Examensarbeten **2012:4**
Institutionen för skogens ekologi och skötsel

Leaf area index in *Vittelaria Paradoxa* parklands in Burkina Faso estimated by light interception and leaf sampling

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Examinator: Gert Nyberg, SLU, Inst för skogens ekologi och skötsel Umeå 2012

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LAI för Vittelaria Paradoxa i Burkina Faso, beräknat genom mätningar av ljusinsläpp och lövarea

Elsa Bengtsson

Nyckelord / *Keywords:*
Agroforestry, LAI, LAI-2000 canopy analyzer, kalibrering / *Agroforestry, LAI, LAI-2000 canopy analyzer, calibration*

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Summary

Burkina Faso as well as most sub-Saharan African countries struggle with providing food for a fast growing population. The dominating farming system is agroforestry parklands. Agroforestry parklands can broadly be defined as areas where scattered trees occur on farmlands as a result of selective clearing. The presence of trees in crop fields may in the long term have a positive effect on the production of annual crops. It is commonly discussed, but not proven, that the presence of trees leads to increased groundwater recharge due to higher infiltration capacity of the soil. Still in Burkina Faso, as in many semi-arid areas, the number of trees in the landscape is decreasing.

Leaf Area Index (LAI) is the total one-sided area of photosynthetic tissue per unit ground surface area. LAI of a forest or an agricultural crop is a key variable for modeling the evapotranspiration on an ecosystem or individual plant/tree level. LAI can therefore be used to better understand understand the connection between the physical properties of the soils and changes in forest cover.

Leaf Area Index can be measured using direct or indirect methods. Direct methods are methods were leaf is measured in a direct way often by leaf sampling, while indirect are methods where LAI is received from variables that can be measured with less effort. The objective of the thesis is to calibrate methods for estimating Leaf Area Index in *Vittelaria paradoxa* parklands in Burkina Faso, by using both direct and indirect methods. The thesis also aims to investigate if there is a strong relationship between the size of the tree, e.g trunk diameter and crown diameter and its LAI

Indirect measurements with the LAI-2000 canopy analyzer (LiCor Inc, *Lincoln, Nebraska*) were made at 9 different plots, which have been earlier established for measurements of sapflow within the "Tree, carbon and water project". Each of the 9 plots consists of 3 trees. This gives a total of 27 trees. Besides those 27 so called sapflow trees were 4 control trees in the same area measured with the LAI-2000 to use as a calibration, all branches on these trees were later cut down and LAI were measured directly.

The result showed a correlation between the two methods. However, the LAI-2000 underestimated the drip line LAI compared to the manually measured drip line To be able to use this correlation factor between the two methods with certainty a larger number of control trees would be needed. There is a correlation between diameter at breast high and indirect measured drip line LAI. However, the correlation is not strong enough that drip line LAI can be predicted based on this factor alone. The same thing can be said about the correlation between drip line area and indirect measured drip line LAI.

Key words; Agroforestry, LAI, LAI-2000 canopy analyzer, calibration.

Samanfatting
Burkina Faso kämpar med att föda en snabbt växande befolkning. Den dominerande lantbruksformen är agroforestrysystem, områden där spridda träd förekommer på jordbruksmark. Förekomsten av träd antas leda till ökad grundvattenbildning som följd av högre infiltrationskapacitet i marken men detta har ännu inte bevisats.

Leaf Area Index (LAI) är den totala ensidiga arean av fotosyntetiserande vävnad per markarea. LAI är en användbar variabel för modellering av evapotranspiration på ekosystem- eller trädnivå. LAI kan därför användas för att få bättre förståelse för sambandet mellan de markens fysiska egenskaper och förändringar i skogstäcket. Leaf Area Index kan mätas med hjälp av direkta eller indirekta metoder.

Syftet med uppsatsen är att kalibrera metoder för estimering av index Leaf Area Index i *Vittelaria Paradoxa* agroforestrysystem. Uppsatsen syftar också till att undersöka om det finns ett samband mellan storleken på trädet, t.ex. stamdiametern samt projicerad kronarea och LAI.

Indirekta mätningar med LAI-2000 canopy analyzer (LiCor Inc, Lincoln, Nebraska) skedde på 9 olika provytor. Totalt mättes LAI indirekt på 31 träd. Fyra av dess träd var kontrollträd. För dessa träd mättes LAI även direkt.

Resultatet visade en korrelation mellan de två metoderna. Däremot underskattade den indirekta mätningen LAI jämfört med den manuella metoden. För att kunna använda denna korrelationsfaktor med säkerhet, skulle ett större antal kontrollträd behövas. Det finns även ett samband mellan brösthöjdsdiameter och indirekt mätt LAI. Dock är korrelationen inte stark nog för att förutsäga LAI enbart med hjälp av denna faktor. Det samma kan sägas om sambandet mellan projicerad kronarea och indirekt mätt LAI.

Nyckelord; Agroforestry, LAI, LAI-2000 canopy analyzer, Kalibrering.

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Introduction

Background

Access to safe drinking water is a basic human right, however still 1.1 billion people lack access to a source with clean drinking-water. About 60 % of these people live in the rural parts of Africa (WHO 2003).The water shortages are especially severe in the climatic zone which is characterized by big seasonal differences in precipitation over the year. In Burkina Faso rain fall during a single wet season is mainly consisting of short intense storms over a 3-5 month period, around 90% of the rains falls during these months (Ingram *et al.* 2002). The climate change expected for West Africa is decreasing and more variable rainfall, which most likely will lead to even bigger problems with water shortages (IPCC 2007).

Burkina Faso as well as most sub-Saharan African countries struggle with providing food for a fast growing population. Burkina Faso is consistently ranking in the bottom five countries in most development indicators. About 90% of the population depends on agriculture for livelihood. Farmers in Burkina Faso face harsh conditions such as soil erosion, insufficient soil nutrient and heavy drought. Most of the crop produced is for the own household and is grown under rainfed conditions (Ingram et al.2002). The dominating farming system is agroforestry parklands. Agroforestry parklands can broadly be defined as areas where scattered trees occur on farmlands as a result of selective clearing. A typical landscape in the area consists of fields with scattered trees above different annual crops (Augusseau, et al.2006).

In Burkina Faso there are extensive parklands, where the shea butter tree, *Vitellaria paradoxa* is the dominating tree species, as in figure 1. Karité, as it is called locally, produce kernals with high fat content. Traditionally, shea butter was the only source of fat for many ethnic groups depending only on agriculture such as the Mossi, the largest ethnic group in Burkina Faso. Still, shea butter is the primary cooking fat for a large part of rural populations where the species occurs. Shea butter is today a very important export to European and Japanese food and cosmetic industries (FAO, 1998). The commercialization of shea products has become an important source of income for rural women and children who gather and process the kernals, as well as for the entire country (Dianda et al 2008).

Figure 1:Vittelaria Paradoxa parklands in central Burkina Faso. Photo Elsa Bengtsson

Trees bring many values to the framers e.g. fuel, timber and non timber products such as fruits and nuts. (Malmer et al. 2010). The presence of trees in crop fields may have a positive effect on the production of annual crops by improving the soil structure and water infiltration, maintaining a vegetative soil cover year-round and a more rapid nutrient cycling due to the production of organic litter. In addition, mixing trees and crops in parklands increase the resilience of the farms by spreading the risks and increases the variety of products produced on farms. However, it needs to be mentioned that the trees cause a shading effect that leads to a decrease in productivity by the crop, at least during years when it is not unusually dry (Garrity, et al.2010). It is commonly discussed, but not proven, that the presence of trees leads to increased groundwater recharge due to higher infiltration capacity of the soil (Hillel 1980). Still in Burkina Faso, as in many semi-arid areas, the number of trees in the landscape is decreasing (Malmer et al. 2010).

It is important to understand the connection between the physical properties of the soils and changes in forest cover (and/or in degree of canopy cover in the parklands) (Sanou et al. 2010, Bruijnzeel 1990). In the tropical semi arid-areas deforestation is likely to lead to increased surface runoff. This means that less water will infiltrate down through the soil and recharge the groundwater (Sanou et al. 2010). Reestablishing forests is a common strategy for soil rehabilitation. The interest for tree planting has however been under increased debate since a number of studies have shown strongly reduced streamflow after afforestation (Malmer et al. 2010). It is however clear that trees have a positive effect on infiltration due to the formation of roots and the growing amount of organic matter in the soil (Ilstedt et al., 2007; Sanou 2010), but questions still exist regarding the tradeoff between increased infiltration and increased water use by trees (Bruijnzeel 2004).

Leaf area index

Leaf Area Index (LAI) was first defined by Watson (1947) as the total one-sided area of photosynthetic tissue per unit ground surface area. Most vegetation has a LAI several times the under-laying soil surface (Breuer, et al. 2003). According to this definition, LAI is a dimensionless variable characterizing the canopy of ecosystems. The amount of foliage in the ecosystem canopy, which can be expressed by LAI controls canopy water interception and transpiration (Jonckheere et al. 2004). LAI also determines radiation extinction and carbon gas exchange and is, therefore, a key driver of biogeochemical processes in ecosystems (Bréda 2003).

LAI of a forest or an agricultural crop is a key variable for modeling the evapotranspiration on an ecosystem or individual plant/tree level (Breuer, et al. 2003). Process-based ecosystem simulations are often used to analyses ecosystem productivity and LAI is a key input parameter to such models (Bréda 2003).The LAI of an ecosystem depends on many factors such as species composition, stand development, site conditions, seasonality, and, if any, the management practices (Jonckheere et al. 2004). LAI changes daily due to changes in foliage over the growing season, especially in spring and autumn. LAI also changes annually driven by forest dynamics (Wells 1990).

In a large, homogeneous plant community, LAI is a reasonable way to express the amount of vegetation (Bréda 2003). However, when wanting to describe foliage amount for individual plants it is more appropriate to use foliage area density (or simply foliage density), which is foliage area divided by canopy volume. When still wanting to use LAI for isolated plants it is vague unless the size and position of the ground area is also given. For example, it can be expressed based on the tree's drip line area, or based on the area associated with the tree as a member of a community (LI-COR, Inc, 1992). Figure 2 explains the term drip line area.

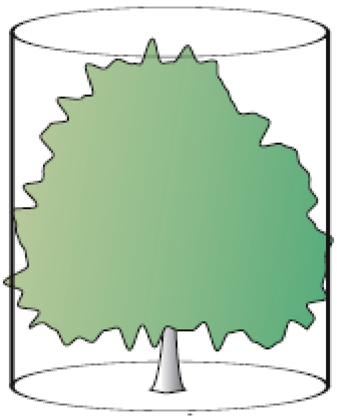

Figure 2 The projected area of a tree, also known as dripline area (LI-COR, Inc, 1992).

Leaf Area Index can be measured using direct or indirect methods. Direct methods are methods were leaf is measured in a direct way often by leaf sampling, while indirect are methods where LAI is received from variables that can be measured with less effort (Jonckheere et al.2004).

Direct methods

LAI can be measured directly by destructive harvesting of leaves from trees or crop or non-harvesting litter traps during seasonally leaf-fall period in deciduous forests. LAI are determined through area measurements on sub-sample of leaves and area accumulation (Bréda 2003). Direct methods are considered the most accurate, but they are labor-intensive, time-consuming and possible destructive and are therefore not suitable for making large-scale implementation. However there is need for ways to validate the indirect methods so the direct methods can be thought of as important calibration methods (Jonckheere et al. 2004). Possible accuracy problems facing direct methods may be caused by the definition of LAI, the up-scaling method, or from the error accumulation due to need of frequently repeated measurements (Bréda 2003).

Indirect methods

Indirect methods, in which leaf area is inferred from measurements of other variables, are in general more rapid, and therefore permit for a larger spatial sample to be obtained (Jonckheere et al.2004).

Indirect non-contact methods, which are the most commonly used, estimates leaf area index from measurements of the transmission of radiation through the canopy, using the radiative transfer theory (Anderson, 1971; Ross, 1981). These methods are non-destructive and are based on a statistical and probabilistic approach to estimation of the contact frequency or the gap fraction. Contact frequency is the probability that a beam penetrating the canopy will come into contact with a vegetative element. Gap frequency, on the other hand is the probability that a beam will have no contact with the vegetation elements until it reaches a reference level, often the ground (Weiss et al. 2004).

During the last 30-40 years, a range of instruments for indirectly estimation of LAI has been developed (Jonckheere et al. 2004). There is documented research that proves these instruments very efficient and reliable, concerning measurement of LAI in forest ecosystems (Welles, 1990). One of these instruments is the LAI-2000 canopy analyzer (LiCor Inc, *Lincoln*, *Nebraska*) which is used in this thesis. However, agroforestry parkland are spatially heterogeneous and open ecosystems, characterizing LAI using indirect methods in this type of ecosystem is challenging because most methods assume homogeneous, and more closed canopies (Ryu et al. 2010). There are also only few studies which evaluated how well these indirect methods work measuring isolated plants or trees (Peper et al. 2003), as will be done in this thesis.

"Tree, carbon and water project"

There is a need of studies of trees affect on the ecological water system in tropical semi-arid areas (Malmer et al. 2010). A better understanding of how trees affects the water system will hopefully give us a better chance of securing the access to safe drinking water for everyone, even with the upcoming climate change. This thesis is made within in the "Tree, carbon and water project" which is a multidisciplinary collaboration between SLU, University of Gothenburg, Linköping University in Sweden as well as Institut de l'environnement et Recherches Agricoles (INERA) and University of Ouagadougou in Burkina Faso. The overall project aim is to clarify the conditions for which increased tree cover may lead to both high carbon sequestration and improved adaptive capacity to climate change, especially groundwater recharge.

Objective

The objective of the thesis is to calibrate methods for estimating Leaf Area Index in *Vittelaria paradoxa* parklands in Burkina Faso, by using both direct and indirect methods. Leaf Area Index is a key variable in modeling trees transpiration. These measurements will be used within the “Tree, carbon and water project” for the validation and up scaling of ongoing sap flow measurements in the same area.

The hypothesis is that it is possible to calibrate indirect LAI measurement made in *Vittelaria paradoxa* parklands in Burkina Faso, using light interception, by comparing with direct measurements of LAI.

The thesis also aims to investigate if there is a strong relationship between the size of the tree, e.g trunk diameter and crown diameter and its LAI.

Material and method

Theory

The LAI-2000 measures the probability of seeing the sky when looking up through a vegetative canopy at different angles. The LAI-2000 consists of an optical sensor and control box. The instrument's sensor uses fisheye optics to project a hemispheric image onto five silicon detectors. If the sensor is level and viewing the sky, detector 1 will measure the brightness straight overhead e.g. at 7 °, while detector 5 will measure the brightness of a ring centered at the 68° zenith angle. A cross section of the sensor is shown in figure 3 (LI-COR, Inc, 1992). The sensor contains an optical filter to reject any radiation to wavelengths below 490 nm, in order to minimize the contribution of radiation that has been scattered by fo1iage. The control box records the sensor's data and performs necessary calcu1ations for determining LAI and mean inclination angle of the foliage. The basic technique combines a measurement of sky brightness from a leve1ed sensor placed above, or for trees and other high vegetation, outside the canopy with a second measurement taken below the canopy (Norman & Wells, 1991).

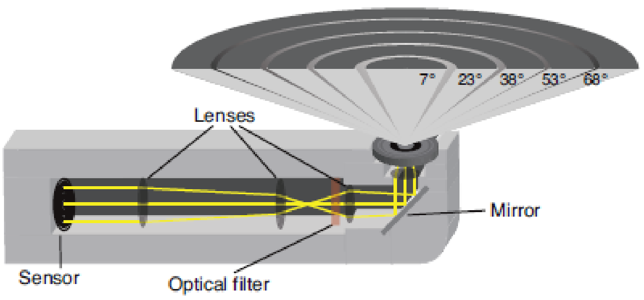

Figure 3. The LAI- 2000 sensor in cross section, displaying the angles of the five detectors (LI-COR, Inc, 1992).

The ratio of each ring's signals is then assumed to be equivalent to the canopy's gap fraction at that ring's viewing angle. Gap fractions are converted to LAI and mean inclination angle in the control box using a method similar to Lang (1987), based on the re1ationship of gap fraction and angle noted by Miller (1967).The assumptions made in the inversion of gap fraction data to obtain structural information are, (i) The foliage is black. It is assumed that below canopy readings do not include any light that is reflected or transmitted by foliage., (ii) foliage is random1y positioned in the canopy, (iii) foliage elements are small compared to the area viewed by each ring, and (iv) The foliage has random azimuthally orientations. Meaning, it does not matter how which inclination angle the foliage has towards the steam as long as all the leaves are not facing in the same cardinal direction. (LI-COR, Inc, 1992).

No real canopy fulfills all these assumptions exactly. Foliage is never totally random, but often clumped along stems and branches, and is surely not black. However, the practical assumptions that need to be made are often not considered too seriously compromising the outcome. Many canopies can be considered random, and living foliage does have relatively low transmittance and reflectance of light below 490 nm (Norman & Wells, 1991).

When a beam of light passes through a vegetative canopy, there is a certain chance that it will be intercepted by foliage. The probability of interception is proportional to the path length through the crown, foliage density (area of foliage per volume of canopy), and the orientation of the foliage. If foliage elements are small compared to the overall canopy, and they are randomly distributed in the sensor view, then it is known that a beam of light from zenith angle θ has a probability of $P(\theta)$ of non-interception. All equations below are based on the LA1-2000 manual (LI-COR, Inc, 1992).

$$P(\theta) = e^{[-G(\theta)\mu S(\theta)]} \tag{1}$$

where $G(\theta)$ is the fraction of foliage projected toward θ, μ is foliage density (m2 foliage per m3 canopy volume), and $S(\theta)$ is path length (m) through the canopy at angle θ. Miller (1967) gives the exact solution for μ as

$$\mu = 2\int_0^{\pi/2} -\frac{ln(P(\theta))}{S(\theta)} sin(\theta)\, d\theta \tag{2}$$

In a horizontally large, homogeneous canopy, path length, S(θ) is related to canopy height h by

$$S(\theta) = \frac{h}{cos(\theta)} \tag{3}$$

In such a canopy, the relation between leaf area index L and foliaged density μ is

$$L = \mu h \tag{4}$$

Substituting these into (2) yields

$$\mu = \frac{2}{h}\int_0^{\pi/2} -ln(P(\theta))\, cos(\theta) sin(\theta) d\theta$$

$$L = \mu h = 2\int_0^{\pi/2} -ln(P(\theta))\, cos(\theta) sin(\theta) d\theta. \tag{5}$$

The formula (2) is used for computing either L or μ: For L, S(θ)=1/cosθ are used, and for computing μ the actual values of S(θ) are used. The difference between L and μ is driven by S(θ).

When multiple observations of P(θ) are available, there are two ways they could be combined: The values of P(θ) could be averaged:

$$\mu = 2\int_0^{\pi/2} \frac{-\ln\left(\overline{P(\theta)}\right)}{S(\theta)} \sin(\theta) d\theta \qquad (6)$$

or the values of ln$P(\theta)$ averaged:

$$\mu = 2\int_0^{\pi/2} \frac{\overline{-\ln(P(\theta))}}{S(\theta)} \sin(\theta) d\theta. \qquad (7)$$

Eqn. (7) will account for clumping (on spatial scales larger than the field of view of the sensor), but Eqn. (6) is appropriate for determining effective leaf area index L, which by definition must ignore clumping. The LAI-2000 computes both of these, and uses Eqn. (7) for its reported leaf area index value L_e, and the ratio of (6) and 7) for computing Ω_{app}, the apparent clumping factor (Ryu et al. 2010).

$$\Omega_{app} = \frac{2\int_0^{\pi/2} \frac{-\ln\left(\overline{\overline{P(\theta)}}\right)}{S(\theta)} \sin(\theta) d\theta}{2\int_0^{\pi/2} \frac{\overline{-\ln(P(\theta))}}{S(\theta)} \sin(\theta) d\theta} \qquad (8)$$

Effective leaf area index, L_e, can be computed by

$$L_e = L\Omega_{app} \qquad (9)$$

Once L or μ is determined from Eqn. (1), Eqn. (2) can be solved for the orientation function $G(\theta)$.

$$G(\theta) = \frac{-\ln(P(\theta))}{\mu S(\theta)} \qquad (10)$$

Figure 4 shows the theoretical values of $G(\theta)$ for an ideal canopy whose foliage is random both in position and orientation, but inclined at a fixed angle. Curves for ten different foliage inclination angles are shown.

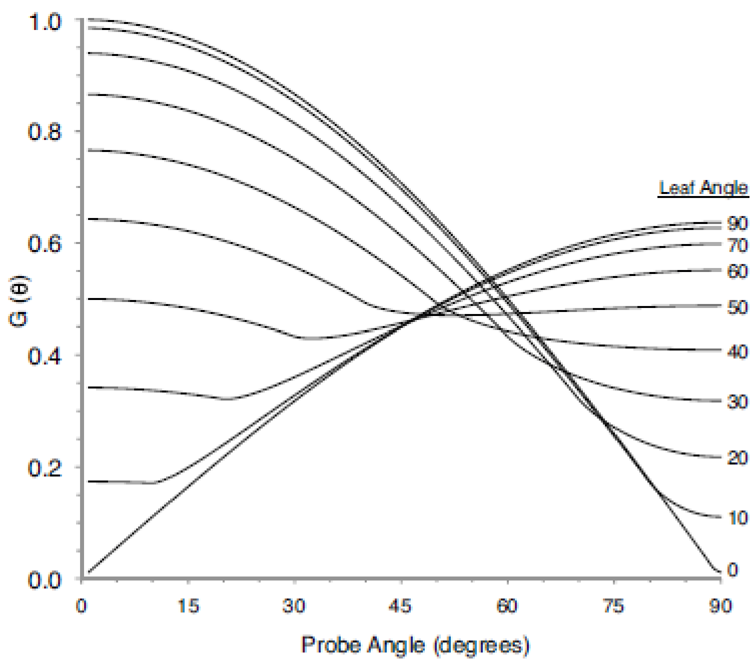

Figure 4 Idealized relationship between projected foliage area and direction for various foliage inclination angels, after Warren Wilson (1959)

The LAI-2000 calculates foliage mean tilt angle $\bar{\alpha}_f$ after the manner of Lang (1986), using an empirical polynomial relating inclination angle to the slopes of the idealized curves between 25° and 65°.

In this section, the subscript *i* refers to optical sensor rings (*i*=1…5), and the subscript *j* refers to observational pairs (*j*=1…N obs). B_{ij} is the *jth* below canopy observation, *ith* ring, and A_{ij} is its corresponding above canopy reading.

The average probability of light penetration into the canopy is computed by

$$\overline{P(\theta_i)} = \frac{1}{N_{obs}} \sum_{j=1}^{N_{obs}} \frac{B_{ij}}{A_{ij}} \tag{11}$$

The 5 values of *P* θ *i* ( ) are labeled AVGTRANS in the LAI-2000 data file.

The probability of light penetration based on averaging the logarithms of transmittance for the *ith* ring is computed from

$$G_i = e^{\overline{\ln(P(\theta_i))}} = e^{\frac{1}{N_{obs}} \sum_{j=1}^{N_{obs}} ln\frac{B_{ij}}{A_{ij}}} \tag{12}$$

The values of G_i are labeled GAPS in the data file.

The leaf area index *L* for the file, labeled LAI, is computed from

$$L = 2\int_0^{\pi/2} \frac{-ln\overline{(P(\theta))}}{S(\theta)} sin(\theta)\, d\theta = 2\sum_{i=1}^{5} \overline{K}_i W_i \tag{13}$$

where

$$\overline{K}_i = \frac{1}{N_{obs}} \sum_{j=1}^{N_{obs}} \frac{-ln\frac{B_{ij}}{A_{ij}}}{S_i} \tag{14}$$

and

$$W_i = sin(\theta_i) d\theta_i \tag{15}$$

K_i is sometimes called the contact number, and is reported with the label CNTCT# in the data file. W_i, is a so called weighting factors.

An apparent clumping factor for each ring, labeled ACFS in the LAI-2000 data file, is computed from

$$\Omega_i = \frac{ln\overline{P(\theta_i)}}{\overline{lnP(\theta_i)}} = \frac{ln\left(\frac{1}{N_{obs}} \sum_{j=1}^{N_{obs}} \frac{B_{ij}}{A_{ij}}\right)}{\frac{1}{N_{obs}} \sum_{j=1}^{N_{obs}} ln\left(\frac{B_{ij}}{A_{ij}}\right)} \tag{16}$$

A total apparent clumping factor, Ω_{app}, labeled ACF in the data file, is computed from

$$\Omega_{app} = \frac{2\int_0^{\pi/2} \frac{-ln\overline{(P(\theta))}}{S(\theta)} sin\,(\theta) d\theta}{2\int_0^{\pi/2} \frac{-ln\overline{(P(\theta))}}{S(\theta)} sin\,(\theta) d\theta} = \frac{2\sum_{i=1}^{5} \frac{ln\overline{P(\theta_i)}}{S_i} W_i}{2\sum_{i=1}^{5} \overline{K_i} W_i} \quad (17)$$

Standard error L_{se} of the leaf area index value is reported as SEL, and is computed from

$$L_{se} = \sqrt{\frac{\frac{1}{N_{obs}} \sum_{j=1}^{N_{obs}} L_j^2 - L^2}{N_{obs}}} \quad (18)$$

where L_j is the leaf area index calculated for an individual A/B pair

$$L_j = 2\sum_{i=1}^{5} K_{ij} W_i \quad (19)$$

where K_{ij} is the contact value for the pair.

$$K_{ij} = \frac{-ln \frac{B_{ij}}{A_{ij}}}{S_i} \quad (20)$$

The standard deviation $K_{\sigma i}$ of the contact numbers is reported as STDEV, and computed from

$$K_{\sigma i} = \sqrt{\frac{1}{N_{obs}-1} \sum_{j=1}^{N_{obs}} \left(K_{ij} - \overline{K_i}\right)^2} \quad (21)$$

Site description

The study sites is located in the parklands of Saponé village, 300 meter above sea level, (12°3′10″N 1°36′13″W) 35 km south of the capital Ouagadougou, central Burkina Faso. The study sites are on rather flat terrain. According to FAO (1988) soil classification system the major soils types are Ferric/Luvisols. The mean rainfall of the last 30 years was 730mm. The rain season stretches from May to October. The overstory is dominated by *Vittelaria Paradoxa* and *Parkia Biglobosa*, the understory is mainly composed of annually crops such as maize, millet and peanuts.

Sampling design

Indirect measurements with the LAI- 2000 were made at 9 different plots, which have been earlier established for measurements of sapflow within the “Tree, carbon and water project”. Each of the 9 plots consists of 3 trees. This gives a total of 27 trees. Besides those 27 so called sapflow trees were 4 control trees in the same area measured with the LAI-2000 to use as a calibration, all branches on these trees were later cut down and LAI were measured directly.

For each of the 31 trees height, diameter at breast height and the drip line area were measured. Diameter at breast height amongst the sapflow-trees range from 29, 5 to 82 centimeter and for the control trees from 29.5 to 88 centimeter. The lowest sapflow- tree is 8,7 and the highest 13,5 meter. The control trees range from 7.2 meter to 15.6 meters high. The manually measured drip line area for the sapflow trees vary between 34.1 and 134 square meters and for the control trees from 39.5 and 172.3 square meters. The control trees are well representing the verity of size amongst the sapflow-trees.

To focus on the comparison between the two methods the 15 sapflow-trees and the 4 control were chosen for analysis in this study.

The measurements were made just before sunrise between 21 August and 15 of September 2011, this to avoid making measurements under direct sunlight. In the instruction manual for the LAI- 2000 they recommend working at sunrise, sunset, or on a cloudy day to avoid direct sun.

Indirect method

The trees were measured following the procedure for isolated plants described in the instruction manual for the LAI- 2000.

For each tree, 4 pairs of below (B) and above (A) the crown readings were made, one in each cardinal direction, as shown in figure 5. Since the trees were asymmetric each pair had to be stored in the control box as a one individual file.

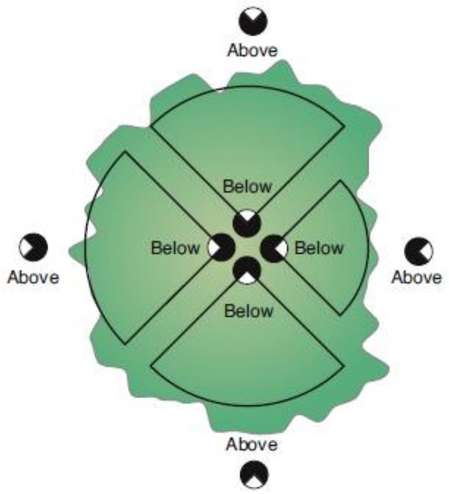

Figure 5. Four pairs of below and above readings were made per tree (LI-COR, Inc, 1992).

The measurements were made with a 90° view cap on the optical sensor to block out the trunk and other sections of the crown. (A) Readings were made in openings as close to the tree as possible and viewing the same part as the sky as the (B) reading. The (B) readings were recorded by placing the sensor close to the trunk at a height of 70 cm above ground.

For each pair of readings a photo of the associated crown profile were taken. The photo included a meter stick to be used as a scale. The photos were later used to create coordinate system of the crown profile, shown in figure 6. These coordinates are needed in the FV2000 software (LiCor Inc, *Lincoln, Nebraska*) to compute canopy volume, foliage density and drip line LAI.

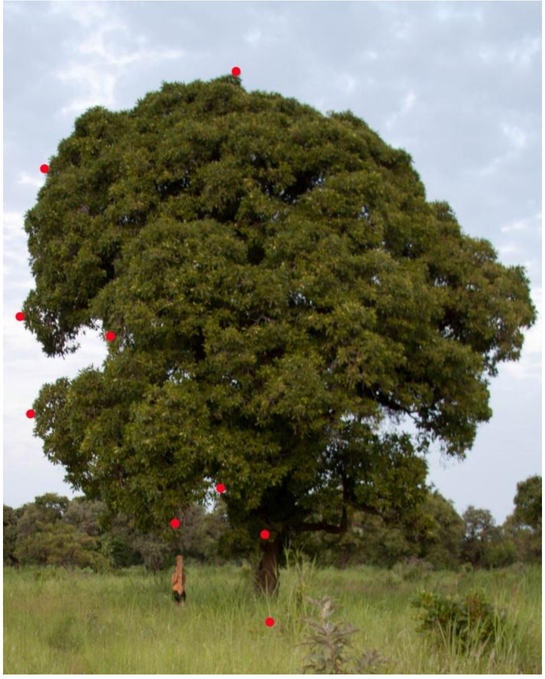

Figure 6. Photos of the crown profile including a meter stick were taken and later used to create coordinate systems. Photo Elsa Bengtsson

All data files stored in the LAI-2000 control box were downloaded to a computer and opened with the FV2000 software to compute canopy volume, foliage density and drip line LAI following the procedure proposed for isolated trees in the LAI-2000 manual. Canopy volume is computed using the x and y coordinates from the coordinate systems made based on the photos of the crown profiles. Drip line area is also obtained from the coordinate systems. Foliage density is foliage area divided by canopy volume. The drip line LAI is foliage density multiplied with canopy volume divided by drip line area.

Direct method

For calibration of the indirect measurements done with the LAI- 2000, 4 trees of different size were chosen. The sizes of the trees were chosen to be representing the range of size amongst the sapflow-trees. These control trees were first measured with the LAI- 2000 following the same procedure as for the sapflow-trees. Then the branches of the trees were cut down. Subsamples of leaves were taken from each control tree from 10 different places in the crown, the samples were weighed on a fine balance scale. Then all remaining leaves from each of the control trees were gathered in plastic bags and weighed.

The total leaf area of the different subsamples from each control tree were computed by first scanning the leafs with an ordinary scanner and store the images as jpg-files. Then the surface area of each leaf was calculated using image software (Image J, *Wayne Rasband National Institutes of Health, USA)*. The area form the individual leaves were added up for every sub-sample and divided by the weight of the sub-sample. This gave square meters per kilogram leaf for each of the control trees. By multiplying the total weight of all leaves from each tree with the representative square meters per kilogram leaf was the total leaf area for each tree estimated. The total leaf area per tree was then divided with the respective drip line area to obtain the direct measured drip line LAI.

Statistical analysis

Linear regression analysis of indirect drip line LAI against direct drip line LAI was done to evaluate the methods. Indirect drip line LAI was also analyzed against diameter at breast height and drip line area to establish if there is any correlation.

Results

There is a large difference between the indirect and direct measured drip line LAI. For all trees the direct measurements resulted in a higher LAI than for the indirect measurements. The values are presented in table 3 and the relationship between the two different measurements is shown in figure 7. Regression analysis of the relationship between the direct and indirect measures shows a r^2 of 0.57 and a p-value of 0.26.

Table1. Both direct and indirect drip line LAI for the control trees.

	Direct and indirect drip line LAI	
Tree	Direct drip line LAI	Indirect drip line LAI
X1	8.71741	1.8
X2	10.3316	4.4
X3	11.3794	4.7
X4	3.01465	1.95

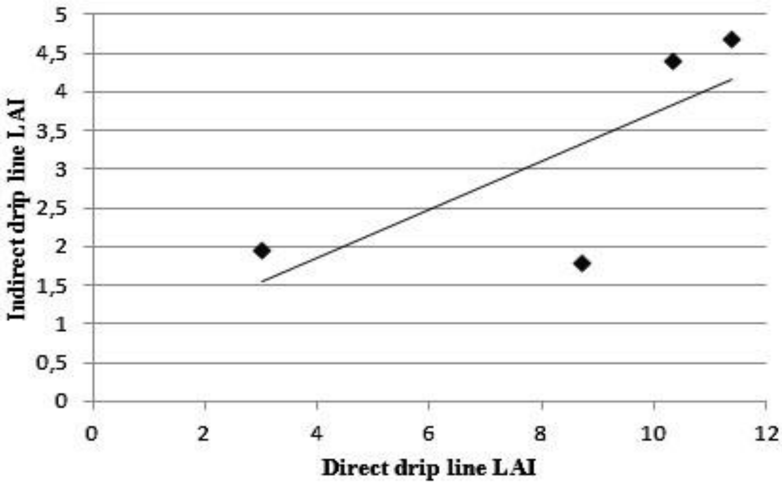

Figure 7. The relationship between the indirect and direct measured drip line LAI. Linear regression shows a r^2 of 0.57 and a p-value of 0.26.

Regression analysis of the relationship between indirect drip line LAI and the diameter at breast height of the tree trunk shows a r^2 of 0.37 and a p-value 0.006 (figure 8), meaning that the variability in drip line LAI is by 37 percent accounted for by the diameter. When doing the regression analysis one tree was identified as co called outliers, (tree number P2K1). An outlier is identified by a residual value that deviate more than 2 standard deviations from the model. This may be caused by a measurement error or in case with P2K1 it can be caused by the trees uncharacteristic crown shape. Regression analysis of the relationship with the P2K1 removed from the sample gave an increase in r^2 from 0.37 to 0.45. The p-value decreased to 0.002.

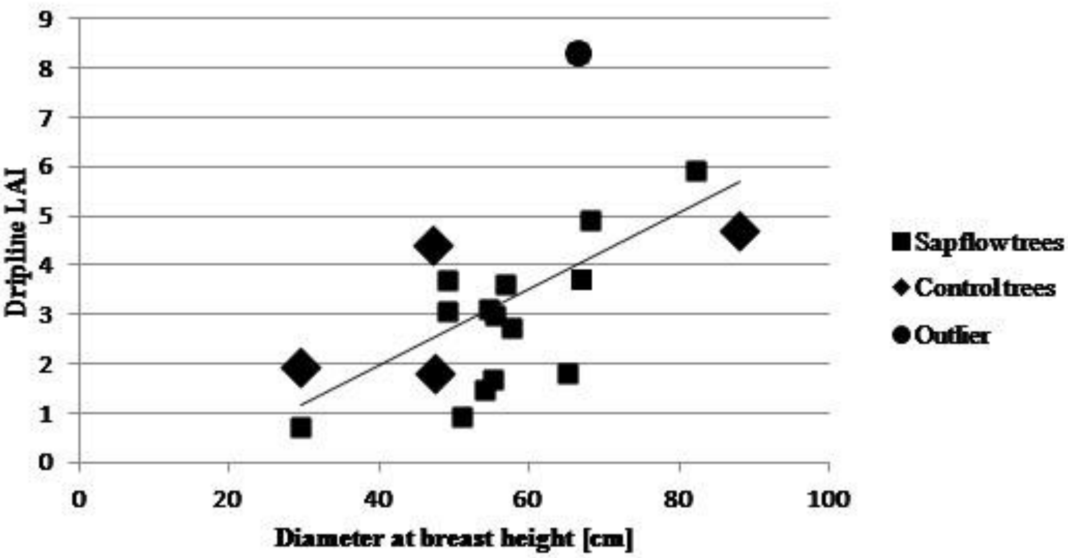

Figure 8. The relationship between indirect drip line LAI and the diameter at breast height of the tree trunks of V. paradoxa trees. Linear regression shown in the figure has a r^2 of 0.37 and a p-value 0.006. If removing the outlier r^2 is 0.45and the p-value 0.002.

Regression analysis of relationship between indirect drip line LAI and the drip line area shows a r^2 of 0.19 and a p-value 0.063 (figure 9). Meaning that the variability in drip line LAI is by 19 percent accounted for drip line area. A p-value of 0.063 means that the factor drip line area is in this case not significant. However, when doing the regression analysis were two trees identified as co called outliers, (tree number P2K1 and P3). This may be caused by a measurement error or in case with P2K1 it can be caused by the trees uncharacteristic crown shape. Regression analysis of the relationship with the P2K1 and P3 removed from the sample gave an increase in r^2 from 0.19 to 0.42 and the p-value decreased to 0.005. Removing the outliers drastically increased both the level of how much drip line area is accounted for the variability in drip line LAI and the significance of drip line area as factor.

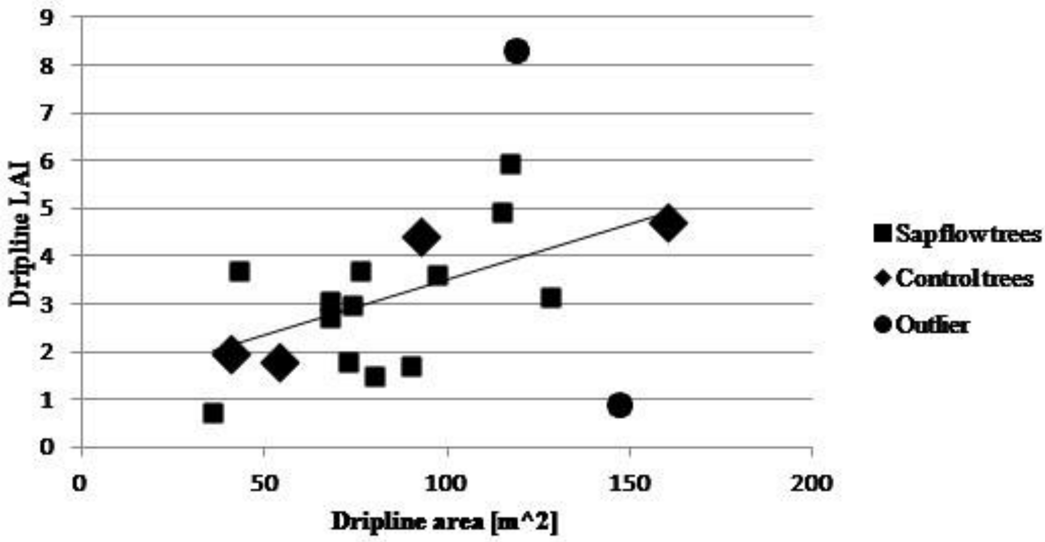

Figure 9 The relationship between indirect drip line LAI and the drip line area of the tree crown. Linear regression shown in the figure has a r^2 of 0.19 and a p-value 0.063. If removing the outliers' r^2 is 0.42and the p-value 0.005.

Discussion

There is a correlation between the indirect and direct method. However, the LAI-2000 underestimated the drip line LAI compared to the manually measured drip line LAI. With control tree X4 removed from the sample, the indirect measured LAI was less than one-third of the direct measured LAI. This is consistent with the result shown by Peper & MacPherson (2003) in a study were the isolated plant method described in the LAI- 2000 manual were used to estimate drip line LAI for *Platanus x acerifolia* and *Platanus racemosa*. This study was contacted at Solano Urban Forest Research Area, a parklike area at Solano Community College near Fairfield in northern California. The aim was to evaluate the accuracy, precision and efficiency associated with four methods of estimating the leaf area of open-grown deciduous trees in urban forests. The type of large deciduous tree and the openness of the landscape they grow in have many similarities to the *Vitellaria Paradoxa* agroforestry parkland in Saponé. Khabba et al (2009) also found that indirect methods, including the LAI-2000, heavily underestimated LAI in a study performed in orange orchards. However, by using the LAI-2000, Villalobos et al. (1995) were able to obtain accurate estimates of isolated olive tree leaf area density.

To be able to use this correlation factor between the two methods with certainty a larger number of control trees would be needed. However, in this thesis the priority was to measure LAI indirectly on a large number of trees to get a large dataset to use in other ecosystem studies, such as the validation and up scaling of ongoing sap flow measurements in the same area.

One possible source of error with the indirect method in this thesis is the method's requirement for above-crown measurements. On the study site it sometimes was difficult to find openings without any other trees interfering to be able to take above-crown measurements viewing the same part as the sky as the below-crown reading. Since the ideal conditions for taking readings with the LAI-2000 is when the sun is below the horizon, but it still needs to be daylight there was an element of time pressure that limited how far away the above-crown measurements could be preformed. This lead to a certain level of compromising with the viewing direction of the above-crown readings. One way around this problem would be to use two cross-calibrated sensors connected to the same control box, one devoted to above-canopy readings the other taking readings below the canopy. Another obstacle was nearby trees and other vegetation influencing the below-crown readings.

One problem with the method is that when measuring several trees some of the detector rings fail to intercept any foliage. A possible way to improve the method would be to place the sensor just above the first branches instead of placing it further down the trunk (figure 10). This would require, at least for the larger trees some kind of ladder. By placing the sensor just above the branches it would minimize the risk that the detector rings would miss to intercept any foliage. It would also increase the portion of crown being measured. This may be the main factor behind the deviating values of tree number P3, P2K1and X4, they all have a very narrow crown shape and it is only a few number of detector rings that intercept any foliage. This can also be one reason behind the overall underestimating since leaves often are grouped along the steam (Khabba et al 2009).

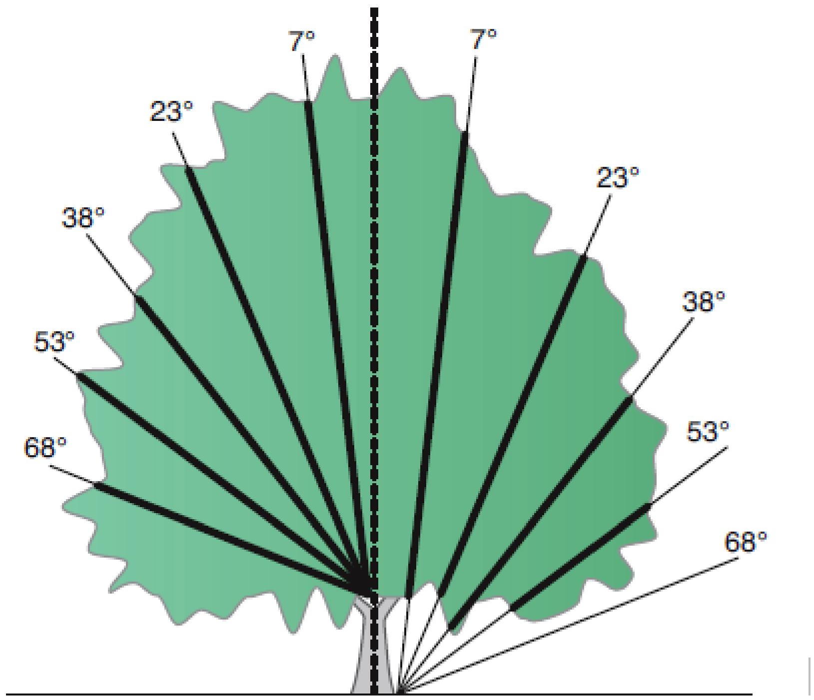

Figure 10. Describing the portion of the crown being measured depending on placement of the LAI-2000 sensor (LI-COR, Inc, 1992).

Why the LAI-2000 underestimated the drip line LAI compared to the true manually measured drip line LAI is difficult to know but a portion of the difference might be explained by the fact that leaf of *Vittelaria Paradoxa* is partly folded. The LAI-2000 is most accurate when used on broad leaf species with completely flat leaves (Jonckheere et al.2004). By how much the folded leaves contributes to the underestimation is however not investigated in the literature. This may be possible to investigate specific for *Vittelaria Paradoxa* .

Possible measuring errors concerning the direct method are probably related to working outside and with a large number of workers. It is likely that some leaves never got weighed due to wind or by mistake. A larger number of subsamples would improve the accuracy of direct drip line LAI measurements.

There is a correlation between diameter at breast high and indirect measured drip line LAI. However, the correlation is not strong enough that drip line LAI can be predicted based on this factor alone. The same thing can be said about the correlation between drip line area and indirect measured drip line LAI. It will be interesting to see how well LAI correlates with sapflow measurers preformed on the same trees.

Conclusions

- There is a correlation between the indirect and direct method.
- LAI-2000 underestimated the drip line LAI compared to the manually measured drip line LAI.
- This is consistent with the result shown by Peper & MacPherson (2003) and Khabba et al (2009).
- There is a correlation between diameter at breast high and indirect measured drip line LAI as well as for drip line area and indirect measurements.
- The correlation is not strong enough that drip line LAI can be predicted based on these factors alone.

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References

Anderson MC. 1971. Radiation and crop structure. In: Sestak Z, Catsky J, Jarvis PG, eds. Plant photosynthetic production: manual of methods. The Hague, The Netherlands.

Augusseau, X., Nikiéma, P. & Torquebiau, E. 2006. Tree biodiversity, land dynamics and farmers' strategies on the agricultural frontier of southwestern Burkina Faso. Biodiversity and Conservation 2006:15, 613–630

Bréda, N., 2003. Ground-based measurements of leaf area index: a review of methods, instruments and current controversies. Journal of Experimental Botany, 54, 392, 2403-2417

Breuer, L., Eckhart, K. & Frede, H.G. 2003. Plant parameter values for models in temperate climates. Ecological Modelling 169, 237-293

Bruijnzeel, L.A. 2004. Hydrological functions of tropical forests: not seeing soil for the trees? Agriculture ecosystems and environment 104, 185-228.

Bruijnzeel, L.A 1990. Hydrology of moist tropical forests and effects of conversion: a state of knowledge review. UNESCO – IHP, Humid Tropics Programme, Paris. 224 p.

Dianda, M, Bajala, J., Diop, T. & Ouédraogo, S.J. 2008. Improving growth of shea butter tree (Vitellaria paradoxa C.F.Gaertn.) seedlings using mineral N, P and arbuscular mycorrhizal (AM) fungi. Biotechnology, Agronomy, Society and Environment 13, 93-102

FAO 1998. Domestication and commercialization of non-timber forest products in agroforestry system. Non-Wood Forest Products 9. Rome

FAO 1988. Revised legend of soils map of the world 1/5 000 000. Soils Resources Report 60. Rome

Garrity, D.P., Akinnifesi, F., Ajayi, O., Weldesemayat, S., Mowo, J., Kalinganire, A., Larwanou, M. & Bayala, J. 2010. Evergreen Agriculture: a robust approach to sustainable food security in Africa. Food Sec. 2010:2, 197–214 Hillel, D 1980. Applications in soil physics. Academic Press, New York. pp. 384-385

Ilstedt, U., Malmer, A., Verbeeten, E. & Murdiyarso, D. 2007. The effect of afforestation on water infiltration in the tropics: a systematic review and meta-analysis. Forest Ecology and Management 251, 45–51.

Ingram, K.T., Roncoli, M.C. & Kirshen, P.H. 2002. Opportunities and constraints for farmers of west Africa to use seasonal precipitation forecasts with Burkina Faso as a case study. Agricultural Systems 74, 331-349

IPCC, 2007 Climate Change 2007: Synthesis report. An assessment of the Intergovernmental Panel on Climate Change.

Jonckheere, I., Fleck, S., Nackaerts, K., Muysa, B., Coppin, P., Weiss M. & Baret F. 2004. Review of methods for in situ leaf area index determination Part I. Theories, sensors and hemispherical photography. Agricultural and Forest Meteorology 121, 19–35

Khabba, S., Duchemin, B., Hadria, R., Er-Raki , J. Ezzahar, A. Chehbouni, A., Lahrouni, A. and Hanich L. 2009. Evaluation of Digital Hemispherical Photography and Plant Canopy Analyzer for Measuring Vegetation Area Index of Orange Orchards. Journal of Agronomy, 8, 67-72

Lang, A.R.G., 1987. Simplified estimate of leaf area index from transmittance of the sin's beam. Agricultrual and Forest Meteorology. 41, 179–186.

LI-COR, 1992. LAI-2000 Plant Canopy Analyser. Instruction Manual. LICOR, Lincoln, NE, USA.

Malmer, A., Murdiyarso, D., Bruijnzeel, L.A. & Ilstedt, U. 2010. Carbon sequestration in tropical forests and water: a critical look at the basis for commonly used generalizations. Global Change Biology 16, 599–604

Miller JB. 1967. A formula for average foliage density. Australian Journal of Botany 15, 141-144.

Peper, P. & MacPherson, E., 2003. Evaluation of four methods for estimating leaf area of isolated trees. Urban Forestry and Urban Greening 2, 019 - 029

Ross J. 1981. The radiation regime and architecture of plant stands. The Hague, The Netherlands: Dr Junk Werlag.

Ryu, Y., Sonnentag, O., Nilson, T., Vargas, R., Kobayashi, H., Wenka, R. &. Baldocchi, D. 2010. How to quantify tree leaf area index in an open savanna ecosystem: A multi-instrument and multi-model approach. Agricultural and Forest Meteorology 150, 63–76

Sanou, J. Bayla, J. Teklehaimanot, Z. & Baize, P. 2010. Soil infiltrability and water content as affected by Baobab (Adansonia digitata L.) and Ne´re´ (Parkia biglobosa (Jacq.) Benth.) trees in farmed parklands of West Africa. Soil Use and Management, 26, 75-81.

Villalobos, F.J., Orgaz F. and Mateos L.1995. Non-destructive measurement of leaf area in olive (*Olea europaea* L.) trees using a gap inversion method. Agricultural and Forest Meteorology. 73: 29-42.

Warren Wilson J. 1959. Analysis of the spatial distribution of foliage by two-dimensional point quadrats. New Phytologist 58, 92-101.

Watson, D.J., 1947. Comparative physiological studies in the growth of field crops. I. Variation in net assimilation rate and leaf area between species and varieties, and within and between years. Annals of Botany 11, 41–76.

Weiss, M., Baret, F., Smith, G.J., Jonckheere, I. & Coppin., P. 2004. Review of methods for in situ leaf area index (LAI) determination Part II. Estimation of LAI, errors and sampling. Agricultural and Forest Meteorology 121 37–53

Welles, J.M., 1990. Some indirect methods of estimating canopy structure. Rem. Sens. Rev. 5, 31–43.

Welles, J.M. & Norman, J.M., 1991. Instrument for indirect measurement of canopy architecture. Journal of Agricultural and Food Chemistry. J. 83, 818–825.

WHO, 2003. Right to water. WHO Health and human rights publication series; no. 3.

Appendix 1

Table 2. Manually measured diameter at breast height, height and drip line area for each tree.

	Manually measured values		
Tree	Diameter at breast height [cm]	Height [m]	Dripline area [m^2]
P1	55	11,1	83,5
P1K1	55,5	9,6	73
P1K2	49	12	48
P2	65	10,7	102
P2K1	66,4	11,5	134
P2K2	56,7	10,5	101
P3	51	10,3	133
P3K1	54,4	12	131
P3K2	57,6	12,4	70
P4	82	12,5	115
P4K1	54	12	79
P4K2	49	8,7	72,5
PS1	68	13,5	116
PS1K1	67	10,3	73,6
PS1K2	29,5	9,1	34,1
X1	47,5	9	50,4
X2	47	11,2	100
X3	88	15,6	172,3
X4	29,5	7,2	39,5

Appendix 2

Table 3. Foliage density, drip line and LAI drip line area values measured with the LAI-2000 and computed with FV-2000 Software.

	Values computed with FV-2000 Software		
Tree	Foliage Density [m^{-1}]	Dripline LAI	Dripline area[m^2]
P1	0,44	1,7	90
P1K1	0,71	2,97	74
P1K2	0,27	3,7	43
P2	0,46	1,8	73
P2K1	1,52	8,3	119
P2K2	0,77	3,6	97
P3	0,21	0,92	147
P3K1	0,31	3,13	128
P3K2	0,4	2,73	68
P4	0,82	5,93	117
P4K1	0,34	1,5	80
P4K2	0,86	3,07	68
PS1	0,72	4,93	115
PS1K1	0,46	3,7	76
PS1K2	0,25	0,73	36
X1	0,42	1,8	54
X2	0,94	4,4	93
X3	0,58	4,7	160
X4	0,73	1,95	41

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