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Assessment of soil respiration patterns in an irrigated corn field based on spectral information acquired by field spectroscopy

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ABSTRACT

The assessment of soil respiration processes in agroecosystems is essential to understand the C balance and to study the effects of soil respiration on climate change. The use of spectral data through remote sensing techniques constitutes a valuable tool to study ecological processes such as the C cycle dynamics. The objective of this work was to evaluate the potential to assess total (Rs) and autotrophic (Ra) soil respiration through spectral information acquired by field spectroscopy in a row irrigated corn crop (*Zea mays* L.) throughout the growing period. The relationships between Rs and Ra with leaf area index (LAI), spectral indexes and abiotic factors (soil moisture and soil temperature) were assessed by linear regression models using the adjusted coefficient of determination (R_{adj}^2) to measure and compare the proportion of variance explained by the models. Results showed significant differences and a high variability in the relationships between Rs and Ra with spectral indexes within the corn field during the phenological stages and in measurements under the plants and between the rows. Best results were obtained when assessing Ra during vegetative stages. However, during the reproductive stages, spectral indexes were better related to Rs which could be related to the presence of rhizomicrobial respiration linked to vegetation activity. Spectral indexes contain significant functional information, beyond mere structural changes, that could be related to carbon fluxes. However, specific models should be applied for the different phenological stages and there is a need to be cautious when upscaling remote sensing models. The results obtained confirm that in irrigated crop systems remote sensing data can produce relevant information to assess both Rs and Ra through spectral indexes.

1. Introduction

The assessment of the CO_2 balance and the production dynamics through photosynthesis and respiration processes in ecosystems has become a fundamental research issue due to the potential impact that this may have on the climate change (Cramer et al., 2001; Dixon et al., 1994; Knapp and Smith, 2001). Agricultural activities are responsible for approximately 13% of the anthropogenic emissions of greenhouse gases (Pachauri and Reisinger, 2007). Intensive agricultural practices have significantly increased in the last century due to human overpopulation, to satisfy market requirements and to ensure farmers benefits causing serious social and environmental impacts (FAO, 2002; Matson et al., 1997; Tilman et al., 2002). Therefore, it is essential to look for improved agricultural practices which reduce the impacts of agroecosystems (Sanchez-Martín et al., 2010; Snyder et al., 2009).

Soil respiration (Rs) is responsible for 60–90% of the total ecosystem respiration (Goulden et al., 1998, 1996). The production of CO_2 by soil respiration is the second most important flux of C in the majority of ecosystems after the photosynthesis process (Raich and Schlesinger, 1992; Schlesinger and Andrews, 2000). Mainly, Rs is composed of autotrophic respiration (Ra) from the metabolism of roots and of heterotrophic respiration (Rh) from microorganisms

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that decompose soil organic matter (Kuzyakov, 2006; Prolingheuer et al., 2010). In agricultural fields spatial distribution of Rs components can be highly variable depending on the type of crop spatial distribution. Rs is higher close to the roots in row crops due to a higher proportion of autotrophic respiration (Amos et al., 2005; Rochette et al., 1991). Prolingheuer et al. (2010) found highly different spatial structure in autotrophic and in heterotrophic components in a winter wheat field, and suggested that an adequate spatial sampling design would be needed in order to assess accurately soil respiration patterns.

Thus, the assessment of these soil respiration processes is essential to understand the C balance and to study the effects of soil respiration on climate change (Buchmann, 2000; Han et al., 2007). It is important to know whether agroecosystems act as sinks or sources of CO_2 over time and space depending on the various factors that can interact on them such as management practices (Lal, 2011; Mosier et al., 2005; Paustian et al., 1997; Sauerbeck, 2001; Uribe et al., 2013).

The improvement of technology has allowed quantifying more accurately the flux of CO_2 between the atmosphere and ecosystems. In this sense, the use of spectral data through remote sensing techniques constitutes a valuable tool to study ecosystem's dynamics and ecological processes for improving land use management and combine economic and environmental revenues. The availability of high frequency remote sensing time series providing continuous land surface observations allows characterizing and monitoring ecosystem's phenology at different temporal and spatial scales (Palacios-Orueta et al., 2012; Tucker et al., 2001; Zhang et al., 2003). Besides other applications, these capabilities are extremely useful to assess the C cycle dynamics (Dong et al., 2003; Heinsch et al., 2006; Turner et al., 2004). However, there are few studies that are focused on estimating Rs from remote sensing products and this is mostly carried out indirectly through spectral indexes related to ecosystem activity (Huang and Niu, 2013; Huang et al., 2012).

Spectral data is usually summarized as spectral indexes which are easy to calculate and could be used as input variables in biophysical models to calculate properties such as moisture content or leaf area index (LAI), and to relate them to physiological processes such as photosynthesis, respiration and gross and net primary production of ecosystems (Baret and Guyot, 1991; Viña et al., 2011; Wang et al., 2005). The most common indexes used are ratio indexes based on measurements obtained within the visible and near-infrared (VIS/NIR) region of the electromagnetic spectrum such as the normalized difference vegetation index (NDVI) (Tucker, 1979) and the enhanced vegetation index (EVI) (Huete et al., 2002). Both indexes are strongly related to photosynthetic activity and therefore offer an important and convenient measure for canopy photosynthesis (Gitelson et al., 2006; Huang and Niu, 2013; Sims et al., 2006). Since it has been shown that NDVI saturates at a high chlorophyll content, i.e., at high LAI values (Buschmann and Nagel, 1993; Gitelson et al., 2003b, 2002; Viña and Gitelson, 2005), EVI was developed to avoid this problem (Huete et al., 2002). Therefore, they seem to be an appropriate basis for assessing ecosystem functioning when vegetation is active during the growing period but probably not at other phenological stages (Palacios-Orueta et al., 2012). In terms of Rs, these indexes could be related to the autotrophic respiration (Ra) of roots due to the relationship between plant photosynthesis and root respiration during the growing period (Kuzyakov and Cheng, 2004, 2001; Xu et al., 2008); however this relationship may not hold in the same manner at different phenological stages (Huang et al., 2012) in which Rh is more significant (Prolingheuer et al., 2010). Indexes based on the shortwave infrared (SWIR) spectral region such as the normalized difference water index (NDWI) (Gao, 1996) are more directly related to soil and vegetation moisture capturing probably different features in the phenological dynamics of the agroecosystems. In the recently proposed spectral shape indices (SSI) (Palacios-Orueta et al., 2006) the shape of the spectral signature in a specific wavelength range is represented using information from three bands instead of two. Depending on the spectral range, different applications of these indexes have been demonstrated (Khanna et al., 2013; Palacios-Orueta et al., 2012; Zhang et al., 2014). Among the SSI indexes, ANIR (the angle at the near-infrared band) is a combination of reflectance values in the Red, NIR and SWIR1 bands and it has been used in several applications (Khanna et al., 2007).

The objective of this work was to evaluate the potential to assess total and autotrophic soil respiration through spectral information acquired by field spectroscopy in a row irrigated corn crop (*Zea mays* L.) throughout the growing period. In order to accomplish this objective, the following issues are taken into consideration:

- The spatial variability of soil respiration within the corn field, specifically underneath the corn plants and between crop rows.
- Differences in dynamics between vegetative and reproductive stages.
- The influence of abiotic factors.

2. Material and methods

2.1. Study area

The study has been carried out during two crop seasons (2011–2012) in an irrigated experimental corn field of the College of Agricultural Engineering of the Technical University of Madrid (Central Spain). The study area is located at UTM X: 437410; UTM Y: 4476875 (Zone 30N; Datum ETRS89) at an altitude of 595 m a.s.l. and is characterized by a Mediterranean climate defined as Csa (temperate with dry or hot summer) according to the Köppen–Geiger classification (AEMET/IMP, 2011). The average annual temperature is 13.1 °C (4.3 °C in January and 24.1 °C in July), and the mean annual precipitation is 455 mm, with autumn–spring maxima and a marked minimum in summer (12 mm in August).

The experimental zone was developed in an area that was leveled approximately 30 years ago by adding earthy and rubble materials over a gentle slope. Therefore, the study area is characterized by an anthropogenic soil with higher pH and higher electrical conductivity than a natural soil which shows an A/C morphology. The A horizon is formed of a 30–40 cm layer, fine textured, with a neutral pH and moderate organic matter content. The C horizon consists of an anthropogenic deposit with a coarse texture, and rich in rubble materials which are constituted mainly by remnants of bricks, ceramic fragments and other construction materials (5% of the soil volume). Main soil parameters are obtained from 3 soil profiles made in the study site (A horizons: pH: 7.6; EC_{se}: 2.8 dSm^{-1}; $CaCO_3$: 2.3%. C horizons: pH: 8.1; EC_{se}: 1.6 dSm^{-1}; $CaCO_3$: 1.7%; and an average "sandy clay loam" sclass).

The study area has been under cultivation approximately for 30 years. Over the last decade, the soil has been subjected to various rainfed and irrigated crops: barley, alfalfa, ryegrass or vetch and other crops such as corn, sunflower, cotton, or beet. Cultivation conditions include manuring during plough practices. Available data indicate an organic matter content of 1.8% in the surface horizon (1.0% of organic C).

2.2. Crop characteristics and phenological stages

Maize (*Zea mays* L.) was sowed in mid-May in 2011 and late-April in 2012. In both cases the plants were irrigated 3 h per week.