2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

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Gross primary production using related vegetation indices

Magna SoelmaBeserra de Moura

Researcherof Embrapa Tropical SemiArid. E-mail: magna@cpatsa.embrapa.br

JosiclêdaDomicianoGalvíncio

Federal Universityof Pernambuco. E-mail: josicleda@hotmail.com

Bernardo Barbosa da Silva

Federal University of Pernambuco. E-mail: bernardo@dca.ufcg.edu.br

Celia Cristina Clemente Machado

Federal Universityof Pernambuco. E-mail: celiamachado.machado@gmail.com

Hewerton Alves da Silva

Federal Universityof Pernambuco. E-mail: he.was@hotmail.com

Tiago Henrique de Oliveira

Federal University of Pernambuco. E-mail: thdoliveira5@gmail.com

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Abstract

The assessment of carbon dynamics in terrestrial ecosystems is of great importance in global climate change research. Caatinga is an exclusively Brazilian biome, and quite lacking in studies, particularly of carbon sequestered by biome. A major difficulty for studies is a function of no observation data in micrometeorological station. The hyperspectral and multispectral remote sensing become increasingly feasible to evaluate the dynamics of carbon in ecosystems, in particular in this Caatinga study area. The objective of this study was to apply correlation analysis and multiple regression to find a relationship between gross primary production (GPP) and vegetation cover index in the Caatinga biome, located in vicinities of Petrolina city, Pernambuco State, Brazil. It was used a HandHeldFieldSpec of ASD to obtain the reflectance data of plant canopy and the vegetation indices. The GPP data were obtained in micrometeorological tower installed into a preserved area of Caatinga biome. The results showed that those vegetation indexes which take water into consideration presented higher correlation with GPP, r^2=0.95. We conclude that it is possible to obtain GPP using only data of vegetation indexes estimated with remote sensing.

Keywords: Spetroradiometry, Caatinga, ecosystems, reflectance.

Introduction

The Caatingais an exclusively Brazilian biome, comprising a total area of 826411 km^{2}in nine Brazilian states, representing about 11% of Brazilian territory. In spite of its biological importance, the Caatinga is the third most degraded biome in Brazil (about 45.3% of the Caatingaarea weremodified, mainly by human pressure) and the less studied and protected. In addition, the continued exploitation of natural resources and the devastation of native vegetation in Caatinga biome have been causing environmental impacts, and changing carbon (C) and nitrogen (N) cycles (Giongo et al., 2011). These two elements are the most important elements for maintaining the ecosystem dynamic, and are, also, associated to climate change.

The carbon quantificationof above-ground, and more particularly below-groundbiomass is difficult in agroforestry systems, besides its importance. Some recent research has determine the carbon sequestration for ecosystems in semiarid and arid lands (Domingo et al., 2011; Luo, et al., 2011; Sousa et al., 2012), also using remote sensing tools (Inoue et al., 2008; Moran et al., 1997; Inoue, 2003;Olioso et al., 2005). According to Xiao et al (2011), an accurate estimation ofthe spatial patterns and temporal dynamics of NEE in terrestrialecosystems at the regional and global scale is of great interest tohuman society and is necessary for understanding the carbon cycle of the terrestrial biosphere.

Caatinga biome has a lack of studies about C dynamic and energy exchange process, and this kind of information it is necessary to understand soil-vegetation-atmosphere interactions (Giongo et al., 2011). It is necessary to know how Caatinga act, if its biome would beidentified as an important sink or drain for atmospheric CO2.

The objective of this study was to apply correlation analysis and multiple regression to find a relationship between gross primary production (GPP) and vegetation cover index in the Caatinga biome, located in vicinities of Petrolina city, Pernambuco State, Brazil.

Data e Methods

Site description

The studied plot is located in a native area of the Caatinga Biome, Petrolina, Pernambuco State, Brazil. This area belongs to Embrapa Tropical Semi Arid and integrate the Site 22 of the ProgramaEcológico de Longa Duração – PELD.The climate is semi arid, with mean annual temperature of 26.0 ^{o}C, a mean rainfall of 525.7 mm which is concentrated mostly in four months (from January to April; Fig. 1). Average minimal value for air temperature was 23.8^{o}C in July, while the maximum occurred in November (27.8^{o}C) (Fig. 1).

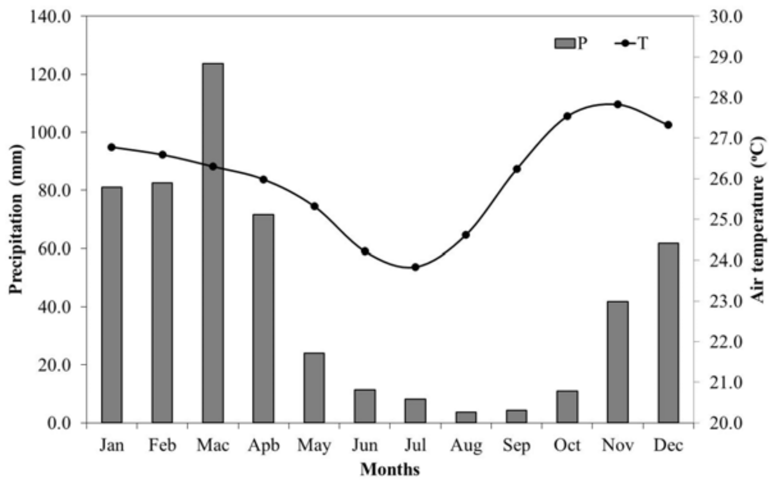

Figure 1. Average monthly precipitation (P, mm) and air temperature (T, ^{o}C) for the last 40 years in Petrolina, Pernambuco State, Brazil.

Micrometeorological and flux measurements

It was used micrometeorological data from a 16 m tall instrument tower fixed at the Caatinga Biome, Brazilian semiarid. A set of meteorological instruments mounted on the tower were used to continuously monitor environmental conditions. For the purpose of the study, it was used data for 16th, June, 2011. Incoming solar radiation (Rg), reflected solar radiation (Rr), atmospheric and surface longwave radiation were measured by a four-component net radiometer (CNR1, Kipp&Zonen, Delft, The Netherlands). Incoming photosynthetically active radiation (PAR) was measured with a quantum sensor (LI-190SA, LI-COR Inc., Lincoln, Nebraska, USA), while a downward looking quantum sensor (LI-190SA, LI-COR Inc.) measured the PAR reflected by surface. An air temperature and relative humidity probe (HMP45C (Vaisala Inc.) was mounted on the tower, and thermistors (107B Soil Temperature Probe, Campbell Scientific) were fixed at 2 and 8 cm depths below the surface. A tipping-bucket rain gauge (CS700, Campbell Scientific), located on the top of the tower, was used to measure total event precipitation. It was used a pair of line quantum sensor (LI-191, LI-COR Inc., Lincoln, Nebraska) to measure the PAR below canopy. The fraction of absorbed photosynthetically active radiation (fAPAR) was derived from PAR measurements. All meteorological sensors were scanned at 30-s intervals and recorded as half-hourly means by a data logger (CR1000) and a multiplexer (AM16x32).

The eddy covariance (EC) system consisted of a threedimensional sonic anemometer–thermometer (CSAT3, Campbell Scientific), mounted at 16 m height, and a fast response infra-red gas analyzer (IRGA, LI7500, LI-COR), used to simultaneously measure changes in CO2 and H2O molar densities. The eddy covariance (EC) technique (Baldocchi et al., 1988; Aubinet et al., 2000; Baldocchi, 2003) was used to measure net ecosystem fluxes of CO2, water vapour (or latent heat, LE) and sensible heat (H).

Hyperspectral reflectance measurements

Reflectance data were collected under clear sky conditions (june 16th) in 2011. Canopy radiance data were collected from 400 to 1000nm using a portable spectroradiometer (HandHeld, ASD, USA), with field of 258 normal to the canopy located at a distance of approximately 2m from the canopy surface. Vegetation reflectance measurements were taken by averaging 5 scans at optimized integration times. We conducted four collected (North-South-East-West) onto four sampling points, totaling 16 points. In this study we plotted four points concerning the mean (average of four collected - North-East South-West) for each geographic area. Reflectance spectra were derived through calibrations relative a 99% white reference panel. Calibration panel reflectance measurements were taken before and after the vegetation measurements.

Vegetation Indexes

WDVI- Water Difference Vegetation Index

To fully explore the hyperspectral data, different kinds of vegetation indexes were calculate (Galvíncio et al., 2012), and among then the Water Difference Vegetation Index – WDVI was that on with the best fit with GPP data.

$$WDVI = R830 - 1.06R660 \quad (1)$$

where R830 is the reflectance in 830nm and R660 is the reflectance in 660nm.

Broadband NDVI

The definition of NDVI utilizes differences in leafabsorptance in the red and near-infrared regions, but Huemmrich et al. (1999) replaced the red domain withPAR and the near-infrared with an optical infrared domainin order to use the upward and downward PAR and globalradiation sensors measurements. Thus, the broadband NDVI was calculated according to Wang et al. (2004).

Statistics

Was applied to analysis of linear correlation and regression to assess the degree of accuracy between the data of GPP with Fieldspec and observed at the station. The equations of correlation and regression using have by Galvíncio& Souza, 2002.

Results and discussion

Meteorological Conditions

The 30-min values of the incoming solar global radiation (Rg), reflected solar radiation (Rr), atmospheric longwave radiation (Ra), surface longwave radiation (Rs), air temperature (Tair), air relative humidity (RH), and wind speed over Caatinga vegetation on 16th June, 2011, in Petrolina, PE, Brazil are revealed in Fig. 2. As shown in Fig. 2a, the variations of incoming (Rg) and outgoing (Rr) solar or shortwave radiation presented, respectively, the maximum of radiation density fluxes about 360.23W m^{-2} and 44.28 W m^{-2} around midday. The average of the ratio Rr/Rg for this day results on 13% of albedo for the Caatinga vegetation. On the same Fig. 2a, values of incoming longwave atmospheric (Ra) and outgoinglongwaveterrestrial (Rs) are similar, and present small variation during the day (422 to 479 W m^{-2}). From Fig. 2a can be also observed the presence of clouds during the day.The net radiation (Rn) represents the budget of the total incoming and outgoing radiation, and for the 16th June, 2011, the cumulative Rn was about 65% of the incoming solar radiation.

Fig. 2b depicts the 30-minute values of the air relative humidity and temperatures. The maximum and minimum RH reached about 91.1% and 56.5% during the 16th June, 2011, in the Caatinga area. The maximum and minimum airtemperatures were about 25.4 °C and 18.7 °C, respectively. The daily average of the air relative humidity and temperature was about 75% and 21°C, respectively. The wind speed measured at 16m over the Caatinga surface is characterized on Fig. 2c. Can be observed values ranging from 2.5 to 5.8 m s^{-1} being the maximum about 14h30 and the lower value during the night time.

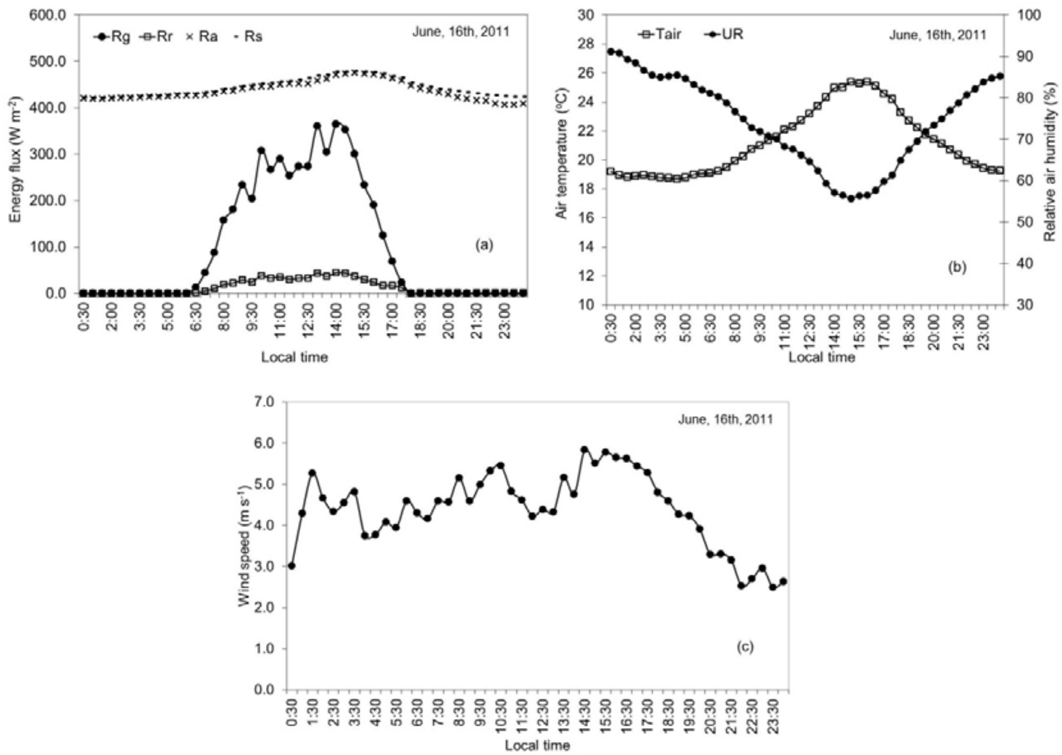

Figure 2. Diurnal pattern of (a) radiation balance, where Rg is the incident solar global radiation, Rr is the reflected solar radiation, Ra is the atmospheric longwave radiation and Rs is the surface longwave radiation; (b) air temperature, Tar and air relative humidity, UR, and (c) wind speed over Caatinga vegetation on 16th June 2011, Petrolina, PE, Brazil.

CO2 Flux

Fig. 3 shows the 30-minuteschanges in NEE in the Caatingafield for 16th June, 2011. The NEE was strongly affectedby incoming PAR intensity. Nighttime NEE, i.e.,ecosystem respiration (Re), ranged around from -2 to +2 µmol m^{-2} $s^{-1}$and was correlated with soil temperature and expressed as linear function (Fig. 3b). Otherwise, others equations should be developed to better represent the relationship between Re and soil and air temperature for Caatinga biome.

GPP values could represent better the photosynthetic activity of ecosystems and may be derived from NEE and Re (Re is the sum of plant and microbial respiration),following the Eq. (2):

$$GPP = -NEE + Re \qquad (2)$$

Note that NEEis positive when CO2 is emitted from theecosysteminto the atmosphere,while GPP andRe are both positive.

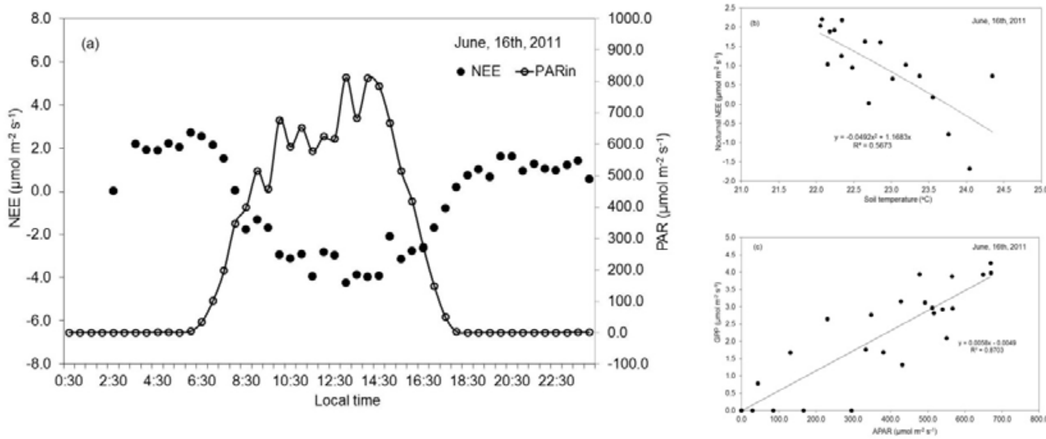

Figure 3. Net ecosystem CO2 exchange (NEE) and incident PAR(a); relationship between nocturnal NEE and soil temperature (b); and, correlation between GPP and APAR overCaatinga biome measured by eddy covariance method on 16th June, 2011, Petrolina, PE, Brazil.

Broadband NDVI and its relationship

The NDVI is sensible to changes in the leaf area, pigments and water relations in plants. So, comparisons at flux tower locations such asCaatingacan provide useful insight into the coupling ofphenology, ecosystem physiology, and remote sensing.For this study, broadband NDVI was calculated from measurements ofPAR and global radiation overthe canopy on 30-minute basis for the studied day and related to FAPAR and GPP obtained by flux tower measurements

Fig. 4 shows the scatter diagrams of broadband NDVI and FAPAR (Fig. 4a) and GPP (Fig. 4b) forweather conditions on 16th June, 2011. The best fit was observed with FAPAR (R2 = 0.923), but it is necessary to analyze the relationship under different weather conditions and status of the vegetation to be more confident about the results, since the caatinga vegetation presents deciduous species and its behavior depends of the soil water availability.

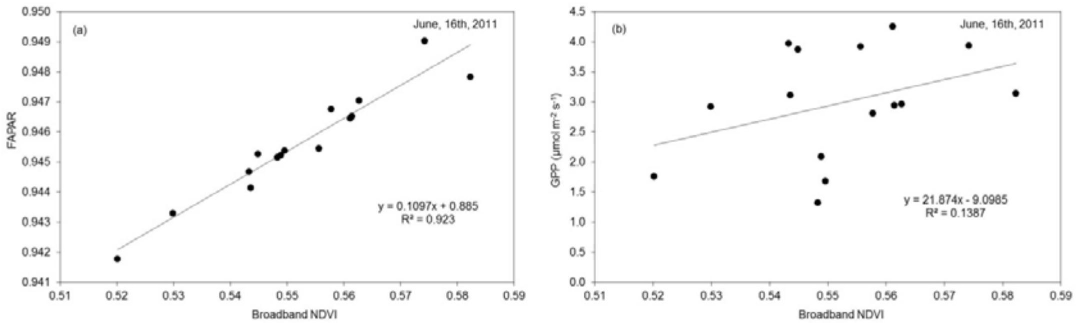

Figure 4. Daily course in broadband NDVI and FAPAR (a) and GPP (b) over Caatinga biome measured by eddy covariance method on 16th June, 2011, Petrolina, PE, Brazil.

The broadband NDVI and GPP relationship was weak. Galvíncio et al., (2012) studied the relationship between NDVI and GPP using handheld spectroradiometer and observed weak correlation (r^2 = 0.20), similar to observed on this actual study (Fig. 4b).On the same way, Wang et al.(2004) determined correlation between NDVI and GPP with r^2 around 0.53 (weak correlation).

For this study, the relation between WDVI and GPP was determined by a handheld spectroradiometer and the results are presented on Fig. 5. It was observed strong correlation of GPP with WDVI (R^2 = 0.95), and the fit equation to estimate GPP is presented on equation 3:

$$GPP = \frac{WDVI + 0.2782}{0.2137} \quad \text{(mmol/m2/s)} \qquad (3)$$

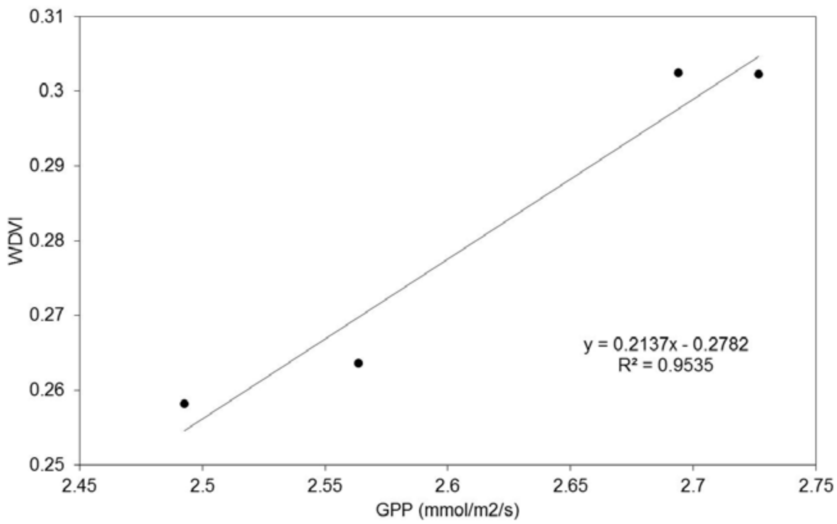

Figure 5. Relationship between GPP and WDVI measured by handheld spectroradiometer over Caatinga biome on 16th June, 2011, Petrolina, PE, Brazil.

Conclusion

The use of eddy covariance and hyperspectral reflectance measurements over Caatinga biome presented strong correlation between vegetation index - WDVI and GPP, and it was developed a new equation to estimate GPP.

This kind of study must be continued. It is necessary to analyze the CO2, water and energy fluxes and its relationship with vegetation indexes under different weather conditions and status of the vegetation to be more confident about the results, since the caatinga vegetation presents deciduous species and its behavior depends of the soil water availability.

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