Acta Iguazu
ISSN: 2316-4093

Estimation of the commercial height of trees with laser meter: a viable alternative for forest management in the Brazilian Amazon

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Artigo enviado em 22/11/2017, aceito em 18/08/2018.

Abstract: Commercial height of the tree is a key variable for estimating the wood stock in tropical forests managed for timber production purposes. Most available measurement devices present limitations to this type of forest, promoting low precision measurements with high variation errors. Laser meter device appears as a viable alternative, since in addition to using trigonometric principles, it is not necessary that the device is close to the eyes of the meter to carry out the measurement. The device can be used to measure commercial height of trees on flat or sloping terrain from any distance from the tree. However, there are no studies evaluating the precision of this device. Due to importance and difficulties evidenced, the objective of this study was to determine the precision of the laser meter method for estimating the commercial height of trees, as compared to the actual measurement in a tropical forest in the Brazilian Amazon. Measurements were made on 300 trees with commercial height between 7 and 14 m. Actual commercial heights were measured with graduated ruler. Applied tests were: paired t-test, graphical analysis of residues and calculations of bias statistics, mean absolute deviation, standard deviation of differences and coefficient of determination (R^2). Paired t-test indicated that the mean of the heights measured by the laser meter is statistically equal to that of the graduated ruler. Measurements with laser meter did not show tendencies (bias) and had low mean error, showing values close to "0". The standard deviation of differences indicated low dispersion of errors. There was no tendency to underestimate or overestimate the commercial heights of trees. Laser meter presents precision for estimating the commercial height of trees in tropical forest in the Brazilian Amazon.

Keywords: Dendrometry, Forest measurement, Trigonometric principles, Tropical forest.

Estimação da altura comercial de árvores com medidor a laser: uma alternativa viável para manejo florestal na Amazônia brasileira

Resumo: A altura comercial da árvore é uma variável chave para estimar o estoque de madeira em florestas tropicais manejadas para fins de produção madeireira. A maioria dos dispositivos de medição disponíveis apresentam limitações a este tipo de floresta, promovendo medições de baixa precisão com erros de alta variação. O dispositivo de medidor de laser é uma alternativa viável, uma vez que, além de usar princípios trigonométricos, não é necessário que o dispositivo fique perto dos olhos do medidor para realizar a medição. O dispositivo pode ser usado para medir a altura comercial de árvores em terrenos planos ou inclinados a partir de qualquer distância da árvore. No entanto, não há estudos que avaliem a precisão desse dispositivo. Devido à importância e às dificuldades evidenciadas, o objetivo deste estudo foi determinar a precisão do método do medidor a laser para estimar a altura comercial das árvores, em comparação com a medida real em uma floresta tropical na Amazônia brasileira. As medições foram feitas em 300 árvores com altura comercial entre 7 e 14 m. As alturas comerciais reais foram medidas com uma régua graduada. Os testes aplicados foram: teste t pareado, análise gráfica de resíduos e cálculos de estatísticas Viés, Média das Diferenças Absolutas, Desvio Padrão das Diferenças e Coeficiente de Determinação (R^2). O teste t pareado indicou que a média das alturas mensuradas pelo medidor de laser é estatisticamente igual à da regra graduada. As medições com medidor de laser não apresentaram tendências (viés) e apresentaram baixo erro médio, mostrando valores próximos a "0". O desvio padrão das diferenças indicou baixa dispersão de erros. Não houve tendência em subestimar ou superestimar as alturas comerciais das árvores. O medidor de laser apresenta excelente precisão para estimar a altura comercial das árvores em floresta tropical na Amazônia brasileira.

Palavras-chave: Dendrometria, Mensuração florestal, Princípios trigonométricos, Floresta tropical

Introduction

The management of tropical forests for timber production purposes in the Brazilian Amazon is carried out with the approval of the Sustainable Forest Management Plan (SFMP) by the competent environmental agencies. Among the requirements for SFMP approval, it is required the quantification of the wood stock of the feasible trees for harvest (CONAMA, 2009). The wood stock is quantified by estimates generated from volume equations specifically for SFMP, using the variables diameter at breast height and commercial height (usually the distance between tree base and beginning of the tree crown) (BURKHART; TOMÉ, 2012).

Measurement accurately trees commercial height is a difficult procedure in tropical forests when compared to planted forests (AVERY; BURKHART, 2015). This process becomes complex in face of the density, diversity, and other obstacles inherent in the tropical forest environment (CLARK et al., 2008; PRIMACK; CORLETT, 2011). For tree height estimates, there are varied types of equipment that are used internationally, called hypsometer, and classified into two categories, according to their construction principle: geometric principle, based on the relation between triangles, such as the hypsometer of Christen; and the trigonometric principle, which is based on the relationship between angles and distances.

Most commonly used devices for standing trees height estimation are based on trigonometric principles and it is necessary for the technician to maintain the known distance from the tree (LOETSCH et al., 1973). In some equipment, such as digital clinometer, the distance is predetermined. Laser hypsometers or ultrasound waves allow to measure at different distances, generally the recommended distance from the technician to the tree is the height to be measured (CAMPOS; LEITE, 2017). On the other hand, in other cases, the technician needs to be close to the tree so as not to lose sight of the crown, in this case, increasing the angle reduces accuracy (DA SILVA et al., 2012; LARJAVAARA; MULLER-LANDAU, 2013).

Low precision of height measurement devices in tropical forest encourages the use of conventional direct measurement (real height) methods, such as the use of graduated or telescopic rulers, which results in more onerous work and high cost (KEARSLEY et al., 2017). It is important to emphasize that these factors motivate some companies to perform the visual estimation commercial height of trees, with or without technician training, generating severe subestimations or overestimations.

In an attempt to solve this difficulty and obtain commercial height data in tropical forests with higher precision, laser distance meter arise as an alternative. This device is also based on trigonometric principles, however, the great difference is that it is not necessary that the device is close to the eyes of the technician to carry out the measurement. Measurement is done with the device at any distance from the eyes as long as the technician remains in the same position to make three measurements necessary to obtain the commercial height.

Laser meter is based on the Pythagorean theorem, which expression can be applied to any triangle of 90 ° angle, using the proof of similar triangles (LOOMIS, 1968). Use of the device is very simple, the technician measures the distance in three points in tree trunk (upper, rectangular and bottom), one at a time, in the order determined on the device's screen. The height is calculated automatically on the device's screen (Figure 1). The device can be used to measure commercial height of trees on flat or sloping terrain from any distance from the tree and makes it possible to carry out permanent measurements, thus achieving maximum and minimum values.

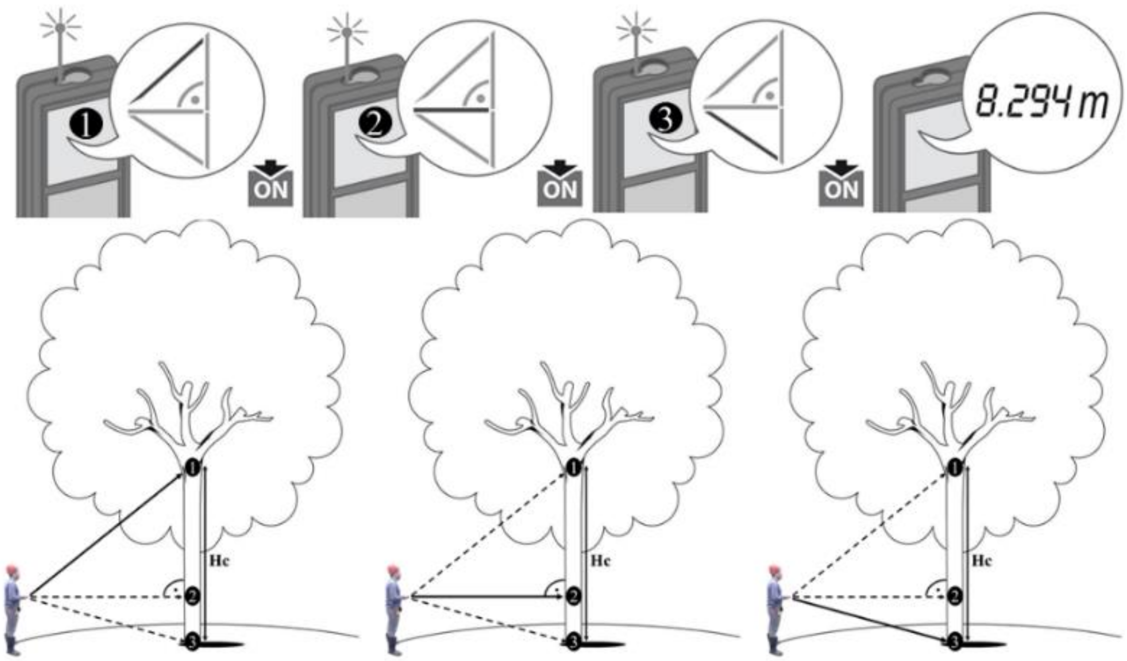

Figure 1. Procedure for obtaining commercial heightThe distances 1, 2 and 3 are measured as indicated on the display. After measurement 3, the commercial height of the tree, in meters, is displayed on the device screen.

Researches on the use of this apparatus are non-existent, thus, it is necessary evaluation to determine its accuracy in the measurement of the commercial height of trees in tropical forests. Due to importance and difficulties evidenced for the height estimation of trees in tropical forests, the objective of this work was to determine the precision of the laser meter method for the estimation of the commercial height of trees, as compared to the direct measurement with graduated ruler, in a tropical forest in the Brazilian Amazon.

Materials and Methods

The experiment was carried out in a forest of Fazenda Gênesis 4°01'56"S and 47º36'19"W) in 481 hectares, municipality of Dom Eliseu, southeast of Pará state, Brazil. Fazenda Gênesis belongs to the Arboris Group, a business group that works with agriculture and forestry in the Amazon, including wood production from planted and native forests. In Fazenda Gênesis, the vegetation is dominated by submontane dense ombrophylous forest (IBGE,

2004). The average temperature is 26.5 ºC with annual precipitation of 2200 mm and rainy season from January to May. Relative air humidity indicates an annual average of 85%. The average altitude in the study area is 180 m and the most common soil type is Yellow Oxisol (VELOSO et al., 1991; SUDAM, 1993; EMBRAPA, 2013).

Materials used were: a graduated ruler and a laser meter. Graduated ruler has a length of 14 m when fully opened and 2 meters fully closed, weighing around 8 kg. The device used was the Makita Laser Meter LD050P which can cost up to 1/10 of the value of the most used devices for measuring tree height. It has dimensional advantages, as it is only 11.6 cm in its largest dimension, weighs approximately 100 g (with battery) and has a measuring range of 50 m with a precision of + 2 mm, besides being resistant to falling and splashing water and shows the readings directly in the digital format.

Laser meter device trigonometrically calculates the data collected by simply measure distance of three points on the tree trunk. The first point is the commercial height to be measured, second point is in the rectangular direction for forming a right triangle and the third point is at the base of the tree. Formation of two rectangular triangles allows the commercial height to be obtained at any distance from the tree and on sloping terrain.

Commercial heights were measured, between 7 and 14 meters, being this the maximum range offered by the graduated rule, in 300 trees randomly selected. Measurements made with the graduated ruler and with the laser meter were obtained by the same technician, to carry out the control and to avoid the influence of the technician on the collected data. Statistical analyses were performed using the software R and Microsoft Excel.

Height frequency histogram was established with the number of classes determined by the Sturges method (1926). Paired t-test (α = 0.05) was applied in order to compare the commercial heights obtained by the laser meter in relation to those obtained by the graduated ruler. The hypotheses of the test were:

Nullity hypothesis (H_0): $\mu l = \mu r$

Alternative hypothesis (H_a): $\mu l \neq \mu r$

Where μl = commercial heights averages measured with laser meter and μr = commercial heights averages measured with graduated ruler.

Furthermore, the residue from the commercial heights obtained with laser meter was calculated as:

$$Error(\%) = \frac{Yi - \hat{Y}i}{Y} 100$$

Where $\hat{Y}$ = heights measured with laser meter and Y = heights measured with graduated ruler.

Additional statistical tests were applied to complement the graphical analysis of the residues: bias, mean absolute deviation (MAD) and standard deviation of differences (S_d). The bias show the existence of some tendency among the residues, the MAD reflects the amplitude between the residues and the S_d expresses the residues homogeneity.

1. Bias:

$$Bias = \frac{(\sum_{i=1}^{n} Yi - \sum_{i=1}^{n} \hat{Y}i)}{n}$$

2. Mean absolute deviation:

$$MAD = \frac{\sum_{i=1}^{n} |Yi - \hat{Y}i|}{n}$$

3. Standard deviation of differences:

$$S_d = \sqrt{\frac{\sum_i^n di^2 - \frac{(\sum_i^n di)^2}{n}}{n-1}}$$

4. Coefficient of determination:

$$R^2 = 1 - \frac{\sum(Y - \hat{Y})^2}{\sum(Y - \bar{Y})^2}$$

5. Sturges formula (1926):

$$N_c = 1 + (3{,}333 \times \log(n))$$

Where Yi = heights measured with graduated

Results and Discussion

Sturges method resulted in 9 heights classes with a class interval of 0.7 m. Frequency distribution of the heights was set up in a normal distribution to apply the t-test paired, in order to compare the heights measured by the graduated ruler and laser meter (Figure 2).

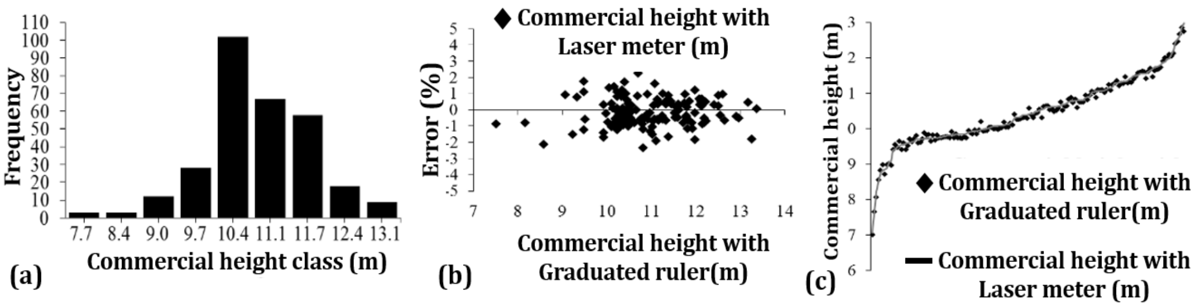

Figure 2. Frequency distribution of trees with commercial height greater than 7 m and less than 14 m (a), distribution of residues of height, in percentage, for the laser meter method (b) and line estimate of the heights measured with laser meter (c).

T-test paired performed did not reject H_0, the mean of the heights measured with laser meter is statistically equal to that of the graduated ruler, with p-value>0.05. The t_{calc} is smaller than the critical value (0.05; 299) of 1.960 (Table 1).

Table 1. Statistical analysis and performance of methods laser meter and graduated ruler.

Method	Commercial height (m)				Statistics				
	MIN	MAX	Mean	Standard deviation	T_{calc}	Bias	MAD	S_d	R^2
Graduated ruler	7.0	12.9	10.45	0.97	0.1930^{ns}	-0.0173	0.0745	0.0872	0.99
Laser meter	7.1	13.0	10.47	0.97					

*ns not significant at 5% probability.

Commercial heights measured with laser meter showed no bias and had a low mean error (MAD) with values close to "0", indicating greater homogeneity. The standard deviation of the differences indicated low dispersion of errors (Table 1).

The errors plotted in graphs to facilitate the visualization of its distribution allow to interpret that they varied between ± 2.5% and that there are no tendencies of the apparatus as the heights increase or decrease. Homogeneity and non-bias observable between the methods are shown with the estimated line drawn from the commercial heights measured with the laser meter simultaneously to the cloud of points represented by the heights measured by the graduated ruler (Figure 2).

Acceptance of H0 provides the evidence that there is no statistical difference between measurement methods. T-test paired allows the comparison to be more practical and easy to understand, since other factors may influence the result in any two samples. This test is extremely useful for comparing the same sample in two different methods (ROSNER, 1995).

The bias, when negative, indicate tendency to overestimate, and positive, underestimate. Bias and mean absolute deviation close to "0" indicate a lower trend and greater homogeneity, respectively, and the lower the standard deviation of differences, the smaller the amplitude of the residues (SNOWDON, 1992).

The method commercial height measurement with laser meter shows satisfactory values when related with trends and amplitude and variation of errors (Table 1 e Figure 2), and compared to other studies in which researchers compared measures of portable instruments based on trigonometric principles with actual heights obtained by conventional methods: David et al. (2012) compared total heights measured with Haglof digital clinometer with real heights measured with telescopic ruler, obtaining MAD of 0.763 m, S_d in average of 1.0 m and errors around ± 25%. Da Silva et al. conducted two studies: one in an eucalyptus plantation (DA SILVA et al., 2012a) and the other in a natural forest (DA SILVA et al., 2012b). In the plantation, the mechanical clinometers presented better performance than the electronic ones, and the bias was significant when the distance to the tree was much smaller than the height of the tree. In the natural forest, the random errors were larger, while the bias remained unimportant. The performance of the Vertex hypsometer in 3 heights classes (15-25 m, 25-35 m e > 35 m) was: MAD of 1.253 m, S_d on average 3.965 m and varying errors ±

40%. Surprisingly, the visual estimation, with training, without instruments was better than the estimate obtained by the Vertex hypsometer.

The comparison precision and feasibility of electronic devices in measurements of height and diameter for purposes of forest inventory made by Couto and Bastos (1988), indicated that the highest percentage errors were obtained in the lowest real heights (trees with less10 m), with variation of ± 17.11%. There was, among the different situations evaluated, the interference of the technician to the tree in the estimation.

Difficulty in minimizing errors is related to the specifications of most forestry measuring devices that recommend the technician to measure the tree at a distance equivalent to the height to be measured (CURTO et al., 2013), however, due to the great variation of the canopy stratum and heterogeneity of spacings in tropical forests, the synchronous visualization of the base and the canopy of the tree is difficulted. The difficulty in visualizing the tree forces the technician to measure the smallest distances. This increases the slope sensitivity of the device, generating greater variation in height reading and, consequently, increasing erroneous estimates (FREITAS; WICHERT, 1998; LARJAVAARA; MULLER-LANDAU, 2013; CAMPOS; LEITE, 2017).

None of the cited studies included a comparison of commercial height measurements with a laser meter. The laser meter method proposed in this work does not present a slope sensitivity, thus, it produces less reading variation when compared to other devices, reducing the risks of error in estimates. It is likely that the relationship between commercial heights measured with laser meter and graded ruler will vary little between forests and potentially between tree species and seasons, depending on the structure of the forest, the deciduous at the time of measurement, etc.

The relationship between commercial heights may also vary between the models of the laser meter, as it is likely to depend on the power of the laser beam (and therefore of the laser visualization when it reaches the shaft of the tree) and the proportion of reflection based on which distance is calculated and detector settings in general, including technical specifications that may be proprietary and which may change over time as new models replace older ones. It is possible that laser-specific correction functions are developed for forest types, but this would require a lot of additional research in this field.

Conclusions

Laser meter presents precision for estimating the commercial height of trees in tropical forest in the Brazilian Amazon. There was no tendency to underestimate or overestimate the commercial heights of trees.

Use of the laser meter is indicated for measuring the commercial height of trees in tropical forests. It is not recommended for measuring total height of trees and no measurements on forests planted with greater spacing between trees. In measuring total height, the leaf area of the tree can affect the laser reflectance, causing an error in the measurement of the device. In forests planted with trees at spacings larger, there is a high incidence of light in the tree trunk, affecting the visualization of the laser.

Future studies should evaluate this type of apparatus in other forest conditions that differ in structure and with other instruments that differ in the specifications to develop a better basis for estimating the actual commercial heights of these measurements.

It would be particularly interesting to evaluate the accuracy of the laser meter in trees of commercial heights greater than 14 meters. This could be easily accomplished by comparing with true commercial heights measured on trees after harvest.

Acknowledgements

This research was funded and conduction by Arboris Group. The authors are thankful for support from the Graduate program in forest science of the Federal University of Viçosa and the scholarship from the CNPq - National Council of Scientific and Technological Development.

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