Use of Unmanned aerial vehicle images as a tool to evaluate stand uniformity in clonal Eucalyptus plantations

Ana Rosária Sclifó Zucon[1]
Brandon Hawkes[2]
Cristiane Camargo Zani de Lemos[3]
Guilherme Zaghi Borges Batistuzzo[3]
Rodrigo Eiji Hakamada[3]
Guilherme Rodrigues de Pontes[3]
Thiago Ubiratan de Freitas[3]
José Henrique Bazani[1]
Clayton Alcarde Alvares[4]
José Carlos Arthur Junior[4]
José Leonardo de Moraes Gonçalves[1]

[1] Universidade de São Paulo - USP/ESALQ
Caixa Postal 9 - 13418-900 - Piracicaba - SP, Brasil
zuconana@gmail.com
bazani.jh@gmail.com
jlmgonca@usp.br

[2]North Carolina State University
Raleigh, North Carolina, USA
bahawkes@ncsu.edu

[3]International Paper
Rod. SP 340, Km 171 Mogi Guaçu – SP - 13840-970
cristiane.lemos@ipaper.com
guilherme.batistuzzo@ipaper.com
rodrigo.hakamada@ipaper.com
guilherme.pontes@ipaper.com
thiago.freitas@ipaper.com

[4]Instituto de Pesquisas e Estudos Florestais – IPEF
Avenida Pádua Dias, 11 - Caixa Postal 530 - CEP: 13400-970 - Piracicaba/SP
arthur@ipef.br
clayton@ipef.br

Abstract. The monitoring of silvicultural quality in eucalyptus clonal plantations is essential to check the quality of forest operations. The uniformity of a stand is considered a fundamental variable to the monitoring. It shows potential improvements in silvicultural practices, enabling increases in stand uniformity and yield. Today, Unmanned Aerial Vehicle (UAV) images are underutilized and have been shown to be a powerful tool in forest monitoring. The main goal of this work was to develop a model to identify the tree' crowns and create a uniformity evaluation method in clonal eucalyptus plantations through the use of UAV. 50 plots of 50m x 20m were allocated within the study area using the ArcGIS 10.1 software. The maximum likelihood classification tool was used, dividing the image in two classes, tree and non-tree. It was then transformed into polygons and the area of the crowns were calculated. The Pvar50 was used as a uniformity index for the crown areas. The result was a low uniformity index (31, 5%) and high fail index (10, 2%), which can be explained due to possible failures in forest activities or drought that occurred after the planting period. The evaluation of the UAV images proved to be a powerful tool to check the silvicultural quality of the stands. In order to get a good maximum likelihood classification, a high image quality it required.
Key-words: UAV images, uniformity, model builder, silvicultural quality

1. Introduction

Eucalyptus plantations are a widespread source of wood in Brazil and have guaranteed the supply of forest raw materials to a vast amount of Brazilian industries. According to ABRAF (2013), the area occupied by Eucalyptus had reached 5.1 million hectares in 2012. But this number continues to increase and the incessant rise in demand for Eucalyptus's wood has led to the need to enhance stand uniformity (MARCOLINO, 2010). However, considering the advances over the years on breeding techniques, we can observe significant variations on stem growth within stands. These variations exist due to different factors such as: soil type, topography, quality of silvicultural practices and so on (RUFINO et al, 2006).

Besides the choice of good genetic material to ensure satisfactory stem growth, there is still a need to improve forestry quality in order to increase productivity and stand uniformity. Thus, monitoring of silvicultural quality is essential, Hakamada (2015) confirms that stand uniformity is a key variable for monitoring operational quality.

Unmanned aerial vehicle (UAV) images are one of the current tools used to monitor recently planted forests. However, there is not much information in the Brazilian literature of the use of UAV images for the quantification and assessment of uniformity of Eucalyptus stands. Therefore, this study proposes the development of a model to classify and individually identify the trees based on UAV images. As an application of this tool, this study also proposes a method to remotely monitor the stand, assessing the stand uniformity and fail rate.

2. Methodology

2.1 Study area

This study was taken in a commercial stand of clonal eucalyptus planted in the region of Altinópolis, countryside of São Paulo state (21°32'S; 47°42'W, figure 1). The climate is classified as Cwa in the Koppen classification, with average annual temperature of 22°C. The altitude is around 638m and annual precipitation of 1461mm. The stand was planted on December 2013 and the UAV images were taken on July 2014.

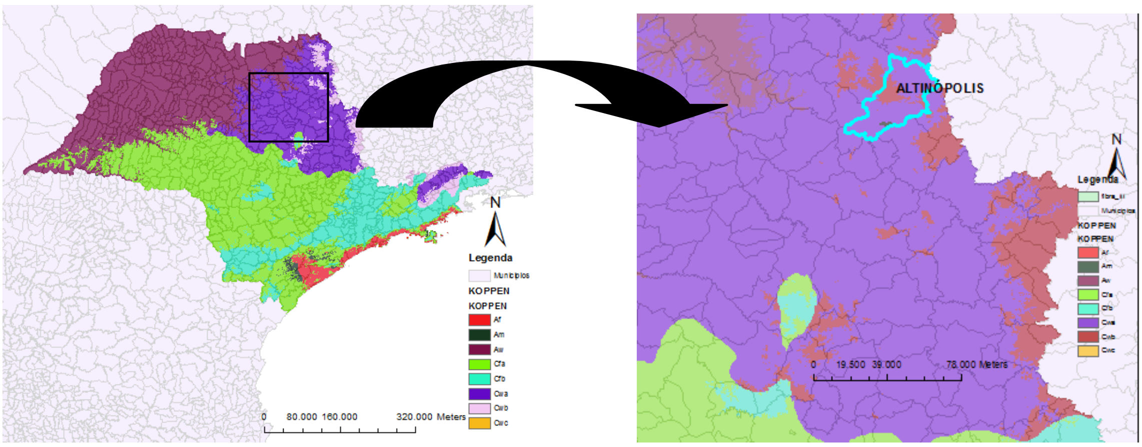

Figure 1. Region of the study area and its climate (ALVARES et al, 2013).

The images were taken from unmanned aerial vehicles (UAV) with a 15 minute long flight, flying 150 m high above the stand. The images were taken in pre-determined points in the stand in order to build an image mosaic, when putting them side-by-side it creates a whole stand image. It resulted in an image of 5cm resolution.

2.2 Field data collection

The crown areas measured in the field can be used to create a relationship between the values that the model outputs in order to get a more accurate estimate of the crown areas. The plots where predetermined to be 6 trees wide by 17 trees long, for a total of 102 trees in each plot (figure 2a), with a total of 3 plots in the stand. The height and the crown diameter were measured, taking two measurements, 90 degrees apart (figure 2b). For each tree the column and row as well as the height and crown measurements was recorded so that each individual tree can be located on the aerial imagery and compared to the corresponding tree measurements taken in the field.

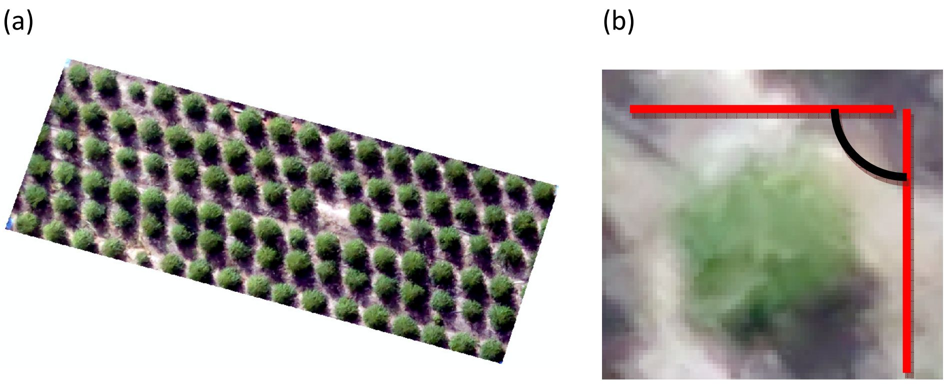

Figure 2. Example of a field plot (a) and the diameter measurement taken in each tree

2.3 Developing the model to identify individual trees

The model to classify and individually identify the trees was created using the software ArcGIS 10.1 with modelbuilder feature. The following tools were used to complete the process.

- Clip – Clips raster to the extent of the outline shapefile
- ML Classification – Classifies the image into four classes based on the training samples (figure 3)
- Filter – Smooths the edges of the classified raster making for a cleaner image
- Integer – Transforms the raster into an integer type raster so it can be reclassified
- Reclassify – Reclassifies the image into two classes, trees and non-trees
- Boundary clean – Smooths the boundaries between zones
- Raster to polygon – Transforms each classified zone into polygons
- Select – Extracts only the polygons that meet the given criteria
- Table to dBase – Exports an excel table containing the areas of all the polygons

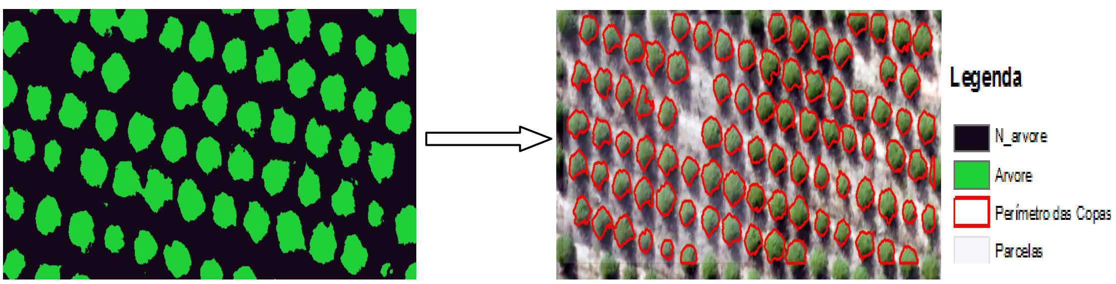

Figure 3. Result of the Maximum Likelihood Classification and the crown's perimeter after using this tool.

2.4 Developing the method

After classifying the image, each polygon refers to an individual tree and its crown area. In order to evaluate the stand's uniformity with a large number of plot samples, 50 plots of 50m x 20m were allocated randomly and in a representative way within the stand (figure 4).

The total area of the 50 plots is 5 hectares, representing 18, 5% of the total stand area (26, 97 ha). Some corrections inside the plots were made such as; the removal of areas where multiple trees were identified as only one polygon, and areas where weed and shadows were identified as trees. Each plot had the total crown area calculated which will be used to calculate the uniformity of the stand.

Figure 4. 50 plots randomly allocated in the stand.

2.5 Evaluating uniformity and fails

After calculating the crown area of each polygon, it was possible to calculate the uniformity index for each plot. The crown area of each tree was chosen as a dendrometric variable. The uniformity was calculated based on a uniformity index called Pvar50 (formula 1) which was also used by Hakamada (2015):

$$Pvar50 = \frac{\sum_{k-1}^{n/2} Variable_{ij}}{\sum_{k-1}^{n} Variable_{ij}} \quad (1)$$

Where:

Pvar50 = cumulative percentage of dendrometric variable of interest 50 % of the smallest trees planted;
Variable = dendrometric variable of interest of the plot i in age j;
N = number of planted trees organized from the smallest to the largest.

3. Results and discussion

3.1 Comparing field data and UAV data

Below (figure 5) we can observe the relationship between field data and UAV data. We can assume a good relationship, considering that the R^2 is higher than 0,8. The straight line (1:1) indicates where all the data should be placed, meaning that the tree crown measured in the field is exactly the same as the one measured in the UAV image. Although, we can observe that this line is a bit dislocated but there is a satisfactory relationship between the variables, showing that the UAV images can be used to evaluate the size of the tree crowns and uniformity of the stand based on this variable.

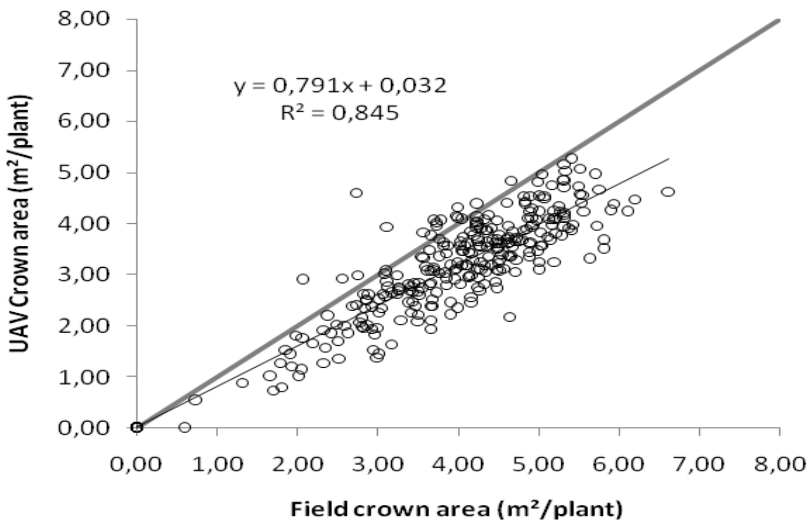

Figure 5. Relationship between crown area measured in the field and in the UAV image.

3.2 Uniformity evaluation

Table 1 shows the results from the Pvar50 calculation based on the crown area. It includes; the minimum value of the mean crown area, variation coefficient (%), and the fail index regarding the 50 plots evaluated from the UAV images.

Table 1. Results from the 50 plots measured in the UAV images (crown area mean, CV and Pvar50 index) and the fail index.

	Mean	**CV**	**Pvar50**	**Fail index**
	m² plant^{-1}	——— % ———		
Plots	3.6	51,6	31,5	10,2

The fail index is over the maximum set by the company, being 3%. According to Hakamada (2012), the optimum range of uniformity to clonal stands varies from 37% to 50%. But the area shows a lower value (31,5%), which could be assigned to two main factors; a drought stress observed in the period after planting (January/February) causing the high fail index and reducing the stand uniformity (figure 2) and the opportunity to improve silvicultural quality.

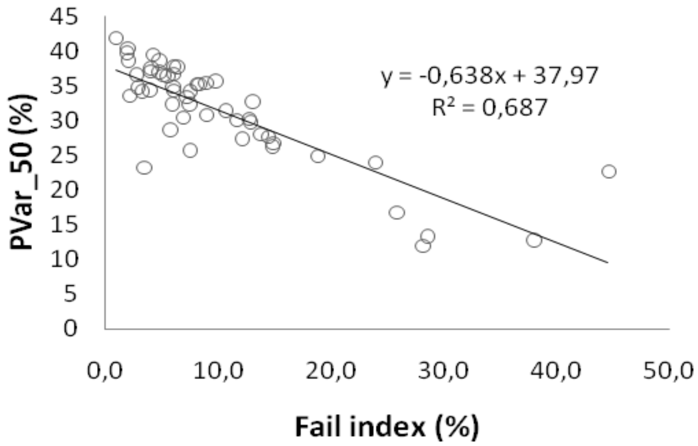

Figure 6. Relationship between the uniformity index Pvar50 (%) and the fail index (%) evaluated in the 50 plots

It is important to point out that the Pvar50 index is sensitive to mortality rate. Therefore, we see on the graph (figure 6) that the stand homogeneity calculated by the index is highly affected by its mortality. Thus, we can observe that there was a good relationship (R^2=0,687) between the Pvar50 and the fail index, which indicates that the greater the number of fails, the lower the uniformity index evaluated. It confirms that certain conditions, such as drought stress, have a high impact on stand uniformity and mortality. Appropriate long-term weather conditions along with high quality silvicultural operations, are necessary to provide the conditions and resources to each individual tree in an appropriate and uniform way. Therefore, this methodology is effecient for qualitative assesment of young stands, which facilitates informed decision-making.

3.3 Evaluating model outputs

The model, when ran successfully, will result in individual trees being identified with a polygon shape file output as a perimeter of each tree crown. But due to poor image quality, eventually the model may not run properly. Thus, it is important to evaluate the polygon shapefile output before using the data.

If the image quality is poor or something went wrong with the model the outputs will not be useful. The main problems can be: trees running together, trees touching each other (figure 7a) and tree crowns being underrepresented (figure 7b). When the first and the second occur, the model used in this work was not able to fix it. These problems may occur due to two main factors: the signature file that was used was not good or the image quality is too poor to accurately classify the tree crown. It occurs because some trees vary in color and a signature file that works well on one image may not work well on another. Thus, the signature file should be taken again. And if it does not work, the image quality should be improved.

Considering this, the best results can be achieved from the model if certain conditions are met. The flight should be done; when the sun is high (10am-14pm), when there is little to no cloud cover, (so it decreases the shady areas), little to no wind (so the tree crowns can be identified better by the model), and with a pixel size of less than 5 cm x 5 cm. These are important criteria in order to achieve the highest image quality possible and to increase the quality of the identification of tree crowns. The age of the trees is also important, so the picture should be taken on trees 3-6 months old and/or 1-2 meter crown diameter, so it decreases the problem with touching tree crowns.

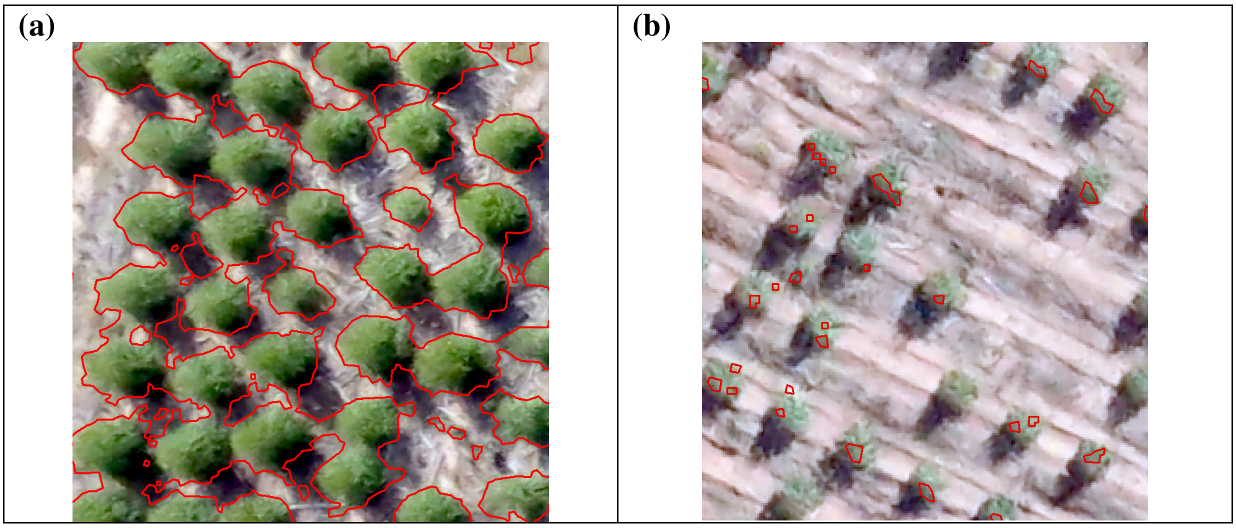

Figure 7. Model outputs; Trees touching each other (a) and tree crowns underrepresented (b).

4. Conclusions

- There was a good relationship ($R^2 > 0,8$) between the data measured in the field and the data measured through the UAV images, meaning that UAV images can be used to evaluate crown area and uniformity;

- The evaluation using the UAV images shows that the stand uniformity (31,5%), is under the minimum expected (37%);

- In order to obtain a good UAV image classification, the image resolution should be sufficiently accurate and should be taken before crown closure. After this study, we recommend that the quality of classification should be evaluated in younger stands than evaluated here;

- The UAV images prove to be a powerful tool in forest monitoring in clonal stands of Eucalyptus, including the evaluation of uniformity and silvicultural quality. It can be a helpful tool in decision-making to correct operations or even to change them.

5. References

ALVARES, C.A.; STAPE, J.L.; SENTELHAS, P.C.; MORAES, J.L.M.; SPAROVEK, G. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, v. 22, n. 6, p. 711-728, 2013.

HAKAMADA, R.E.; STAPE, J.L.; LEMOS, C.C.Z.; ALMEIDA, A.E., SILVA, L.F. Using forest inventory and uniformity among trees to monitor silvicultural quality in Eucalyptus clonal plantations. **Scientia Forestalis**, Piracicaba. No prelo.

HAKAMADA, R.E. **Uso do inventário florestal como ferramenta de monitoramento da qualidade silvicultural em povoamentos clonais de *Eucalyptus***. Dissertação de mestrado. Piracicaba, 2012.

MARCOLINO, L. **Crescimento de clones de eucalipto em quatro espaçamentos de plantio no interior de São Paulo. Monografia do curso de graduação em Engenharia Florestal**. Universidade Federal Rural do Rio de Janeiro. 2010.

RUFINO, T.M.C.; THIERSH, C.R.; FERREIRA, S.O.; JUNIOR, H. K.; FAIS, D. **Uso da Geostatística no Estudo da Relação entre Variáveis Dentrométricas de Povoamentos de *Eucalyptus sp.* e Atributos do Solo**. Ambiência, Guarapuava – PR, v.2, p. 83-93, 2006.