Estimation of leaf area index of banana orchards using the method LAI-LUX

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Abstract: This paper aimed to compare leaf area index (LAI) from two genotypes banana orchards (Grand Naine and Tropical) estimated by biometric measurements with the LAI-LUX method. This method is based on measurements of radiation transmittance using a digital luximeter. There were under and overestimation of LAI using the LAI-LUX method. The measurements taken on orchards aged over 8 months have shown the mean relative error of -4.35% related to cultivar Tropical and +2.77% for the Grand Naine. The overall results revealed the underestimation of results by 3.85% when the 'Grand Naine' banana cultivar was analyzed and overestimation of 6.3% in the case of cultivar 'Tropical'. These results have shown the potential to the practical use the method LAI-LUX to estimate LAI in banana orchards but are also necessary to improve the studies in new orchards (up to 8 months) for better understanding the main sources of error.

Key words: luximeter, leaf area index, *Musa* spp., blue light transmittance

Estimativa do índice de área foliar de pomares de bananeira pelo método IAF-LUX

Resumo: Este trabalho visou comparar o índice de área foliar (IAF) de pomares de bananeira (*Musa* spp.) estimados por método envolvendo medidas biométricas de folhas com o método indireto de estimativa IAF-LUX. Este método baseia-se em leituras de transmitância de luz com uso de um luxímetro digital. Houve tendência de sub e superestimativas pelo IAF-LUX. Para pomares com idade superior a 8 meses os erros relativos médios foram -4,35% para cultivar Grand Naine e +2,77% para bananeira Tropical. Em média, houve subestimativa de 3,85% para Grand Naine e superestimativas de 6,3% para a bananeira Tropical. Esses resultados evidenciam a potencialidade de uso do método IAF-LUX. Estudos mais detalhados deverão ser realizados para aumento da confiança nos resultados principalmente até os oito meses do plantio.

Palavras-chave: luxímetro, índice de área foliar, *Musa* spp., transmitância de luz azul

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Introduction

The plant leaf area (LA) is used in carbon sequestration modeling, in models to calculate the evapotranspiration, in irrigation water requirements, in nutrient requirements, pruning and many different agricultural practices (Coelho Filho et al., 2012). There are several difficulties in quantifying LA of isolated plants related to the plant height and large number of leaves. Generally, if a direct method is used to estimate LA, it requires a large number of measurements to make a representative sample and minimize error of estimate, resulting in laborious procedures. In fact, the use of direct methods is still important to estimate LA in studies involving plant growth analysis, photosynthesis, incidence of pests and disease (Lucchesi, 1984; Benincasa, 1988). In drip irrigation management, when the transpiration is higher than soil water evaporation, the modeling of LA is fundamental because the variable drives the plant transpiration together with ETo (Coelho Filho et al., 2004). The LA has been used in papaya (Coelho Filho et al., 2007) and banana (Oliveira et. al., 2013) drip irrigation management based on simple models to calculate transpiration of plants according to Coelho Filho et al. (2004) and Pereira et al. (2006).

There are many feasible methods and equipments for non destructive estimation of LA and leaf area index (LAI). Regarding isolated tree plants, direct biometric measurements of leaves or indirect measurements using regression models based on branches, trunk or crop silhouette (Holland, 1968; Barlow, 1969; Palmer, 1987; Angelocci & Valancogne, 1993; Coelho Filho et al 2005) may be applied. Among different methods available to estimate LAI the use of direct and/ or diffuse light transmittance through vegetative canopy is widely used. There are different types of equipments/brands each with different methodological approach (Coelho Filho et al., 2012). These methods provide rapid, reliable and objective estimation of leaf area index (LAI) (Jonckheere et al., 2004).

Coelho Filho et al. (2012) developed a new approach (LAI LUX) applying the blue light diffuse transmittance to estimate LA of 'Tahiti' acid lime plants or LAI in a rubber tree plantation using a low cost digital luximeter. The LAI LUX method works well with a good performance compared to destructive measurements in 'Tahiti' acid lime plants and in rubber tree plantations. The same methodology was used by Oliveira (2011) in 'Tahiti' acid lime orchards with different ages under semiarid conditions. A model using light transmittance measured with a luximeter and plant size dimensions of coffee was used by Ribeiro et al. (2013) with reliable results.

In an attempt to find practical solutions to simplify the estimating of leaf area index (LAI) under field conditions, this work aimed to use the LAI LUX method in commercial orchards of two cultivars of banana (*Musa* spp.) and test the performance of the method based on nondestructive direct measurements.

Material and Methods

The present work was conducted under field conditions at Embrapa Cassava & Fruits at Cruz das Almas in the State of Bahia (Latitude: 12º40'39''S, Longitude: 39º06' 23''W, Altitude: 225m). The local climate is characterized as sub-humid with total annual mean precipitation of 1,143 mm. The winter is the wet season with moderate excess water and mean daily temperature of 24.5 ºC.

The measurements using the LAI LUX method were performed in orchards of two varieties of banana (*Musa* spp.): 'Grand Naine' and 'Tropical'. The measurements started from the sixth month after planting. The plants were adequately irrigated using a drip irrigation method. The scheduling and water depths were based on measurements of soil water matric potential and daily plant evapotranspiration estimated using the meteorological variables taken from a climate station (INMET), localized 200 m far from the experimental area.

The plant spacing was 2 m (line) x 2.5 m (row). Plots with 10 plants were delimited in each orchard, where the measurements were performed, each one totalizing a working area with 50 m².

The method used to estimate the plant total leaf area (TLA) within plots was proposed by Alves et al. (2001). This method is based on information of biometric measurement of the third leaf taken from each plant within a plot (Eq. 1).

$$TLA = 0.0000901 \times (L \times W)^{1.2135} \tag{1}$$

where:

TLA - total leaf area, m²
L   - leaf length, cm
W - leaf width, cm

Monthly frequencies of direct measurements of TLA in the orchards were adopted. The plot leaf area index (LAI) was estimated by Eq. 2.

$$LAI = \frac{\overline{TLA}}{PSA} \qquad (2)$$

where:

TLA - total leaf area (mean), m²

PSA - plant spacing area, m²

The indirect estimation using the blue light transmittance was achieved using the LAI LUX method, based on measurements from a digital luximeter (ICEL – LD 550) and theory and recommendations by Coelho Filho et al. (2012). The equipment manufacturer specifications are: scale 0 to 200 lux: resolution of 0.1 lux, nominal precision of ±3%; scale 200 to 2000 lux: resolution of 1 lux, precision of ± 3%; scale 2,000 to 20,000 lux: resolution of 10 lux, precision of ± 5%; scale 20,000 to 200,000 lux: resolution of 100 lux, precision of ± 5%.

The luximeter sensor was covered with a blue light filter (Coelho Filho et al., 2012) that allowed only the passage of solar radiation between 400 to 460 nm, in the blue wavelength. This wavelength is characterized for high absorption by chlorophyll and carotenoids (Souza et al., 2011; Vieira et al., 2010) and low transmittance and reflectivity. In this spectral region the value of absorption by leaf blade may be up to 95% depending on the type of plant (Montheith & Unsworth, 1990). Fraction of wavelength widespread coming to the equipment sensor avoiding the complementary reflectance and transmittance propagated through the vegetative canopy. To achieve the hypothesis that only diffuse radiation should be captured by the luximeter sensor, the measurements were performed always in the evening with predominantly beam diffuse radiation.

The measurement of blue light transmittance through the vegetative canopy (I/I_o) was taken randomly within the plot area, with a minimum distance of 0.5 m from the plant pseudostem to attempt reduce its effect on values. Approximately 10 measurements of transmittance per plot were made. The LAI were calculated using the Eq. 3 (Coelho Filho et al., 2012):

$$LAI = -\frac{Ln\left(\frac{1}{n}\sum \frac{I}{I_o}\right)}{1 - \frac{1}{n}\sum \frac{I}{I_o}} \qquad (3)$$

where:

I_o - beam diffuse radiation above the vegetative canopy (without vegetation obstruction), lux

I - beam diffuse radiation below the vegetative canopy, lux

The relative error (RE) was used to compare the LAI estimated from the methods, Eq. 4. Correlation coefficients and d concordance index (Willmott, 1982) were also used.

$$RE = \frac{(LAI_e - LAI_r)}{LAI_r} \times 100 \qquad (4)$$

where:

LAI_e - LAI provided by LAI-LUX method

LAI_r - LAI provided by biometric measurements.

Results and Discussion

The values for LAI at different times varied between 1.24 and 2.65 and 0.62 and 2.57. The mean values were 2.13 and 1.62, respectively, for 'Grand Naine' and 'Tropical' cultivars (Table 1 and 2). These LAI results corroborate with the results of other experiments. Oliveira et al. (2010) found LA means rising proportionally with the age of plants, reaching approximately 9 m² in the ninth month. This value represents a LAI of 1.8 in agreement with results in Table 1. Different irrigation systems and genotypes of banana were evaluated during the first three crop cycles by Marques et al. (2011). They found LAI, estimated by direct methodology, varying between 1.37 and 2.03 associated with drip irrigation treatments.

Regarding cultivar 'Tropical' banana there were some LAI estimations with mean relative error higher than 20%. The LAI presented a high amplitude of variation from 0 to 100.15% in the plot 1; 3.28 to 81.26% in the plot 2 and 0.9 to 70.32% in the plot 3, with a mean value of 30.00, 25.19 and 19.39%, respectively (Table 1).

The results observed for 'Grand Naine' cultivar revealed mean RE less than 20%. The RE was 13.88% related to plot 1, 10.89% to the plot 2 and 13.09% to the plot 3. The LAI amplitude of variation was lower compared to 'Tropical' banana, respectively, 1.38 to 61.94%; 1.43 to 34.04% and 2.03 to 39.22% (Table 2).

The age of the orchard affected the LAI estimation by the LAI LUX method. The values of relative error (RE) had a tendency of overestimation up to eight months. These results might be in function of a low LAI and partial shading of soil by plant leaves. This statement can be proven for 'Tropical' banana when RE presented high values until the eighth month while for 'Grand

Table 1. Leaf area index estimated by biometric method (LAI Biometric) and by measurements of transmittance of blue light using a luximeter (LAI-LUX) with the relative error (RE) between methods tested during growth of first cycle of 'Tropical' banana orchard

Month after planting (MAP)	Plot 1			Plot 2			Plot 3		
	LAI Biometric	LAI LUX	RE (%)	LAI Biometric	LAI LUX	RE (%)	LAI Biometric	LAI LUX	RE (%)
6	0.62	1.22	95.11	0.73	1.27	75.25	0.72	1.23	70.32
7	0.64	1.28	100.15	0.70	1.27	81.26	0.94	1.44	52.04
8	0.71	1.13	58.13	1.01	1.30	28.36	1.00	1.14	13.93
9	1.39	1.37	-0.87	1.26	1.36	8.32	1.51	1.56	3.13
10	1.80	1.77	-1.63	1.84	1.78	-3.28	2.09	1.95	-6.68
11	1.73	1.73	0.04	1.84	1.93	5.36	1.96	2.18	11.47
12	2.43	2.63	7.98	2.51	2.65	5.53	2.53	2.83	11.73
13	2.03	2.08	2.42	2.43	2.29	-5.80	2.57	2.45	-4.33
14	1.79	1.86	3.89	1.72	1.95	13.51	2.20	2.18	-0.90
Mean	1.55	1.67	30.00	1.56	1.76	25.19	1.72	1.88	19.39

Table 2. Leaf area index estimated by biometric method (LAI direct), Leaf area index estimated by measurements of transmittance of blue light using a luximeter(LAI-LUX) and relative error (RE) among methods tested during grown first crop cycle of 'Grand Naine' banana orchard

Month after planting (MAP)	Plot 1			Plot 2			Plot 3		
	LAI Biometric	LAI LUX	RE (%)	LAI Biometric	LAI LUX	RE (%)	LAI Biometric	LAI LUX	RE (%)
6	1.24	2.00	61.94	1.55	2.08	34.04	1.47	2.05	39.22
7	1.66	1.71	2.76	1.77	1.92	8.56	2.16	2.21	2.03
8	2.34	1.97	-15.72	2.53	1.96	-22.83	2.48	1.80	-27.30
9	2.30	2.44	6.15	2.27	2.04	-10.25	2.27	1.99	-12.66
10	2.33	2.12	-8.92	2.47	2.54	2.79	2.27	2.46	8.18
11	2.64	2.44	-7.44	2.43	2.30	-5.35	2.65	2.47	-6.98
12	2.14	2.17	1.38	2.23	2.26	1.43	2.13	2.01	-5.46
13	2.09	1.93	-7.68	2.00	2.09	4.06	1.99	1.88	-5.34
14	2.02	1.76	-12.93	2.07	1.89	-8.67	2.03	1.82	-10.59
Mean	2.08	2.06	13.88	2.15	2.12	10.89	2.16	2.08	13.09

Naine' a high RE value was observed only over the sixth month. The maximum RE was registered during the three first months of analysis, it reached 100.15% for cultivar Tropical and 61.94% for Grand Naine. From the ninth month of the plant vegetative cycle there was a RE reduction in all plots and the mean values were close to zero, respectively +2.77 e -4.35 for 'Tropical' and 'Grand Naine'. The overestimation of LAI values over the sixth to eighth month for 'Tropical' banana contributed to overall higher mean value of LAI compared to biometric measurements while the LAI estimate for banana 'Grand Naine' was close to biometric method and slightly lower (Tables 1 e 2).

The LAI LUX provided a good estimation of leaf area index in the orchards. The LAI estimations by LAI LUX method fitted well with a straight line passing through the origin with slopes which deviate less than 7%. There was a strong agreement between the methods tested with a high overall value of concordance index d (0.91) of Willmott (1982). There was good correlation between LAI estimated by LAI LUX and the biometric method used (R^2 = 0.68 for 'Tropical' and 0.74 for 'Grand Naine'). The slightly lower correlation associated to

'Tropical' banana might be function to the higher values of RE when the LAI varied between 0.5 and 1 (Table 1; Figure 1). The mean difference between methods were -3,85% for 'Grand Naine' banana and +6,3% for 'Tropical' banana (Figure 1).

The LAI were underestimated when 'Grand Naine' orchard presented values higher than 2 (mean RE of -6.45% when LAI>2) probably related to overlapping of leaves. These sources of

LAI LUX (Tropical) = 1.0635x; r^2 = 0.68

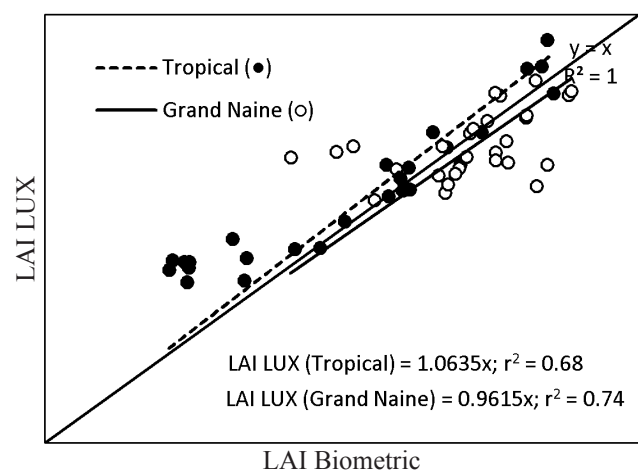LAI LUX (Grand Naine) = 0.9615x; r^2 = 0.74

Figure 1. Relationship between LAI estimations in banana orchards (cultivar Tropical and Grand Naine) using transmittance of blue light (LAI LUX) and biometric method (LAI Biometric)

error are common while using different types of equipment to estimate LAI from the canopy beam transmittance, especially in forest species, mainly in function to clumping of leaves (Chason et al., 1991; Macfarlane et al., 2000). According to Soto Ballestero (1992) the overlapping of banana leaves is associated with the non synchronized growth of the root and shoot that affect the fruit quality. These underestimation errors were not verified in the 'Tropical' banana (mean RE of 2.32% when LAI >2). In fact a slight overestimation was observed for the majority of data (Tabela 1) and might be related to angle of leaves in these plants allowing light penetration through the canopy and, therefore, less overlapping of leaves compared to 'Grand Naine'. Comparisons between measurements of LAI LUX and LAI 2000 were performed in a rubber tree plantation by Coelho Filho et al. (2012), that also reported underestimation of LAI (<8%).

Although the problems verified on LAI estimate until the eighth month in the first cycle of the crop, the overall results presented in this paper are promising because this period represents the initial phase of crop cultivation. The mean RE after the eighth month presented a mean value of 6.2% considering the two cultivars and the estimate using the LAI LUX method fitted well with a straight line passing through the origin (Table 1 and 2; Figure 1). However, it is suggested that new studies should be conducted to understand the main sources of error mainly during the initial growth phase of the first plant cycle. Possibly a correct and criterious approach of spatial sampling within orchard could minimize the LAI error estimation during this phase.

Conclusion

The LAI-LUX is a promising method to monitor the LAI of banana orchards, with rapid field measurements and low cost, but less precise when the orchard presents partial shade of soil by the plant leaves.

Literature Cited

Alves, A. A. C.; Silva Júnior, J. F. S.; Coelho, E. F. Estimation of banana leaf area by simple and non-destructive methods. In: Congresso Brasileiro de Fisiologia Vegetal, 7, 2001, Ilhéus. Anais... Ilhéus: Sociedade Brasileira de Fisiologia Vegetal, 2001, v.1, CD Rom

Angelocci, L. R.; Valancogne, C. Leaf area and water flux in apple trees. Journal of Horticultural Science, v.67, p.299-307, 1993.

Barlow, H. W. B. The relation of leaf area to stem cross section. Report of East Malling Research Station for 1968. 1969. p.117-119.

Benincasa, M. M. P. Análise do crescimento de plantas: Noções básicas. Jaboticabal: FUNEP, 1988. 42p.

Chason, J. W.; Baldocchi, D.D.; Huston, M. A. A comparison of direct and indirect methods for estimating forest canopy leaf area. Agricultral and Forest Meteorology, v.57, p.107-128, 1991.

Coelho Filho, M. A.; Angelocci, L. R.; Campeche, L. F. S. M.; Rojas, J. S. D. ; Folegatti, M. V. Relações entre transpiração máxima, área foliar e evapotranspiração de referência em pomar jovem de lima ácida ´Tahiti´ (Citrus latifolia Tan.). Revista Brasileira de Agrometeorologia, v.12, p.265-274, 2004.

Coelho Filho, M. A.; Angelocci, L. R.; Vasconcelos, M. R. B.; Coelho, E.F.; Estimativa da área foliar de plantas de lima ácida 'Tahiti' usando métodos não-destrutivos. Revista Brasileira de Fruticultura, v.27, p.163-167, 2005.

Coelho Filho, M. A.; Angelocci, L. R.; Villa Nova, N. A.; Marin, F. R.; Righi, C. A. Método para estimativa do IAF de árvores isoladas ou de plantações com dossel fechado. Revista Brasileira de Engenharia Agrícola e Ambiental, v.16, p.529-538, 2012.

Holland, D. A. The estimation of total leaf area on tree. Annual Report of the East Malling Research Station for 1967. 1968. p.101-107.

Jonckheere, I.; Fleck, S.; Nackaerts, K.;Muys, B.; Coppin, P.; Weiss, M.; Baret, F. Agricultural and Forest Meteorology, v.121, p.19-35, 2004.

Lucchesi, A. A. Utilização prática da análise quantitativa do crescimento vegetal. Anais Escola Superior de Agricultura "Luiz de Queiroz". v. XLII., p.40l-428, 1984.

Macfarlane, C.; Coote, M.; White, D. A.; Adams, M. A. Photograph exposure affects indirect estimation of leaf area in plantations of Eucalyptus globules Labill. Agricultural and Forest Meteorology, v.100, p.155-168, 2000.

Marques, P. R. R.; Donato, S. L. R.; Pereira, M. C. T.; Coelho, E. F.; Arantes, A. M. Características agronômicas de bananeiras tipo Prata sob diferentes sistemas de irrigação. Pesquisa Agropecuária Brasileira, v.46, p.852-859, 2011.

Monteith, J. L.; Unsworth. M. H. Principles of environmental physics. 2.ed. London: Butterworths, 1990. 291p.

Oliveira, J. M.; Coelho Filho, M. A.; Coelho, E. F. Crescimento da bananeira Grande Naine submetida a diferentes lâminas de irrigação em tabuleiro costeiro. Revista Brasileira de Engenharia Agrícola e Ambiental, v.17, p.1038-1046, 2013.

Oliveira, V. V. M. Estimativa de área foliar e transpiração em lima ácida 'tahiti' no semiárido Baiano. Cruz das Almas: UFRB. 2011. 77p. Master´s Dissertation.

Palmer, J. W. The measurements leaf area on apple tree. Journal of Horticultural Science, v.62, p.5-10, 1987.

Pereira, A. R.; Green, G; Villa Nova, N. A. Penman-Monteith reference evapotranspiration adapted to estimate irrigated tree transpiration. Agricultural Water Management, v.83, p.153-161, 2006.

Ribeiro, K. M.; Braga, R. A.; Scalco, M. S.; Horgan, G. W. Leaf area estimation of medium size plants using optical metrology Revista Brasileira de Engenharia Agrícola e Ambiental, v.17, p.595-601, 2013.

Soto Ballestero, M. Bananos: cultivo y comercialización. San José: Litografia e Imprenta LIL, 1992. 674p.

Souza, G. S.; Santos, A. R.; Silva, J. S.; Ferreira, D. R. Teores de pigmentos fotossintéticos, taxa de fotossíntese e estrutura de cloroplastos de plantas jovens de *Mikania laevigata* Schultz Bip. ex Baker (Guaco) cultivadas sob malhas coloridas. Enciclopédia Biosfera, v.7, p.1843-1854, 2011.

Vieira, E. L.; Souza, G. S. de; Santos, A. R. dos; Silva, J. dos S. Manual de Fisiologia Vegetal. São Luís: EDUFMA, 2010. 230p.