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Estimation of the carbon and energy fluxes of a forest plantationin a lignite mine restoration

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Abstract: The estimation of carbon and energy fluxes between the ecosystems and the atmosphere is critical for the assessment of their overall performance and their contribution to the global carbon cycleand climate change mitigation. In this study we present one-year measurements of the carbon assimilation and energy fluxes of a forest plantation in the restored fields of the Western Macedonia Lignite Center, Greece, with the use of the eddy covariance technique. The dominant species of the plantation is *Robinia pseudoacacia* L. The results of this study can contribute to the better understandingof the species ecophysiology under harsh conditions. The energy closure for the site can be considered very adequate, as the sum of latent and sensible heat flux was equal to 88% of net radiation minus soil heat flux. According to our measurements, the ecosystem acts as a carbon sink for about half of the year,and as a carbon source for the rest of it. The ecosystem acts marginally as a carbon sink, with a total gain of about 15 g C m^{-2}

Keywords: eddy covariance technique, Net Ecosystem Productivity, Gross Primary Productivity *Robinia pseudoacacia.*, Greece

1 Introduction

The study and accurate estimation of ecosystem carbon and energy fluxes is critical within the scope ofunderstanding their overall performance and their response to the ongoing climate change. Terrestrial ecosystems absorb atmospheric CO_2 in order to produce organic compounds through photosynthesis, a procedure that on ecosystem level is known as Gross Primary Productivity (GPP), while at the same time they release CO_2 in the atmosphere through ecosystem respiration (R_{eco}). The eddy covariance technique (Baldocchi 2003) is a micrometeorological method that considered as the most reliable to provide measurements of carbon and energy fluxes on ecosystem level (Balzarolo et al. 2014).

The rising levels of atmospheric CO_2 concentration due to anthropogenic emissions and their attributedclimate change, leads to a need of a transformation to a lower carbon impact model. Until this transformation is achieved, fossil fuel combustion for energy production is not very easy to be totally abandoned, so there is also a strong need for the determination of methods of mitigation or carbon offsets(Galatowitsch 2009). In this direction, carbon farming, i.e. the establishment of plantations in disturbedlands, has been recognized as a very promising and economically viable method, not only for carbon sequestration, but also for ecological restoration and biodiversity enhancement of the disturbed lands (Evans et al. 2015). *Robinia pseudoacacia* is a species that has met many applications in restoration projects (Carl et al. 2017; Skousen and Zipper 2014), however its ecophysiological performance is not well studied yet (Vítková et al. 2017). The aim of this study is to present the results of one year of measurements of ecosystem carbon and energy fluxes of a *R. pseudoacacia* plantation in the restored areas of the Western Macedonia Lignite Center, Greece, contributing to the better understanding of the species performance and developing a methodology that can be used in other relative applications.

2 Data and Methodology

2.1 Study site

The site is located on a flat field of about $5*10^5$ m^2 (40.59 °N, 21.65 °E) that is part of a greater plantedarea of about $24*10^6$ m^2 in the restored areas of the Western Macedonia Lignite Center. The dominant species of the plantations is *Robinia pseudoacacia*, a deciduous broadleaf species, which accounts of 95% of the total area of the plantations. The age of the trees at the study site is about 20 years. The meantree height in the study site is 13.5 m and is relatively homogenous. Understory vegetation consists mainly of perennial grasses, with *Cynodon dactylon* being the dominant one. The growing period of theunderstory grass starts after leaf fall, as the leaves of trees are very thin and delicate, resulting in a veryquick decomposition, and it is active until the trees' leaf expansion, in the beginning of May. The substrate consists of deposition material from the mining process that, in general, is very depleted and poor (Papadopoulos et al.

2015). Mean annual precipitation for the ten-year period (2010-2020) is 510±156 mm and mean annual temperature for the same period 13.36±0.92 °C, as they estimated from the nearby meteorological station of the National Observatory of Athens (http://penteli.meteo.gr/stations/amyntaio/).

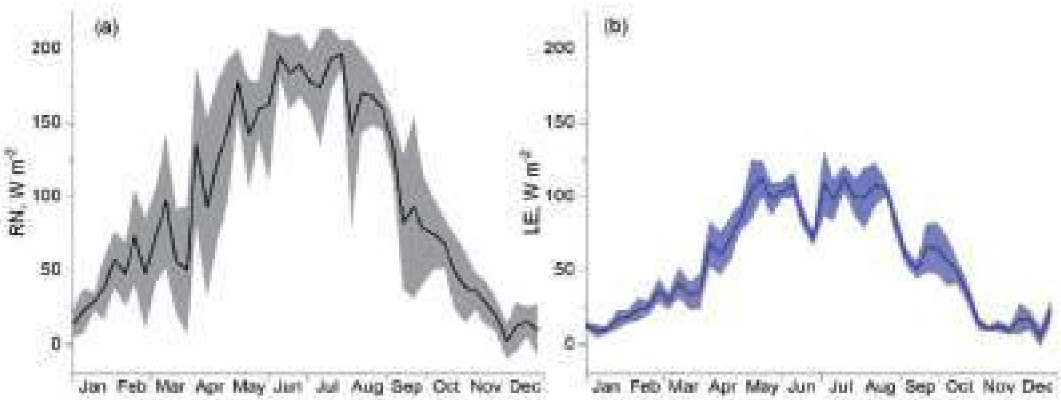
2.2 Eddy covariance measurements

In the study site, an eddy tower has been installed at the end of July 2019 and since then continuous measurements are taken (Photo 1). The tower was placed in the middle of the forest, so that unidirectional measurementscan be achieved. It is equipped with an integrated IRGA analyzer and sonicanemometer (Irgason, Campbell Scientific Inc) with enhanced barometer (PTB 110, Vaisala Inc), that performs high frequency CO_2/H_2O and temperature measurements, as well as 3-dimension wind speed analysis. The analyzer was placed in the top of the tower, at a total height of 17.5 m,providing us an average fetch radius of 200 meters. The tower is also equipped with a full meteorological station, including, among others, a net radiometer (NR Lite2, Kipp and Zonen BV), a temperature/humidity probe(HygroClip2 Advanced, Rotronic Inc) and 3 soil heat flux plates (HFP01,Hukseflux Thermal Sensors BV). Raw data are collected from a datalogger(CR1000X, Campbell Scientific Inc) in a frequency of 10 Hz and processed on-site via an integrated analysis software (EasyFlux DL, Campbell Inc) and post-processed with a use of a computer software (EddyPro 7, Licor GmBh). Data processing and corrections (i.e. WPL, planar fitting, time lag optimizations, spike removal, spectral corrections etc.), as well as quality control, were performed with the use of the EddyPro software, according to standardized eddy covariance methodology (Aubinet et al. 1999, 2012). Data gap-filling and flux partitioning were done with the use of a standardized methodology, as well (Reichstein et al. 2005). The default time step of data processing was 30 min and then scaled to daily time steps. The period of data acquisition for this study was 1/1 – 31/12/2020.

Photo 1: The eddy tower in the study site.

3 Results

The seasonal fluctuations of energy fluxes net radiation (Rn), latent (LE), sensible (H) and soil heat flux(G), are presented in Fig.1. The peak period of net radiation activity is met during the period betweenthe beginning of June until the end of July (Fig.1a). Latent heat flux (Fig.1b) reaches its highest values from the beginning of May until the middle of August, with a severe intermediate decrease during June,indicating some mild water stress during that period. Sensible heat flux (Fig.1c) is generally lower thanthe respective latent heat flux, indicating that the studied ecosystem is likely to be more water rather thatair cooled (Rotenberg and Yakir 2011). Soil heat flux (Fig.1c) accounts for the smallest component of the total energy budget, maximizing its values during spring and summer. The energy closure for the site can be considered very adequate, as the sum of latent and sensible heat flux was equal to 88% of netradiation minus soil heat flux (Fig.1, embedded diagram), which is at the top of the performance amongrelative systems (Allen et al. 2011; Burba 2013). According to our results, the accuracy of the installedsystem is very high, so the results can be considered very reliable. Mean daily temperature, total precipitation and total solar radiation for the study period are presented in Table 1.



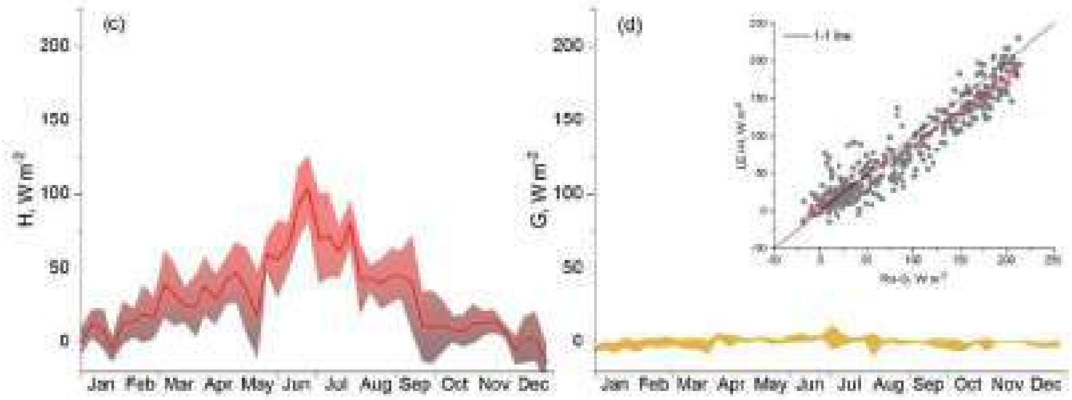


Fig.1. Seasonal fluctuation of daily energy fluxes for 2020 (8day running averages), Net radiation (Rn) (a),latent heat flux (LE) (b), sensible heat flux (H) (c) and soil heat flux (G) (d). The embedded diagram shows the energy balance equation.

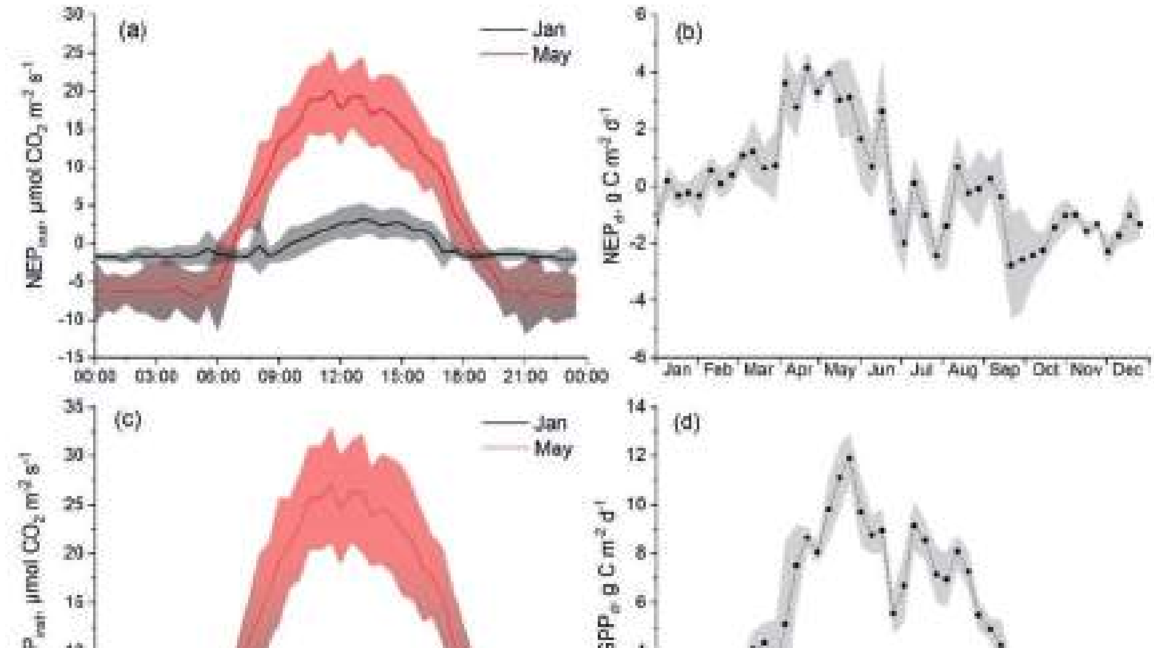


Fig. 2. Seasonal fluctuation of NEP and GPP during the study period. In Fig.1a and 1c, mean half hourly NEPand GPP values during the peak and the lowest seasonal ecosystem activity are presented. In Fig.1b and d are presented the seasonal fluctuation of the respective daily values in 8-day running averages.

The seasonal fluctuation of Net Ecosystem Productivity (NEP) and Gross Primary Productivity (GPP) is presented in Fig.2b and 2d, for both daily values and representative daily instant values fluctuation during the seasons of the highest and lowest ecosystem activity. The peak activity for GPP was during May and was associated with increased photosynthetically active leaf area. The GPP declined from Juneuntil the beginning of November. The values of GPP were relatively high during the growing period butso was and the ecosystem respiration. Seasonally, the peak activity for NEP was from the middle of April until the middle of May. The ecosystem acts as a carbon sink for about half of the year, and as a carbon source for the rest of it (Fig.2b). In the beginning of growing season, from March until end of June, the ecosystem acts as a sink of CO_2 but during the summer period tends to be source due to increased ecosystem respiration and the decomposition of the soil organic matter. At the end of growingseason in September, there is also a period where the ecosystem is limited sink. On annual basis, the studied ecosystem acts marginally as a carbon sink, with a total gain of about 15 g C m^{-2} of ecosystem area. The studied ecosystem doesn't seem to suffer from severe water stress during the study period, which is obvious by both GPP (Fig.2d) and LE (Fig.1d) values. The daily curve of NEP and GPP (Fig.2a, Fig.2c) in May showed that the NEP acts as sink during day light period showing the maximum activity between 10:00 and 14:00 h. In May only during night due to ecosystem respiration acts as source.In January NEP and GPP had low value, and low ecosystem respiration due mainly to low air temperature. The NEP had limited positive value only around noon from 12.00 to 15.00 h. This study can also efficiently guide the performance of additional relative applications in carbon offset and mitigation studies, contributing to carbon sink quantify.

Table 1. Meteorological parameters during the study period (1/1-31/12/2020).

Parameter	Value	Units
Mean daily temperature	13.2±7.4	° C
Annual precipitation	493.6	mm
Annual solar radiation	5688.11	MJ m^{-2}

4 Conclusions

In this study we presented the results of a one-year study of carbon and energy fluxes between a forest plantation and the atmosphere with the use of the eddy covariance technique. The results showed the seasonal performance of energy and carbon fluxes of *Robinia pseudoacacia* plantations. The energy closure for the site can be considered very adequate, as the sum of latent and sensible heat flux was equalto 88% of net radiation minus soil heat flux. The NEP showed that ecosystem acts as a carbon sink for about half of the year, and as a carbon source for the rest of it. The GPP values are high but also the ecosystem respiration. Consequently, on annual basis, the ecosystem acts marginally as a carbon sink, with a total gain of about 15 g C m^{-2}.

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