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Annual net ecosystem carbon exchange by a sugar beet crop

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Abstract

Eddy covariance measurements of CO_2 fluxes were conducted in 2004 at the agricultural site of Lonzée, Belgium, over a sugar beet crop. Additional measurements of biomass net primary production and leaf area index (LAI) were carried out. The response of the fluxes to climatic and non-climatic variables was analysed. Nighttime fluxes were dependent on turbulence, temperature and high soil water content. The u_* correction was determined using a statistically based algorithm. The lower u_* threshold was 0.1 m s^{-1}. Daytime fluxes during maximum canopy development depended mainly on incident radiation and its repartition between direct and diffuse components. A limited response to saturation deficit and soil water content was also observed. The evolution of assimilation and respiration throughout the growing season was studied. Maximum assimilation fluxes were observed in July when canopy had not fully developed and these then decreased from the end of July to the harvest, due not only to a reduction in radiation but also to a reduction in canopy assimilation capacity. Normalised respiration evolution presented two peaks during the year: the first in July, when the assimilation was at its greatest, and the second after the harvest, during the crop residues decomposition. The annual sequestration, estimated by half-hourly flux summing and measurement gap filling, was -0.61 ± 0.11 kg C m^{-2} and the impact of the u_* correction and of the residues decomposition was estimated to be 5.3 and 3.5%, respectively.

Keywords: Eddy covariance; Sugar beet crop; Annual sequestration; Net ecosystem exchange; u_* threshold

1. Introduction

Since the mid 1990s, continuous micrometeorological measurements of the net exchange of carbon dioxide, water vapour and energy among various terrestrial ecosystems and the atmosphere have been conducted worldwide (Baldocchi et al., 2001; Baldocchi, 2003; Valentini, 2003). The main objective of these measurements is to determine the contribution of various ecosystems to the global carbon cycle.

Croplands cover about one-third of the land surface of Europe (FAO Statistical Databases, 2003) and have the potential to mitigate about 16–19 Tg C per year (Freibauer et al., 2004). The cropland area represents a quarter of Belgium land surface (MRW-DGA, 2005). Most crops in the region are managed following a 4-year rotation scheme with alternation between cereals (mainly winter wheat) and crops such as sugar beet, potato, chicory and silage maize. The sugar beet crop covers more than 10% of the crop area in Belgium (INS, 2003).

The objectives of this study were: (i) to identify the environmental or biophysical factors that control the daytime assimilation and nighttime emission, (ii) to determine the seasonal distribution of these fluxes and (iii) to quantify the annual CO_2 net exchange by the crop and assess its sensitivity to management practices and methodological choices. The effects of some

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methodologies on the carbon sequestration estimation were also addressed.

2. Materials and methods

2.1. Site description

The study site is cropland in Lonzée about 45 km SE of Brussels, Belgium (50°33′08″N, 4°44′42″E, 165 m asl). The climate is temperate maritime. The mean annual temperature is about 10 °C and the annual precipitation is about 800 mm.

The cropland is a quadrilateral area of ca. 12 ha located on a fairly flat plateau with a maximum slope of 1.2% in a WSW direction. The site provides a fetch of 240 m in the SW which is the main wind direction. The farm is located 400 m WSW from the measurement point. There are no other buildings or roads for more than 1000 m. The second main wind direction is NE, with a fetch of 200 m. This side of the area is bordered by a road with very light traffic, beyond which croplands extend more than 900 m. The soil is a Luvisol (FAO classification). It is composed of 18–22% clay, 5–10% sand and 68–77% silt and contained 3.7 kg m^{-2} total organic carbon in September 2004.

The land has been cultivated for more than 70 years. For the past 6 years, the crops have been 50% cereal and 50% potato and sugar beet. In 2004, the soil was tilled to a depth of 0.30 m in late February and sugar beet (*Beta vulgaris* L.) was sown on 30 April. The crop was harvested on 29 September. The yield was 1.53 kg m^{-2} dry matter or 0.632 kg m^{-2} carbon. On 1 April 2004, 156 kg ha^{-1} mineral N were applied. In the preceding years, 180 kg ha^{-1} mineral N and 60 kg ha^{-1} organic N (sugar lime) had been applied in 2003, 156 kg ha^{-1} mineral N, 14 kg ha^{-1} phosphorus and 42 kg ha^{-1} potassium in 2002 and 180 kg ha^{-1} mineral N in 2001. No farmyard manure had been applied since 1996.

2.2. Measurement system

2.2.1. Eddy covariance and meteorological system

Fluxes of CO_2, water vapour and sensible heat were measured with an eddy covariance system placed at a height of 2.7 m and consisting of a research-grade sonic anemometer (model Solent Research R3, Gill Instruments, Lymington, UK) and an infrared gas analyser (IRGA) model Li-7000 (LiCor Inc., Lincoln, NE, USA). The eddy covariance system was the standard system used in *CarboEurope-IP* and *Fluxnet* networks (Moncrieff et al., 1997; Grelle and Lindroth, 1996; Aubinet et al., 2000). Air from the vicinity of the sonic anemometer was drawn through a 12.4 m long and 4 mm i.d. PTFE into the analyser. Data from the sonic anemometer were gathered at a sampling rate of 20 Hz using EDDY software (Kolle, Max-Planck-Institute for Biogeochemistry, Germany). This software was also used to determine online and post-process flux.

Complementary measurements were made on a half-hourly basis. They included air temperature and humidity (RHT2, Delta-T Devices Ltd., Cambridge, UK) at a height of 1.3 m, soil temperature (PT100) at a depth of 3, 5.5, 9, 26 and 56 cm and soil humidity (ThetaProbe, Delta-T Devices Ltd., Cambridge, UK) at a depth of 5, 20 and 50 cm. Global (CM21, Kipp en Zonen, Delft, NL), net (Q*7.1, REBS, Seattle, WA, USA), global photosynthetically active (PAR Quantum Sensor SKP 215, Skye Instruments Ltd., UK) and global and diffuse photosynthetically active (Sunshine sensor type BF3, Delta-T Devices Ltd., Cambridge, UK) radiation were measured at a height of 2.7 m. Rainfall and mean atmospheric pressure (MPX4115A, Motorola, Phoenix, AR, USA) were also measured at the site.

2.2.2. Data treatment

Half-hourly fluxes were calculated in the post-processing of the 20 Hz time series data. The fluxes were rotated (2D) in order to align the streamwise velocity component with the direction of the mean velocity vector. High frequency losses due to the sampling tube were corrected experimentally (Eugster and Senn, 1995; Aubinet et al., 2001). The transfer function was determined by comparing the CO_2 and H_2O flux co-spectra with the sensible heat co-spectrum. The transfer function was approximated by a first-order function equivalent to that of a low pass filter composed of a self-induction coil and a unitary resistance (Eugster and Senn, 1995). The inductances were: $L_{CO_2} = 0.1$ and $L_{H_2O} = 0.4\ \Omega$ s.

The fluxes were submitted to a stationary test (Foken and Wichura, 1996). Three levels of quality were defined: data that meet the quality test with an allowed difference of 30%, data that meet the test with an allowed difference of 50% and data that failed the test. The responses of the fluxes to environmental factors were established from data of the first category. The impact that elimination of bad quality data had on annual carbon sequestration was estimated in Section 3.5.

Half-hourly changes in CO_2 storage were calculated using a single concentration measurement at a height of 2.7 m. Although this technique is questionable when used above tall vegetation where eddy covariance systems should be placed at great heights, it works fairly