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Mobile technologies in forestry sector: using smartphones to measure trees height

Tecnologias móveis no setor florestal: usando smartphones para medir a altura das árvores

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This paper aims to evaluate the usage of the smartphone app “Smart Measure” to measure the tree’s height, comparing the results with real heights obtained using a measure tape after logging and with heights obtained with two hypsometer instruments (Suunto and TruPulse 200), usually used in forestry. We evaluated 30 trees of *Eucalyptus* spp. aged 6 years in a homogeneous planting. Trees were measured by 3 previously trained operators which didn’t have any communication between themselves. Tree’s height was obtained and analyzed using descriptive statistical analyses and factorial analyses. The ability and the training of the operator were determinant factors, but the three instruments presented the possibility to obtain trustable and precise height measurements, in a way that the app “Smart Measure” can be utilized with accuracy to measure the trees if there’s a previous training by the operator.
Keywords: dendrometry, forest inventory, hypsometer.

O objetivo deste trabalho foi avaliar o uso do aplicativo Smart Measure em smartphone para a mensuração da altura de árvores, comparar os resultados com as alturas reais obtidas com trena após o abate e com os resultados de dois instrumentos hipsométricos (Suunto e TruPulse 200) tradicionalmente utilizados no setor florestal. O trabalho foi realizado com 30 indivíduos localizados em plantio homogêneo de *Eucalyptus* spp. com 6 anos de idade. As árvores foram mensuradas por 3 operadores, com treinamento prévio e sem comunicação entre si. As alturas obtidas foram comparadas e analisadas, por meio de estatísticas descritivas e análises fatoriais. A habilidade e o treinamento do operador foram fatores determinantes, mas os três instrumentos apresentaram possibilidade de obtenção de medidas de altura confiáveis e precisas, de modo que, o aplicativo Smart Measure pode ser utilizado com confiabilidade para a medição de altura de árvores, desde que haja treinamento prévio do operador.
Palavras-chave: dendrometria, inventário florestal, hipsômetro.

1. INTRODUCTION

Correct measuring trees height and diameter at breast height (DBH) has a fundamental importance in forest inventory and forest management, as it directly influences the estimative of individual volume of the trees, and consequently, the volumetry of the hole forest [1, 2]. In this sense, to provide a correct prognosis of native or planted forest stands, we need precise data. Because of that, forest inventory studies and forest biometry constantly need to improve measuring processes, aiming to decrease errors in the procedures, improving the quality of the results and the responses to evaluate the dynamics of the forest stands [3].

The tree DHB, when compared with tree’s height, is an easier variable to obtain, since it can be directly measured by utilizing a measuring tape or a tree caliper, decreasing considerably the errors during the measuring process [4]. Trees height, on the other hand, can be directly obtained mainly by using specific instruments such as hypsometers [5], which present significant and considerable errors. According to Couto and Bastos (1988) [6], one meter of error in the measurement of the total height of a tree can correspond to 14% of error in its cylindrical volume.

Due to the necessity to find ways to estimate trees height that result in decreased percentage of errors that are inherent to the field practice, advances in technology and instruments with better accuracy are increasingly necessary. Because of being an ordinary equipment in the daily life of people, the smartphones are becoming subject of research interest to transform them in smarter instruments, aiming to include them in many industrial segments. In this sense, the use of smartphones comes up as an option to subsidize the demand of a more practical and accessible tool to optimize field activities.

The fast development of mobile technics introduced the smartphones in the forestry sector [1], mainly related to topics that involve estimating wood volume. The apps, a technology specifically developed to smartphones, are increasingly becoming an accessible tool to be utilized in the scope of forest inventory and management because they are simple, practical and have a lower cost when compared to the hypsometers currently available in the market. The advance in hardware technologies for smartphones brings a new reality to a wide set of tolls that can be applied daily by the user, being easy to utilize.

Despite the technological advances and the emergence of smartphone apps that assist the forestry sector, especially forest management and inventory, there is a lack of research related to the evaluation of the use of those apps, regarding to their accuracy, when compared to commonly utilized equipment's to measure trees height [7]. Besides that, altering the methods and usual technics of research in this sector is important to increase the technologic investigation in the forestry sector, in addiction to decrease the intensity of work in plantations.

Our study aims to evaluate the use of the smartphone app "Smart Measure" to measure trees height by comparing their results with the real heights obtained with a measuring tape after logging and with two hypsometric instruments (Suunto and TruPulse 200), both widely utilized in the forestry sector.

2. MATERIALS AND METHODS

Fieldwork was carried in a homogeneous plantation of *Eucalyptus* spp. aged 6 years, implemented using a 3 m x 3 m design, in an area with a flat topography in Rio Grande do Norte, northeast Brazil (Figure 1).

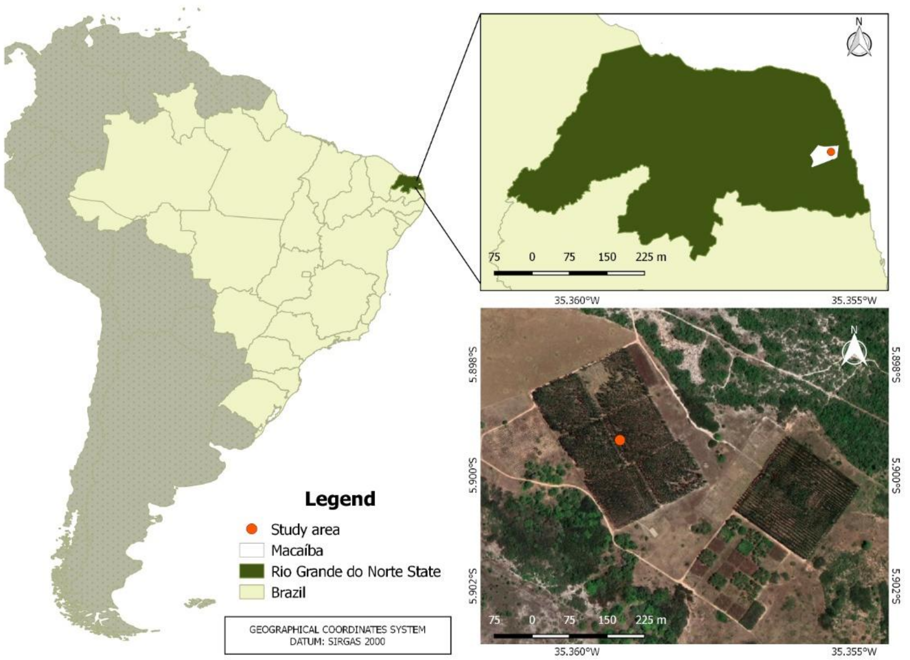

Figure 1: Location of the homogeneous plantation of Eucalyptus spp. in the northeast region, Brazil.

To measure the trees height, we utilized the app “Smart Measure” (version 1.6.7) and two hypsometers: Suunto and TruPulse 200. The heights were estimated using the instruments and then compared with the real height, measured after cutting with a tape measure. The “Smart Measure” stands out for its ease of use and accessibility, allowing users to measure tree height using just their smartphone camera. The intuitive interface simplifies the measurement process, making it accessible even for less experienced users.

The Suunto is recognized for its high precision, reliability, and durability, making it ideal for topographic and height measurements. The TruPulse 200 offers reliability and precision, known for its ease of use and the ability to perform distance and height measurements in a variety of environmental conditions.

The main difference between the “Smart Measure” and hypsometers is the use of the smartphone camera for height measurements, providing a convenient and cost-effective solution for a wide range of users. Hypsometers are instruments designed specifically for this purpose, so they have a higher cost.

Altogether there were 30 trees sampled by three distinct operators, each of them utilizing the app “Smart Measure” and the hypsometers Suunto and TruPulse 200. In this way, there were a total of 90 samples for each instrument. The sampling sufficiency was defined using the equation (1) proposed by Barnes (1977) [8] as follow:

$$N \geq \frac{t^2+CV^2}{E^2} \quad (1)$$

Where:
N = minimum number of observations needed;
t = tabulated value, for the probability level desired and (n-1) degrees of freedom;
CV = coefficient of variation (%);
E = admissible error (%).

To measure the height of the trees using the instruments, we established 15 meters from the tree in advance. The operators received unified pre-training, conducted by the same trainer, and following the same methodology, aiming to ensure a more efficient use of the instruments during fieldwork. During the data collection, there was no communication between the operators to avoid biased results. Additionally, the area underwent grass cutting to facilitate the visualization of the trees' base and reduce possible measurement errors.

We processed the data utilizing software Microsoft Excel and proceeded with statistical analyzes using Minitab version 17. The mean values were analyzed using an analysis of variance (ANOVA) and multifactorial analysis of variance (two way), followed by Dunnet test with 5% of probability to make comparisons between them. To verify possible bias from each operator with each of the measuring instruments, we calculated the relative error (%) according to the equation (2):

$$ER\ (\%) = \frac{|H-\hat{H}|}{H} 100 \quad (2)$$

Where:
ER (%) = relative error;
H = trees real height (m);
$\hat{H}$ = estimated height using the instrument (m).

We also estimated bias (BIAS) (equations 3 and 4), the average of the absolute deviation (AD) (equations 5 and 6), the standard deviation of the differences (DPD) (equation 7) and the mean square root of the error (RMSE) (equation 8), using the following equations:

$$\text{BIAS} = \frac{\sum_{i=1}^{n} Y_i - \sum_{i=1}^{n} \hat{Y}_i}{n} \quad (3)$$

$$\text{BIAS (\%)} = \frac{BIAS}{\bar{Y}} 100 \quad (4)$$

$$\text{AD} = \frac{\sum_{i=1}^{n} |Y - \hat{Y}|}{n} e \quad (5)$$

$$\text{AD (\%)} = \frac{MD}{\bar{Y}} 100 \quad (6)$$

$$\text{DPD} = \sqrt{\frac{\sum_{i=1}^{n} di^2 - \left(\sum_{i=i}^{n} di\right)^2 / n}{n-1}} \quad (7)$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2}{n}} \quad (8)$$

3. RESULTS

When analysing the average value of the actual tree height, obtained using a tape measure after cutting, it is observed that the TruPulse was the only instrument that showed no statistical difference among the three operators. On the other hand, the average height values obtained with the Suunto by operators 1 (SU1) and 2 (SU2), as well as the average height values obtained with the "Smart Measure" app by operators 1 (SM1) and 3 (SM3), differed statistically from the actual average height. As a result, operators 3 (SU3) and 2 (SM2) demonstrated superior performance when using the Suunto hypsometer and the "Smart Measure" app, respectively. Regarding the "Smart Measure" app, operator 2 (SM2) obtained the most accurate results, with the average height values showing no statistical difference compared to the actual average height obtained with the tape measure and presenting the lowest relative error (-4.29%) (Table 1).

Table 1: Descriptive statistic for the tree's height, for each instrument utilized by each operator.

Instrument	Measuring tape	Suunto			TruPulse			Smart Measure		
Operator	-	1	2	3	1	2	3	1	2	3
Treatments	Control	SU1	SU2	SU3	TR1	TR2	TR3	SM1	SM2	SM3
μ (m)	20.62a	22.83b	22.55b	21.45a	19.94a	19.49a	21.27a	23.22b	21.51a	23.08b
S^2	6.52	13.45	13.25	12.40	6.15	7.01	9.033	13.02	5.46	11.68
σ	2.55	3.67	3.64	3.52	2.48	2.65	3.01	3.61	2.34	3.42
CV (%)	12.38	16.06	16.14	16.42	12.43	13.58	14.13	15.54	10.86	14.81
Error (%)	-	-10.71	-9.34	-4.00	3.29	5.47	-3.15	-12.57	-4.29	-11.91

μ = mean, S^2 = variance, σ = standard deviation, CV = variation coefficient.
Mean values followed by distinct letters are statistically different according to Dunnett's test (α = 0,05).

The smallest biases were observed in the results of operators 1 and 3 when using the TruPulse hypsometer (TR1 and TR3). It is important to note that positive and negative values indicate underestimation and overestimation, respectively. In this context, operator 1 (TR1) underestimated tree height, while operator 3 (TR3) overestimated it. When using the Suunto hypsometer and the "Smart Measure" app, all operators overestimated tree height, with the lowest estimate obtained by operators 3 (SU3) and 2 (SM2), indicating better performance with these instruments. The RMSE values per instrument and per operator ranged from 1.36 to 3.25 m, with the highest error values observed in operators 1 (SM1) and 3 (SM3) when using the "Smart Measure" app, and the lowest errors observed in operators when using the TruPulse hypsometer, highlighting greater ability with the equipment (Table 2).

Table 2: Bias (V), average of absolute deviation (MD), the standard deviation of the differences (DPD) and the mean square root of the error (RMSE) for the trees evaluated, by instrument and for each operator.

Instrument	Suunto			TruPulse			Smart Measure		
Operator	1	2	3	1	2	3	1	2	3
Treatments	SU1	SU2	SU3	TR1	TR2	TR3	SM1	SM2	SM3
BIAS	-2.21	-1.92	-0.825	0.68	1.13	-0.65	-2.59	-0.88	-2.45
BIAS (%)	-10.7	-9.34	-4.00	3.29	5.47	-3.15	-12.57	-4.29	-11.91
AD	2.43	2.04	1.62	1.09	1.44	1.28	2.8	1.45	2.89
AD (%)	10.67	9.04	7.56	5.48	7.40	6.04	12.06	6.75	12.52
DPD	1.85	1.64	0.52	0.60	1.02	0.37	1.78	0.60	1.69
RMSE	2.66	2.43	1.88	1.36	1.73	1.71	3.25	1.91	3.16

Operators 1 (TR1) and 2 (TR2), when using the TruPulse instrument, were the ones who most underestimated the heights of the trees measured compared to the average value of 20.62 m obtained with the tape measure after cutting. In contrast, the average values obtained with the other instruments overestimated the heights. The "Smart Measure" app, when used by operators 1 (SM1) and 3 (SM3), presented estimated values further from the real average value. On the other hand, when used by operator 2 (SM2), the app presented values like the average value of the control treatment (Figure 2).

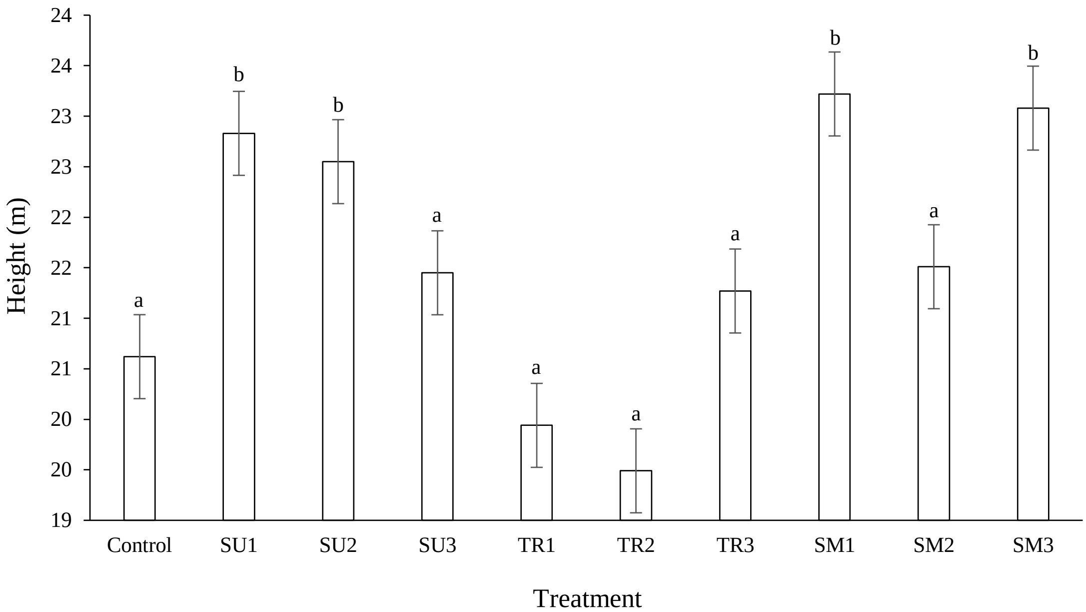

Figure 2: Average tree height by treatment (instrument and operator). CO = control; SM = Smart Measure; SU = Suunto; TR = TruPulse; 1, 2, 3 = operators. Different letters indicate statistical difference (P < 0.05; Dunnett).

It is observed that the operators demonstrated excellent skill with the TruPulse hypsometer. Additionally, the results achieved by operator 2 also suggest ability in using the "Smart Measure" app. On the other hand, operator 3 also demonstrated skill with the Suunto hypsometer (Figure 2). Thus, the three operators showed similar results with the TruPulse, while with other instruments, at least one operator statistically differed from the others (SU3 and SM2). All instruments were validated, as at least one operator obtained statistically distinct results.

4. DISCUSSION

Each of the evaluated instruments, with at least one of the operators, showed a similar estimated average height to the actual average height obtained with a tape measure after tree cutting, demonstrating that even with prior training, the operators exhibited distinct abilities when using each of the instruments. The TruPulse hypsometer was the easiest instrument to operate, considering that the average values obtained by the three operators did not differ from the actual average value. In contrast, based on relative error, we could observe better performance from operator 3 with the “Smart Measure” application.

Regarding the relative mean error observed per instrument for each operator, and considering the results obtained with the TruPulse hypsometer used by the three operators evaluated, the results obtained by operator 3 (SU3) with Suunto hypsometer and operator 2 (SM2) with the app “Smart Measure”, we could observe an error that was similar to the findings from Curto et al. (2013) [9]. The authors found a relative mean error of 4.26% and 4.74% using a digital clinometer, and 6.22% and 5.15% for the Vertex when measuring trees in a flat area with a mean height of 19.62 m and 23.13 m, respectively.

Couto and Bastos (1988) [6] evaluated measurement errors in the heights of *Eucalyptus* spp. trees in a flat area, associating those errors to the operator, measurement instrument, distance between the operator and the three, trees height class and its interactions, and observed that the relative error for the operator varied between -1.02% and -7.35%, while the error for measurement instrument varied between -0.36% to -6.79%, a variation that is similar to the one found in our study. The authors reported that all the analyzed factors influenced the magnitude of the error when estimating the trees height, and that each operator presented errors that were bigger or smaller regarding the instrument utilized, taking in consideration that each operator was more familiarized with a determinate instrument. In this sense, the authors concluded that the operators presented a higher ability when utilizing the Haga equipment, followed by Suunto, Blume-Leiss, Haglof and Weisei.

Villasante and Fernandez (2014) [10], when comparing the heights obtained with the app “Smart Tools” to the commonly utilized hypsometers (Vertex and Blume-Leiss), found a different pattern from our study, since they detected that the errors obtained when using the app were significantly superior than the errors found with other commonly used hypsometers, with a pronounced tendency to underestimate the results, and this error increased as the trees height increased. Thus, it is possible to infer that the "Smart Measure" application may offer better precision, considering that one of the evaluated operators obtained a very close average height to the actual height measured with a tape measure after cutting.

The smaller bias value was obtained using TruPulse hypsometer, indicating that this was the instrument with a better accuracy when considering all the operators evaluated, and with predominance of errors related to the underestimation of the trees height, only operator 3 (TR3) overestimated. When utilizing the Suunto hypsometer and the app “Smart Measure”, all operators overestimated the trees height, and operators SU3 (Suunto) and SM2 (Smart Measure) were the most accurate.

In a study evaluating different instruments to measure trees height in a hybrid population of *Eucalyptus urophylla* S.T.Blake and *Eucalyptus grandis* W.Hill with a mean tree height of 27.71 m, Oliveira et al. (2014) [11] found that the dendrometric clipboard, the electronic clinometer and the Bitterlich relascope were the instruments with a better accuracy regarding the real height obtained using a measuring tape, with a relative error that varied from +0.11% to

+4.40%. However, the laser hypsometer was evaluated as an unreliable instrument when evaluating the trees height accuracy, with a tendency to underestimate the results and with a relative error of +10.14%, like the operators that presented a lower performance when utilizing the hypsometer Suunto and the app “Smart Measure”, in this case instead of underestimating the trees height presented a tendency to overestimation.

A study by Bijak and Sarzyński (2015) [1] in the central region of Poland using a population of *Pinus sylvestris* L., compared the results from the apps “Smart Measure” and “Measure Height” to the height obtained for the same trees using the hypsometer Suunto, and found that both apps are accurate to estimate the heights of smaller trees (12 to 18m). On the other hand, the apps underestimated considerably the height of higher trees (> 20 m). The relative error varied from -29.2% to +12.8% with a mean value varying from -1.4% to -5.6%, with the smaller values observed when using the app “Smart Measure”.

The variation observed for the RMSE values demonstrated that the differences in the ability of each operator can lead to higher or smaller errors when utilizing distinct instruments. Nonetheless, our results diverge from those found by Bijak and Sarzyński (2015) [1] when utilizing the apps “Smart Measure” and “Measure Height”. The authors found errors that were inferior to those found in our study, as the RMSE for the app “Smart Measured” varied from 1.01 to 1.11 m, while the app “Measure Height” varied from 2.04 to 2.46 m, respectively. This difference might be related to the training of the operators, which demonstrated the possibility to obtain precise tree height measurements at a low cost when utilizing those apps, since nowadays most of the professionals and farmers utilize smartphones in a daily basis and have access this kind of technology.

Xinmei et al. (2020) [12], when evaluating the use of smartphones to measure dendrometric variables, observed that the relative error found when measuring the trees height didn’t exceed 5.76%, while the RMSE was 2.16%. The authors concluded that the precision of the instrument matches the necessary criteria to be utilized in forest inventories carried in Chinese territory. These results are similar to the ones obtained in our study by the operators with a better ability and precision when utilizing the hypsometers TruPulse, Suunto and the app “Smart Measure”.

Although the app “Smart Measure” was the instrument with a higher variation on its RMSE, considering all the operators evaluated, the results were similar to those found by Vastaranta et al. (2015) [8] when evaluating the efficiency of the app “TRESTIMATM” to obtain dendrometric variables in a boreal forest in Finland. The authors compared the height values obtained using the app with those obtained using the hypsometer Vertex and found that the app “TRESTIMATM” presented a reasonable accuracy, considering that the RMSE varied from 2.1 to 2.3 m. It is important to highlight that operator 2 (SM2) obtained the most accurate results when utilizing the app “Smart Measure”, once the RMSE was inferior to the value considered as having a reasonable accuracy, which demonstrates that with adequate training this app can provide trustworthy and accurate height measurements.

It is important to highlight that these results are influenced by the operator, and it is essential to train them properly to systematically reduce errors during the measurement process. With adequate training, the operator can acquire the necessary skills to use the "Smart Measure" application, reducing errors until they match those observed with traditional hypsometers.

5. CONCLUSIONS

The evaluated instruments showed the possibility of obtaining reliable and accurate height measurements for trees. Furthermore, the skill and training of each operator are determining factors. The TruPulse was the instrument that offered the most accurate height measurements. The smartphone application "Smart Measure" can be accurately used to measure tree height, as opposed to specific hypsometers, but it requires better prior training.

6. BIBLIOGRAPHIC REFERENCES

1. Bijak S, Sarzyński J. Accuracy of smartphone applications in the field measurements of tree height. Folia For. Pol 2015;57(4):240-4. doi: 10.1515/ffp-2015-0025
2. Goodbody TRH, Coops NC, Marshall PL, Tompalski P, Crawford P. Unmanned aerial systems for precision forest inventory purposes: a review and case study. For Chron. 2017;93(1):71-81. doi: 10.5558/tfc2017-012
3. Wu X, Zhou S, Xu A, Chen B. Passive measurement method of tree diameter at breast height using a smartphone. Comput Electron. Agric. 2019;163:104875. doi: 10.1016/j.compag.2019.104875
4. Saremi H, Kumar L, Turner R, Stone C, Melville G. Impact of local slope and aspect assessed from LiDAR records on tree diameter in radiata pine (*Pinus radiata* D. Don) plantations. Ann For Sci. 2014;71(7):771-78. doi: 10.1007/s13595-014-0374-4
5. Bragg DC. Accurately measuring the height of (real) forest trees. J For. 2014;112(1):51-4. doi: 10.5849/jof.13-065
6. Couto HTZ, Bastos NLM. Erros de medição de altura em povoamentos de *Eucalyptus* em região plana. IPEF. 1988;39(1):21-31.
7. Vastaranta M, Latorre EG, Luoma V, Saarinen N, Holopainen M, Hyyppä J. Evaluation of a smartphone app for forest sample plot measurements. Forests. 2015;6(12):1179-94. doi: 10.3390/f6041179
8. Barnes RM. Estudo de movimentos e de tempos: projeto e medida do trabalho. 6. ed. São Paulo: Edgar Blücher; 1977.
9. Curto RDA, Silva GF, Soares CPB, Martins LT, David HC. Métodos de estimação de altura de árvores em floresta estacional semidecidual. Floresta. 2013;43(1):105-16. doi: 10.5380/rf.v43i1.26791
10. Villasante A, Fernandez C. Measurement errors in the use of smartphones as low-cost forestry hypsometers. Silva Fenn. 2014;48(5):1-11. doi: 10.14214/sf.1114
11. Oliveira XM, Oliveira RR, Ramalho FMG, Cabacinha CD, Assis AL. Accuracy and time of operation of some instruments for measuring height trees. Encic Biosfera. 2014;10:2336-44.
12. Xinmei W, Aijun X, Tingting Y. Passive measurement method of tree height and crown diameter using a smartphone. IEEE Access. 2020;8:11669-78. doi: 10.1109/ACCESS.2020.2965216