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Comparing measurements methods of carbon dioxide fluxes in a soil sequence under land use and cover change in North Eastern Spain

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ABSTRACT

Carbon dioxide measurements from soil surface may indicate the potential for soil respiration and carbon consumption according to microbial biomass and root activity. These processes may be influenced by land use and cover change, and abandonment especially in the upper soil organic layer. Seven environments from cultivation to late abandonment, with the same soil type classified as Lithic Xerorthent, were tested to ascertain the respiration capacity according to the current use and cover, and to establish the ability to preserve and eventually increase the organic matter pools after abandonment. Given the importance of carbon dioxide measurements at soil surface, a comparison between the classic soda lime method (SL) and a rapid method based on infrared sensor analyzer (IR) was performed from autumn 2008 to autumn 2009 in the field. The field measurements of CO_2 proved significant correlations between the values from the two techniques under the same natural conditions and along the period of observation. However, the values of CO_2 measured by the soda lime method were always higher than those obtained by the infrared analyzer. This pattern was attributed to the difference in time of measurement, larger in the former method, and type of measurement technique. Despite that the trend of measured CO_2 values was rather similar along the year. On average, the highest values of CO_2 emission in the field were recorded in the warmest periods of the year and with soil surface moisture not lower than 3% independently on the method used. High soil surface temperature with soil moisture below 3% decreased drastically the CO_2 production from the dry soil. The cultivated environments and soil under forests have resulted higher CO_2 producers than abandoned soils depending on the age of abandonment, climatic conditions, and within abandonment perturbations. Those abandoned soils preserved by perturbations like wildfire showed a higher potential for accumulating organic carbon, as indicated by the lowest emission of CO_2 with respect to SOC content, during the period of observation. Results demonstrated the reliability of the methods used to evaluate the soil carbon dioxide production capacity and allowed to classify through environments with increasing potential for carbon sequestration. The classification was rather similar by using both methods indicating a higher susceptibility to carbon loss in the following order: soil under Vines (V) > under Olives (O) > under Pine trees (PI) > under Cork Trees (S) > under Pasture (PR) > under Cistus scrub (MC) > under Erica scrub (MB) by using the SL method and V > O > PI > S > MC > MB > PR by using the IR method. Indications about the need of management of abandoned areas were also considered in order to recover the landscape heterogeneity.

1. Introduction

The consumption of organic matter in soil by heterotrophic microorganisms and the respiration of plant roots are known to produce carbon dioxide, which is finally released to the atmosphere (Jensen et al., 1996). Thus mineralization and humification processes may affect atmospheric CO_2 concentration as much as mineralization exceeds humification. The humification process is based on the relative susceptibility of the type of fresh organic field wastes and decaying debris to biological decomposition, mainly depending on C/N ratio, soil moisture and temperature. This process implies also consequent biochemical transformations of labile (carbohydrates) and more stable (lignin and phenolic compounds) organic fractions into humus. In case of carbohydrates as starting point the carbon percentage that makes it to humus is less than 20%, so that mineralizable labile organic compounds are most easily lost as CO_2 through mineralization (Zech et al., 1997). If the starting point is lignin, tannins, or other phenolic groupings (mostly found in wood and leaves) the percentage may reach 75%. In this case, low-mineralizable humic substances may increase in the soil and be preserved in the form of stable organic compounds for decades or even centuries if the soil is accurately managed. Soil structure and porosity as well as bulk density are tightly related with mineralization and humification processes. When intensive soil tillage or mismanagement cause low structure and poorly distributed porosity, metabolization of labile or even stable organic

Abbreviations: SL, Soda lime method; IR, Infrared gas analyzer method.

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fractions into CO_2 is likely to increase, favoring mineralization, decline in structural stability and compaction. Conversely, a stable structure with positively sorted porosity tends to maintain better soil conditions through stable organic compounds persistence and structural stability improvement. To minimize the carbon dioxide emission by mineralization of organic matter fractions, any agricultural practice or spontaneous plant succession preserving humic compounds in the soil system, may favor this system to act as an organic carbon sink, playing an important role in balancing carbon dioxide concentrations in the global carbon cycle. There are contrasting opinions on how land use and cover change and land abandonment may influence soil organic carbon (SOC) content and consumption or either its redistribution in time and space, involving biological activity, porosity, soil temperature and water regimes (Bajracharya et al., 2000; Levy et al., 2004). According to the previous land use and management before abandonment, land use and cover change, and abandonment may increase erosion processes affecting SOC content (Chengere and Lal, 1995). However, eroded soils contain relevant amount of SOC which may be redistributed and preserved in depositional areas (Bajracharya et al., 1998). Also, farmland abandonment may lead to natural vegetation succession increasing plant species colonization and the recovery of suitable organic horizons. Because of the varied effects on SOC and microbial activity, land use and cover change and land abandonment have important influence upon soil respiration, C flux to the atmosphere and C sequestration in soil. Measurements of carbon dioxide fluxed from the soil are therefore important in order to add information on the carbon dynamics. Nevertheless, there is a considerable uncertainty in the CO_2 measurements from soil surface, mainly due to differences in the methods used (Raich and Schlesinger, 1992). Nannipieri et al. (1990) relate soil respiration to the general metabolic activity of soil microorganisms to obtain energy for their growth through the decomposition of decaying organic debris. The effectiveness of soil microbial activity on the organic substrate depends primarily on soil properties such as moisture, temperature, infiltration capacity, clay content, and soil aeration (Buchmann, 2000; Zibilske, 1994). Moreover, soil respiration rates may be very sensitive to seasonal changes in soil temperature and water content because of their influence in microbial activity and root growth (Davidson et al., 1998; Kelting et al., 1998; Lee et al., 2003). Several methods have been reported for the estimation of carbon dioxide emitted from soils. The soda lime absorption and the infrared gas analyzer methods for CO_2 estimation are the most common used in the field and laboratory (Keith and Wong, 2006; Rochette et al., 1992). Other methods like Eddy Covariance are being also used though need of more specific and sophisticated procedures (Baldocchi, 2003).

In the North East Iberian Peninsula, terraced soils have been maintained for many decades at low agricultural management and then progressively abandoned. The change in the previous mosaic of land exploitation, the increased erosion processes and the periodical occurrence of wildfire has changed the soil properties as well (Dunjó et al., 2004; Pardini et al., 2003, 2004) arising questions on how these changes may have affected the organic reserve and the C flux from the soil. Thus, the objectives of this study were the following: i) to measure and compare the CO_2 emission capacity by means of the soda lime static method and the infra-red gas analyzer method in these peculiar soils; and ii) to evaluate on statistical basis the efficiency of the methods to detect the ratio between the organic carbon pool and the C–CO_2 loss, along one year of measurements (2008–2009).

2. Materials and methods

2.1. Description of the study area

The area belongs to the Natural Park of Cap de Creus, NE Iberian Peninsula. It is located in the Alt Empordà region and occupies approximately 30 km², ranging from 30 to 300 m asl. All the area has a significant ecological value expressed by the impressive geological and biological features, with unique examples of maritime and littoral terrestrial environments (Franquesa, 1995).

In this area, the climate is severely affected by the effects of the *Tramuntana* wind, from the Northern Pyrenees Mountains. It is a cold wind with normally a high speed (up to 90 km h^{-1}) having a strong drying effect on the soil water content. Rainfall is seasonally irregular and the mean annual precipitation is around 450 mm with peaks increasing in spring and autumn. A Mediterranean xeroteric climate is common, with hot summers around 35 °C and cold winters rarely below 0 °C. The mean annual average temperature is set between the isotherms of 15–16 °C (Dunjó et al., 2003). Soils are shallow (0–40 cm depth) and poorly developed in agreement with parent material composition, mainly granodiorite and schists. The horizon sequence is generally Ap, C/R and according to Soil Taxonomy System (Keys to Soil Taxonomy, 1992) these soils are classified as Xerorthent lithic. The majority of soil environments are completely covered by old terraces created several centuries ago and exploited mainly for wine, olive oil and cork production. Agricultural release started progressively in the last century when diverse plant diseases decimated vineyards, olive groves and cork plantations, and then with the advent of mechanized agriculture the terraces were almost completely abandoned around the fifties. Spontaneous plant colonization of the old terraces conform a much disorganized territory, very sensitive to wildfire. Currently 90% is covered with two main stages of scrubs according to fire occurrence: The much longer preserved by fire scrub area covering ≈55% of surface and the more affected by fire scrub area covering ≈35% of surface and often showing regressive vegetation dynamics caused by wildfire during the natural plants succession. Cork and pine trees and pastures are also occupying small patches covering ≈1.7% each respectively, as small patches are still cultivated with vines and olive trees covering ≈2.5% each, respectively. Some new interest in recovering agricultural land has arisen recently by landowners as a measure to reduce fire risks. Land use change in this area has lead to changes in the hydrological cycle, increasing erosion and nutrients depletion (Pardini et al., 2003). In the environments under study representative sites were selected in each soil environment in order to have similar slope (~20%) and orientation (NE).

Finally, seven soil environments were selected in this study: Terraced soils under cultivated vines (V) (*Vitis vinifera*) and under olive groves (O) (*Olea europaea*) maintained at minimal agricultural management. The monitored area of soils under vines had an extension of 0.5 ha, 16% slope and 6% of canopy cover, and the soil profile was 40 cm deep. The area delimited for soils under olive groves was also 0.5 ha, 18% slope, 15% of canopy cover and the total soil depth was 38 cm. Terraced soils under stands of cork trees (S) (*Quercus suber*) representing residuals of ancient cultivation for cork production, and under stands of pine trees (PI) (*Pinus pinea*) reforested in 1955. Both types of trees are approximately 4–5 m tall with understory composed mainly by *Brachipodium retusum*. The area of soils under cork trees had 0.5 ha extension, 15% slope, 70% of plant canopy and a total soil depth of 37 cm. Similarly, the area of soils under pine trees had 0.5 ha of surface, 17% slope and 70% of canopy cover, with a soil profile 40 cm deep. Terraced soils under pastures (PR) with meadows of *B. retusum*, *Trifolium stellatum*, *Dactylis glomerata*, *Lavandula stoechas* are currently in transition to scrubland for gradual abandonment of grazing activity. The monitored area was 0.5 ha, 18%, 35% of canopy cover and a total soil depth of 25 cm. Terraced soils under scrub (MC) are mainly covered by *Cistus monspeliensis*, *Cistus albidus*, *Cistus salvifolius*, *Calicotome spinosa* and some patches of *B. retusum*. This site was devastated by fire repeatedly in 1984, 1988, 1990, and 1994 and it is satisfactorily regenerated by natural plants. The representative monitored area of this soil environment was 0.5 ha, with 20% slope, 50% of plant canopy and a soil profile 33 cm deep. Terraced soils under scrub (MB) are mainly covered by *Erica arborea*, *B. retusum*, *L. stoechas* and some sprouts of *Quercus coccifera*. This environment