Geoderma 264 (2016) 188–194

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Electromagnetic induction: A support tool for the evaluation of soil CO_2 emissions and soil organic carbon content in olive orchards under semi-arid conditions

Egidio Lardo, Aissa Arous, Assunta Maria Palese *, Vitale Nuzzo, Giuseppe Celano

Dipartimento delle Culture Europee e del Mediterraneo: Architettura, Ambiente, Patrimoni Culturali, Università degli Studi della Basilicata, via San Rocco, 3 — 75100 Matera, Italy

ARTICLE INFO

Article history:
Received 16 July 2015
Received in revised form 15 October 2015
Accepted 18 October 2015
Available online 5 November 2015

Keywords:
Total soil respiration
EMI
EC_a
SOC
Soil sampling

ABSTRACT

Electromagnetic Induction (EMI), a non-invasive geophysical technique, can be a useful tool to study soil distribution of physical–chemical characters that strongly influence total soil respiration. Soil respiration emission flux (FCO_2) was followed in an orchard (0.7 ha) with olive trees placed at irregular distances. FCO_2 was measured in four different days at 6:00 and 15:00 h. Correlations between soil respiration and soil apparent electrical conductivity (EC_a), measured by the EMI technique, were assessed. Statistically significant linear relationships were found between EC_a, measured at 7 kHz, and FCO_2 ($R^2 > 0.6$). The strong relations found between daily FCO_2 and EC_a values allowed to spatialize soil respiration rate at field scale. The EMI technique combined with the statistical software called ESAP (Electrical conductivity Sampling, Assessment, and Prediction) seemed to be a very efficient tool to choose representative soil sites within the field on where to measure FCO_2. The EMI/ESAP procedure was also compared with two soil sampling procedures, Joint Research Centre European Method (JRC-EU) and regular grid sampling, in order to estimate average soil organic carbon (SOC) value within the olive orchard. Results suggested that the above mentioned approach could be an interesting solution to reduce number of samplings and their cost reaching, in the meantime, reliable assessments of FCO_2 and SOC at field scale.

1. Introduction

During the last decade the interest on soil CO_2 emission and carbon sequestration in terrestrial ecosystems has increased (Janssens et al., 2003; Smith, 2004) especially in the evaluation of temporal and spatial CO_2 soil fluxes. Soil respiration is the major source of CO_2 released by terrestrial ecosystems (Raich and Schlesinger, 1992) and it is used as a reference for calculating total greenhouse gases (GHGs) budget to better understand and quantify the emissions from soils (Allaire et al., 2012).

Soil CO_2 flux (FCO_2) consists in the gas release by respiration of plant roots and their related symbiotic microorganisms (autotrophic component), by soil microorganism respiration (heterotrophic component) and by dissolved soil organic matter due to chemical reactions. FCO_2 may be influenced contemporarily by many factors such as climatic variables (humidity, temperature, radiation); soil biological, physical and chemical characteristics; agronomical management (tillage, irrigation, fertilization, manure application, pruning, plant phenology, etc.) (Bauer et al., 2006; Gregorich et al., 1998; Reth et al., 2005; Rochette and Angers, 1999; Sainju et al., 2008; Smith, 2003) and field morphology (Garrett and Cox, 1973; Hanson et al., 1993). The close interaction between the above reported variables influences consistently FCO_2 values and their evaluation in time and space becomes difficult due to the enormous variability of such parameters (Allaire et al., 2012).

This variability has long been studied and many methods have been tested in this way. However, to date, no specific method was defined as standard (Pumpanen et al., 2004). The chamber based method is used to measure FCO_2 on a small scale (Norman et al., 1992; Meyer et al., 1987), while portable instruments enable field spatial investigation of FCO_2.

The most critical aspect, especially in heterogeneous soils, is the definition of representative sampling points on where to carry out the FCO_2 measurements. Usually, the number of sampling points is influenced and limited by labour costs and work time when portable instruments are used, by cost of instrumentations when the fixed chambers are employed (Adachi et al., 2005). Similarly, there are problems in defining the method of soil sampling to evaluate the content of soil organic carbon (SOC). Therefore, it is necessary to choose the degree of accuracy and representativeness of the space to consider. Soil sampling is normally conducted by classical methods (randomly, regularly grid) or by using the European sampling method of Joint Research Centre (JRC-EU) proposed by Stolbovoy et al. (2007).

To reduce the number of sampling points, a stratified method can be used (Rodeghiero and Cescatti, 2008). Also, for a quick and reliable choice of the soil sampling design, a statistical approach, named EC Sampling, Assessment, and Prediction (ESAP) was proposed and developed by Lesch et al. (2002). Apparent electrical conductivity values (EC_a, see below) coming from geophysical field surveys are input of the ESAP

* Corresponding author.
E-mail addresses: assunta.palese@unibas.it, dinapalese@hotmail.it (A.M. Palese).

http://dx.doi.org/10.1016/j.geoderma.2015.10.014
0016-7061/

software that uses the Response Surface Sampling Design (RSSD) statistical methodology to select a set of sample sites which optimizes the prediction model (Lesch et al., 2002). Using ESAP software a set of limited sampling sites (6, 12, or 20 sites) having desirable spatial and statistical characteristics can be selected (Hunsaker et al., 2009).

Another tool to study soil parameters spatial variability is the electromagnetic induction technique (EMI), a non-invasive geophysical technique to describe soil distribution of apparent electrical conductivity values (EC_a) (Corwin et al., 2003). EC_a is an integrated value of soil physical, chemical and biological properties which affect total soil respiration. In fact, Lardo et al. (2015) in a recent preliminary study, performed on vineyard field, found a strong relationship between EMI signal and FCO_2.

To verify and to improve these assumptions, relationships between spatial variation of EC_a and soil respiration were studied within a heterogeneous olive orchard located in Southern Italy. This research was carried out also to propose a methodology for choosing an adequate number of field representative FCO_2 measurement sites.

2. Materials and methods

2.1. The experimental site

The experimental olive orchard (*Olea europaea* L. — cv Maiatica) was located in Southern Italy (Miglionico — Matera Province, 40.554378 N; 16.515857 E) and it was grown under rainfed conditions. The climate is semi-arid with an annual precipitation of 574 mm (mean 1976–2009) and an average annual temperature ranging from 15 to 17 °C. Olive trees were about 30 years-old. They were irregularly planted on a sandy loam soil classified as *Eutric Cambisol* (Regione Basilicata, 2006). The olive orchard (0.70 ha) was located on a certain slope (3%) and its soil surface was entirely covered by volunteer grasses mowed at least once per year.

2.2. Measurements of soil respiration, soil temperature and soil water content

Soil respiration flux (FCO_2), expressed as μmol CO_2 m^{-2} s^{-1}, were measured using a non-dispersive infrared gas analyser (Li-6400, LI-COR, Lincoln, NE, USA) equipped with a soil respiration chamber (Model Li-6400-09) which measures CO_2 concentration and determines the efflux by fitting the chamber to a polyvinyl chloride collar. A soil temperature sensor (PT105T) was attached to the equipment. A detailed description of the system functioning is reported in Pumpanen et al. (2004).

In order to study FCO_2 variability within the whole olive orchard, 20 polyvinyl chloride collars of 0.105 m in diameter and 0.10 m in height were inserted in the soil to the depth of 0.08 m at the nodes of a regular grid. Each node was distant from the others 39.4 ± 17.5 m. To evaluate the FCO_2 microvariability, other collars were placed at different distances (0.5, 1.5, 3, 5 m) from the trunk of three olive trees.

Each collar position was georeferred. In order to reduce a disturbance-induced CO_2 efflux, collars were installed at least 48 h prior to the measurement campaigns. Herbaceous plants within the collars were cut and residues removed in coincidence of soil FCO_2 measurements. FCO_2 measurements were performed on 9th and 20th of October 2012 and on 9th and 17th of April 2013 at 6:00 and 15:00 h which are the daily moments of minimum and maximum soil respiration rate. The average of the two measurements, for each sampling site, allowed us to obtain mean daily value of FCO_2 (Irvine and Law, 2002).

Soil temperature and soil volumetric water content (SWC) were measured at 0.15 m depth in coincidence of the FCO_2 measurements. In particular, SWC was measured by means of the Fieldscout TDR 300 (Time Domain Reflectometry) soil moisture metre.

2.3. Electromagnetic induction measurements

Electromagnetic induction (EMI) surveys were carried out after each FCO_2 measurement considering the site-specificity of this technique due to the complex interaction among multiple, interacting and variable soil features (Doolittle and Brevik, 2014).

EMI acquisitions were performed by a multi-frequency EMI sensor (GSSI Profiler EMP-400, Nashua NH 03060-3075 US). Such equipment, reported in Doolittle and Brevik (2014), can operate to measure simultaneously up to 3 frequencies between 1 kHz and 16 kHz, with intercoil spacing of 1.2 m. For this study, frequencies at 3, 7 and 14 kHz were chosen to collect information about different soil layers. The instrument was used in vertical dipole mode (VDP). The depths of the magnetic field penetration were about 1.5 m for VDP modes (Allen et al., 2007). The instrument sensitivity varies as a non-linear function of depth (McNeil 1990). The apparent soil electrical conductivity (EC_a), expressed in mS m^{-1}, was used as EMI output. The instrument was calibrated according to its technical standards. Data were collected in continuous every 0.75 s. EC_a measurements were made walking at a speed of about 4–5 km h^{-1} in order to obtain a regular distribution of EMI signal in the field. Each acquisition was georeferenced by means of Global Positioning System (GPS). Data were processed by MagMap2000® and Surfer Golden® software in order to map EC_a values by linear kriging method. Anomalous EC_a data due to the iron fence that surrounds the property were not taken into account during the elaboration phase.

2.4. Soil samplings and soil analyses

A soil sampling was performed on 12 September 2012 following the regular grid technique. Twenty points were identified in coincidence of the nodes of the regular grid. As reported before, each node was distant from the others around 40 m and it was georeferenced. Three soil samples were taken from the 0–0.2 m layer in the area of competence of each node (1 m of diameter) and then were mixed to form a single composite sample.

Another soil sampling was carried out the day after according to the JRC-EU procedure (Stolbovoy et al., 2007). Three sampling areas were identified within the olive orchard as function of its area (Stolbovoy et al., 2007). Soil samples were collected from the 0–0.2 m layer in coincidence of 75 points and then were mixed to form three composite samples (3 sampling areas × 25 sampling points).

To obtain an alternative and accurate sampling scheme for the identification of the most representative FCO_2 and SOC sampling points and the reduction of sampling labour and costs, the ESAP–EMI integrated procedure was used. In the present study, the ESAP–RSSD procedure was applied to EMI data interpolated by the linear kriging method and run twenty times in order to identify equivalent sets composed by 6 potential soil sampling points. This public statistical software, developed by the USDA-ARS ESAP-95 Version 2.35R (Lesch et al., 2000), uses the Response Surface Sampling Design (RSSD) statistical methodology to select a set of sample sites which optimizes the prediction model (Lesch et al., 2002).

After that, for each extraction the couples of potential and actual soil sampling points (these last obtained according to the regular grid procedure) which showed the minimum distance were identified. Among the identified twenty couple sets, that showing the mean minimum distance (4.1 ± 1.0 m, mean ± standard deviation) and the minimum sum of distances (24.7 m) was chosen to perform regression analysis on their EC_a values and the corresponding values of SOC and FCO_2.

Soil samples were air dried and sieved at 2 mm. On these samples the following analyses were carried out according to Pauwels et al. (1992): soil particle size analysis by means of the Andreasen pipette method; soil pH and electrical conductivity (EC_e) (soil: water, w w^{-1}, 1:1 ratio); SOC by the dichromate oxidation method (Walkley and Black, 1934).