scale. Overstory trees used nearly all water lifted by the taproot to meet their own transpirational needs (Barron-Gafford et al. 2017).
• We present the first study using continuous ARQ estimates (ratio between CO2 efflux/O2 influx) to evaluate annual CO2 losses of carbon produced from soil CO2 production ($R_{soil}$). We found that up to 1/3 of $R_{soil}$ was emitted directly to the atmosphere, whereas 2/3 of $R_{soil}$ was removed by subsurface processes. These subsurface losses are attributable to dissolution in water, biological activities and chemical reactions (Sánchez-Cañete et al. under review).

We can conclude that based on the results obtained in this project, we have improved the understanding of the mechanism underlying the soil CO2 transport, storage and emission to the atmosphere. We must change our point of view regarding $R_{soil}$ studies from an inappropriately conceived system in which all CO2 is produced by biology and emitted directly to the atmosphere, to a dynamic system where the soil CO2 is produced and removed by the interaction of combinatorial biological processes, hydrologic and wind transport and associated geochemical reactions. If soil CO2 respired but not emitted were having into account in the $F_{soil}$, gross primary production estimates would be reduced, with enormous implications on carbon exchange studies from ecosystem to global scale.


Actual and futures publications originated by DIESEL can be found on Sánchez-Cañete’s website (http://www.ugr.es/~enripsc/index2.html )

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