Ecological Indicators 82 (2017) 357–366

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Measuring leaf area index in rubber plantations − a challenge

Marc Cotter[a,*], Folkard Asch[a], Thomas Hilger[a], Arisoa Rajaona[a,b], Alexandra Schappert[a], Sabine Stuerz[a], Xueqing Yang[a,c,d]

[a] Institute of Agricultural Science in the Tropics (Hans-Ruthenberg Institute), University of Hohenheim, 70593 Stuttgart, Germany
[b] Africa Rice Center, c/o FOFIFA Tsivatrinikamo, Ambaniandrefana. B.P. 230, Antsirabe 110, Madagascar
[c] World Agroforestry Centre (ICRAF), China & East Asia Office c.o. Kunming Institute of Botany CAS, Kunming 65021, China
[d] Key laboratory for Plant Diversity and Biogeography of East Asia, Kunming Institute of Botany CAS, Kunming 65021, China

ARTICLE INFO

Keywords:
Leaf area index
Rubber
Radiation interception
Gap fraction

ABSTRACT

In order to estimate water use, water requirements and carbon sequestration of tropical plantation systems such as rubber it is adamant to have accurate information on leaf area development of the plantation as the main determinant of evapotranspiration. Literature commonly suggests a number of different methods on how to obtain leaf area index (LAI) information from tree plantation systems. Methods include destructive measurements of leaf area at peak LAI, indirect methods such as gap fraction methods (i.e. Hemiview and LAI 2000) and radiation interception methods (i.e. SunScan) or litter fall traps. Published values for peak LAI in rubber plantation differ widely and show no clear trend to be explained by management practices or the influence of local climate patterns. This study compares four methods for determining LAI of rubber plantations of different ages in Xishuangbanna, Yunnan, PR China. We have tested indirect measurement techniques such as light absorption and gap fraction measurements and hemispherical image analysis against litter fall data in order to obtain insights into the reliability of these measuring techniques for the use in tropical tree plantation systems. In addition, we have included data from destructive harvesting as a comparison. The results presented here clearly showed that there was no consistent agreement between the different measurements. Site, time of the day and incoming radiation all had a significant effect on the results depending on the devices used. This leaves us with the conclusion that the integration of published data on LAI in rubber into broad ranging assessments is very difficult to accomplish as the accuracy of the measurements seems to be very sensitive to a number of factors. This diminishes the usefulness of literature data in estimating evapotranspiration from rubber plantations and the induced environmental effects, both on local as well as regional levels.

1. Introduction

The cultivation of rubber (*Hevea brasiliensis*) has had a considerable ecological and economic impact in South-East Asia in the last decades (Fox et al., 2013; Li et al., 2007; Li et al., 2005; Xu et al., 2005; Ziegler et al., 2009). Both, land use patterns and cropping systems were strongly affected, as well as the provisioning and balance of ecosystem services and functions in the region (Häuser et al., 2015a, 2015b). The expansion of rubber transferred this system into marginally suitable areas, often on the expense of locally adapted agricultural systems or highly diverse rainforests (Ahrends et al., 2015). In general, the suitability of any area for rubber cultivation hinges on two factors, namely the production potential which is defined, among others, by both the photosynthetic capacity of the trees and the seasonal water-availability and water use of the plantation; each limiting the production potential of the system. Both factors depend on the physiologically active leaf area per tree, and since the trees are grown in plantations, the physiologically active leaf area per hectare plantation. Another important factor, the temperature environment in which rubber is grown, and its influence on growth rates and yields has been discussed a number of papers (e.g. Golbon et al., 2015; Veatch-Blohm et al., 2007) and will not be part of this study.

Leaf Area Index (LAI), the quotient of one sided leaf area per unit ground area ($m^2 m^{-2}$) (Watson, 1947) is an indicator used to describe the structure and density of plant canopies (in this definition best suited for broadleaf species). Its main purpose in plant production is to describe the size of the source for biomass accumulation in relation to the land area that is being cultivated. By measuring or estimating LAI accurately key ecosystem processes essential for the assessment of impacts on climate or system balance (Sprintsin et al., 2011) such as evapotranspiration and carbon accumulation via photosynthesis can be characterized. LAI can be employed to up-scale instantaneous single leaf observations to canopy level.

* Corresponding author.
E-mail address: marc.cotter@uni-hohenheim.de (M. Cotter).

http://dx.doi.org/10.1016/j.ecolind.2017.07.019
Received 3 March 2017; Received in revised form 6 July 2017; Accepted 6 July 2017
Available online 14 July 2017

LAI describes the area of potential transpiration water loss of a plant stand and is thus an important parameter in water balance estimations i.e. determining the amount of water intercepted by the canopy, the amount of water that reaches the soil, and the water lost by evapotranspiration that is a function of canopy dynamics and microclimate. LAI has been reported to be a strong controlling factor of seasonal changes in transpiration of rubber trees, strongly interacting with and partially over-shadowed by the plant available water content in the soil (Sopharat et al., 2015). Therefore, Kumagai et al. (2015) used LAI and the closely related plant area index (PAI) as an input variable in their study on rubber plantations to estimate mean canopy stomatal conductance. With this approach the authors attempted to estimate field water balances over different seasons and study sites, as well as to analyze changes in stomatal regulation over the seasons. Pansak et al. (2010) calibrated the contact cover fraction of the Rose equation (REF) in the erosion submodule of the *Water, Nutrient and Light Capture in Agroforestry Systems* (WaNuLCAS) model, using non-destructive LAI measurements. In the same model, LAI serves to model the relative light capture by crops or trees and determines their growth rate (Hussain et al., 2015a, 2015b). LAI, thus, significantly contributes to plant growth and agronomic models (Taugourdeau et al., 2014) from plantation via watershed to landscape scale hydrological cycles and carbon storage potential. However the accuracy of determining LAI dynamics in growing crops or plantations remains a challenge due to the spatial and temporal variability, stand heterogeneity and stratification as well as seasonal and inter-annual variability (Bréda, 2003).

1.1. Comparing methods of LAI determination

A number of methods and measuring techniques exist to obtain LAI data. A direct measurement is the actual measuring of leaf area, most commonly used in combination with either allometric equations (Bartelink, 1997) or counting of leaves (Gower and Norman, 1991) to allow up-scaling to tree level. Another possibility for direct measurements is to use the specific leaf area (SLA) which is the quotient of the leaf surface area and the weight of that area (Smith et al., 1991). Destructive sampling of (total) leaf biomass or the determination of leaf biomass from leaves collected via litter traps beneath the canopy when multiplied with SLA, allow assessing the leaf area index of one canopy section. Both approaches are highly labor intensive and are marginally suitable for assessing of large plantations or natural forest systems.

Indirect measuring techniques for LAI include the use of field-based non-destructive optical or spectral methods (reviewed by Bréda, 2003) and satellite based remote sensing. Several authors have reported using remote sensing techniques, most commonly NDVI measurements, in combination with LAI from ground truth activities (Pradeep et al., 2014, Rusli and Majid, 2014, Taugourdeau et al., 2014). NASA e.g. is offering global datasets of MODIS based LAI.

While this approach is promising for large scale assessments, the difficulty of clearly differentiating land use classes via remote sensing remains. Rubber plantations for example had been shown to pose some challenges in this regard, especially early stages before complete canopy closure that can easily be misclassified into agricultural fallow, grasslands or other perennial land uses, depending on local management preferences (Li and Fox, 2012).

A commonly used approach between the two extremes of remote sensing and destructive sampling is the above mentioned non-contact optical measurement of LAI. Gap fraction inversion (GFI) is one of the techniques used to estimate LAI by measuring total, diffuse and direct radiation transmittance at stand floor level assuming random, non-clumpy leaf arrangements. In case of clumping, e.g. when working with conifers, epiphytes or overlapping broadleaf canopies, statistical methods exist to adapt LAI measurements to complex canopy structures (Sprintsin et al., 2011).

One drawback of these optical approaches is the fact that not only leaves cast shadows, but also twigs, stems and other non-leaf materials as well as “clumping” interact with light transmittance. In literature, this is often described as the difference between LAI and effective LAI_e (Sprintsin et al., 2011). A range of methods is discussed on how to convert plant area indices (PAI) to LAI (Kumagai et al., 2015; Ryu et al., 2012).

Jonckheere (2004) reviewed *in-situ* LAI measurements and suggested the use of digital camera based systems. Hence, an ideal system should use a hemispherical sensor that allows simultaneous assessment of gap fractions at a range of zenith angles and permits derivation of the gap fraction distribution as a function of the zenith angle to obtain information on leaf clumping. In addition, it should be able to discriminate between green and non-green canopy elements. These authors also concluded the need for further testing LAI devices and defining standardized field protocols. Weiss (2004) stressed that there is need to validate the current assumptions used in the gap fraction models, emphasizing the directional dependence of clumping (e.g. horizontal vs. vertical) and its scale. Devices providing a 3D computer-generated canopy are adequate tools for such studies. Another critical issue is the sampling strategy to derive *in-situ* LAI values, which is rather complex and still needs further investigation.

The different approaches for estimating LAI vary widely in their results. Sprintsin et al. (2011) reported up to 20% variation in LAI measurements when comparing optical, allometric, and leaf litter methods for study sites in conifer plantations. Data presented by Pradeep et al. (2014) suggests variations of around 12.5% between optical and satellite based methods in rubber plantations.

1.2. Leaf area index values reported for rubber plantations

Water use and latex production are strongly influenced by the active leaf area of the deciduous rubber trees in a plantation. Seasonal dynamics of leaf growth and thus water use and carbon acquisition determine the seasonal resource use as well as the economic return of the rubber plantation. When cultivated in regions with a pronounced dry season, rubber plantations shed their leaves simultaneously. Ecological, economic, and matter flux models, therefore, depend strongly on accurate estimations of active leaf area and leaf area dynamics. LAI values reported for peak leaf area of rubber plantation vary widely in literature. This is partly due to differences in age structure and management of the plantations, the variety of topographic and climatic environments in which rubber is grown but also due to the methods that were used to determine the LAI. Rusli and Majid (2014) reported for latex producing plantations LAI values of 3.0 for medium aged canopies, 5.5 for canopies of mature stands, and optimum ranges of 7.2–9.0 for canopies of mature 15-year-old plantations. In contrast, using MODIS Data for the same area but due to pixel size not differentiated between the different stands resulted in mean values for LAI of 2.6. Another study from Kerala state, India, did also use MODIS data for remote sensing based LAI studies on rubber, and complemented these with non-contact optical measurements using a SunScan Canopy Analyzer SS1 (Pradeep et al., 2014). They reported values from field measurements ranging from 3.5 for maximum foliage period compared to values between 3.5 and 4 for the MODIS data from the same period. LAI values decreased to 1 during the height of seasonal defoliation and during an outbreak of abnormal leaf fall disease. Peak LAI values of up to 8 or more were reported by two studies using surface reflectance measurements (Guardiola-Claramonte et al., 2010; Pradeep et al., 2014). Beckschäfer et al. (2013) compared different approaches for remote sensing based LAI predictions in rubber plantations using RapidEye images using LAI derived from Hemispherical Image Analysis as reference values.

Two of the key drawbacks of these satellite based LAI values are the heterogeneity of the source data, both in space and in time. Seasonal defoliation may lead to insecurities in the determination of LAI from satellite images, while small-scale variations in land use, between rubber and teak plantation or secondary forest for example, can compromise the accuracy of the allocation of measured LAI values to distinct land use classes.

Kumagai et al. (2015) conducted Plant Area Index (by the definition used in their work LAI plus stem and branches) measurements on two sites in Cambodia and Thailand. They reported adjusted PAI values for both sites peaking at a seasonal maximum between 4 and 5. Similar ranges of LAI using a LI-COR LAI 2000 in Cambodia were reported as part of a study