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Ecosystem total LAI partitioning in a seasonally dry tropical forest

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Introduction

The leaf area index (LAI) has been quantified for different vegetation types around the world. However, there is a lack of studies that partition the ecosystem total LAI into LAI for individual plant species. This is particularly important for natural ecosystems that have dominant species driving the total LAI. Here, we present an effort to estimate LAI for dominant species in an are of the Brazilian Caatinga.

Figure 1. Caatinga vegetation seasonality.

Figure 2. Brazilian biomes with emphasis to the Caatinga.

The Caatinga

The Caatinga (Fig. 2) is a seasonally dry tropical forest, which is the dominant vegetation of the semi-arid northeast of Brazil. It consists of over 1,000 vascular plant species (30–60 plant species per ha) characterized by different physiognomies and drought survival strategies. The trees and shrubs of the Caatinga have a strong seasonal and inter-annual variation in phenology, which causes LAI to vary widely. The vegetation reaches a LAI of 4 m2 m-2 during the wet season (despite the low ratio (~ 0.2) of precipitation over potential evaporation), and most of the species become leafless for periods ranging from weeks to months during the dry season.

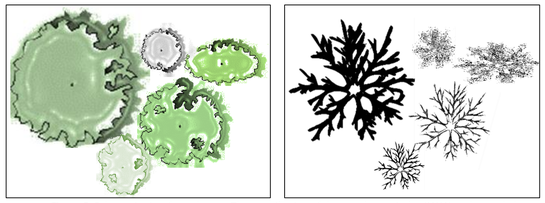


Figure 3. Schematic view from the top. The contribution of the woody area index (WAI) to the total plant area index (PAI): a) on the left is minimal when the LAI is maximum; b) on the right is maximal when the plants are leafless.

Methodology

Overview

Our approach is based on the fact that the Caatinga LAI has timely responses to the soil moisture variations. We use a soil moisture bucket model to estimate the soil-adjusted vegetation index (SAVI), which in turn will be used to estimate the total plant area index (PAI). With individual (per species) PAI measurements, we estimate the LAI for each dominant species.

Field data

Our area of study is an experimental site with pristine Caatinga vegetation at the Embrapa Tropical Semiarid in Petrolina, Brazil. We used measurements of rainfall, soil moisture content and PAI. The tree inventory was conducted by members of the Nordeste project.

Remote sensing

We obtained SAVI series from 106 cloud-free Landsat images (from 2011 to 2018). We used these data for calibration and verification of the model.

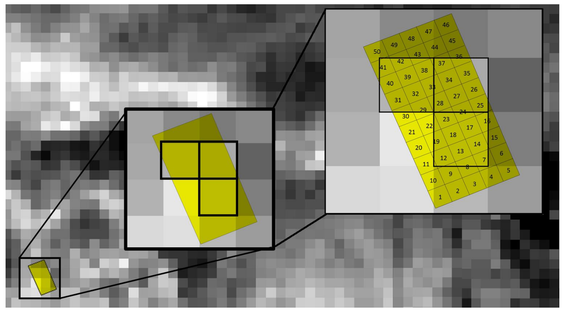


Figure 4. Surveyed subplots (10 x 10 m) and Landsat pixels .

Modelling soil moisture and vegetation index

To estimate the soil moisture (s) and SAVI (N) we used the methodology that Souza et al. (2016) applied to and validated for a Caatinga experimental area.

$$nZ_r\frac{ds(t)}{dt} = R(t) - I(R(t)) - Q(R(t);s(t)) - ET(s(t)) - L(s(t))$$

$$ET(s) = \begin{cases} E_w\dfrac{s-s_h}{s_w-s_h}, & s_h < s \le s_w, \\ E_w + (E_{max}-E_w)\dfrac{s-s_w}{s^*-s_w}, & s_w < s \le s^*, \\ E_{max}, & s^* < s \le 1. \end{cases} \qquad L(s) = K_s s^{2b+3}$$

n = soil porosity (48%); Zr = root system depth (40 cm); R = daily rainfall (cm); Q = runoff (cm);
ET = evapotranspiration (Emax = 5.5 cm/day, Ew = 0.05 cm/day); L = leakage (cm);
s* = stress onset point (17%); sw = wilting point (8%), sh = hygroscopic soil moisture (6%);
Ks = saturated hydraulic conductivity (192 cm/day); b = 3.8.

SAVI (N) estimation

$$\frac{dN(t)}{dt} = k_A A(s)[N_{max} - N(t)] - k_R[N(t) - N_{min}] \qquad A(s) = \begin{cases} 0, & s \le s_w, \\ \dfrac{s-s_w}{s^*-s_w}, & s_w < s \le s^*, \\ 1, & s^* < s \le 1. \end{cases}$$

kA and kR control the rising and recession of SAVI values based on the minimum mean square error of long-term SAVI time-series (obtained with MODIS); A is a coefficient based on the soil moisture that regulates kA.

LAI estimation

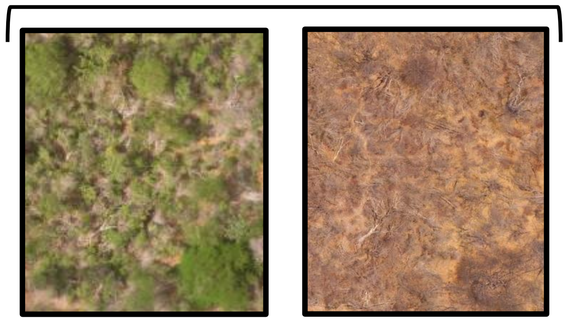
We obtained LAI by extracting the woody area index (WAI) from the PAI following the equations calibrated and verified for the same area (Miranda et al., 2019, Poster number EGU2019-1816 in this session):

$$\begin{cases} PAI = 3 \times (e^{SAVI}) - 2 \\ \mathrm{WAI} = \{1 - [\ln(\mathrm{PAI}) \times 0.5]\} \times \mathrm{PAI} \\ LAI = PAI - WAI \end{cases}$$

Table 1. Species and respective main characteristics used in the model for the study area.

	Species	Crown diameter (m)	Coverage fraction (%)
1	*Commiphora leptophloeos*	7.2	39.5
2	*Cenostigma microphylla*	3.0	20.6
3	*Senegalia piauhiensis*	2.1	11.2
4	*Mimosa tenuiflora*	2.3	8.3
5	*Manihot pseudoglaziovii*	2.0	7.4
6	*Sapium glandulosum*	2.5	6.5
7	*Spondias tuberosa*	2.7	3.6
8	*Handroanthus spongiosus*	2.8	1.9
9	*Croton conduplicatus*	1.9	0.9

Plant area index was continuously measured throughout the years



Wet season – Highest LAI values | **Dry season – Leafless plant status**

Figure 5. Aerial images of the study area in the wet and dry seasons

We measured PAI of the individual species described in Table 1 (5 replicates) to establish at which ratio the PAI varies among them under different soil moisture conditions.

Figure 6. PAI measurements using a ceptometer AccuPAR (AccuPAR@ LP-80, Decagon Devices)

Results

Soil moisture and SAVI

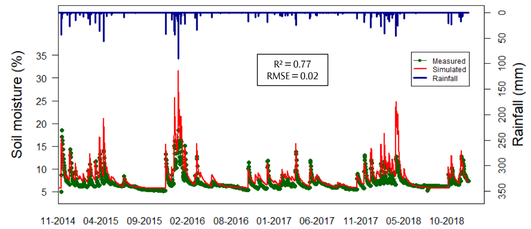


Figure 7. Multi-year variation of measured and simulated soil moisture.

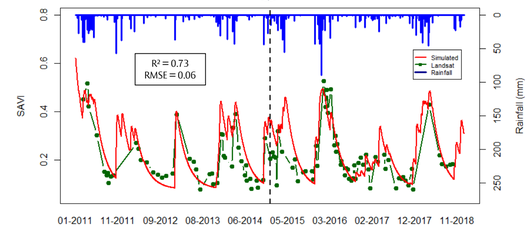


Figure 8. Multi-year variation of measured and simulated SAVI.

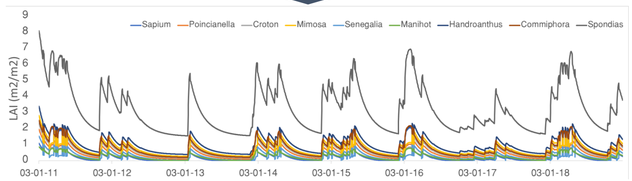


Figure 9. LAI results per species

Conclusions and further work

- This methodology can be used to discretize the LAI of different plant species in relatively sparse vegetation like the Caatinga, where most species had their LAI varying between 1 and 3 m^{-2} m^{-2};
- We will improve the LAI partitioning considering the different senescence and abscission that each species exhibits.

References

Souza R, Feng X, Antonino A, Montenegro S, Souza E, Porporato A. (2016) Vegetation response to rainfall seasonality and interannual variability in tropical dry forests. Hydrological Processes 30 (20): 3583–3595 DOI: 10.1002/hyp.10953

Acknowledgements

We thank the funders (NERC and FAPESP) and the Nordeste Project team.

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