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Articles

Uniformity indices for young *Eucalyptus* plantations derived from drone

Índices de uniformidade de plantios jovens de *Eucalyptus* obtidos por meio de imagens de drone

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ABSTRACT

Forest plantations exhibiting heterogeneous growth may experience production losses. In this context, understanding stand uniformity is essential for making silvicultural decisions regarding the area in which the plantation is established. Therefore, the objectives of this study were to: (a) investigate the feasibility of using drones to map the structural uniformity of forest plantations; and (b) demonstrate the applicability of uniformity indices for assessing the structure of young Eucalyptus plantations. The study was conducted in one-year-old clonal plantations located in Ortigueira, Paraná, Brazil. Drone imagery was acquired using the Phantom and Sequoia platforms, both equipped with red, green, and blue (RGB) sensors. A digital elevation model, a digital surface model, and an orthomosaic were generated from these images. The following uniformity indices were calculated: PH_{25}, PH_{50}, and PH_{75}, $CV_{\%}$, and G. Indices derived from conventional forest inventory data were compared with those obtained from drone imagery using the chi-square (χ^2) test. Plantation uniformity was successfully estimated from drone imagery. The uniformity indices derived from drone data did not differ significantly from those obtained using the conventional forest inventory method. The PH_{25} index may lead to a distorted interpretation of uniformity in plantations with high three mortality rates. The combined analysis of PH_{50}, PH_{75} $CV_{\%}$, and G provides a more comprehensive assessment of plantation structural uniformity.

Keywords: Structural uniformity; Forest plantations; Ratio model

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RESUMO

Plantios florestais com crescimento heterogêneo podem ocasionar perdas na produção. Nesse sentido, conhecer a uniformidade é fundamental para tomar decisões silviculturais sobre a área em que o plantio está inserido. Dessa forma, os objetivos deste trabalho foram: a) investigar a viabilidade do uso de drones para o mapeamento da uniformidade estrutural de plantios, e (b) demonstrar a aplicabilidade de índices de uniformidade na avaliação da estrutura de plantios jovens de *Eucalyptus*. O estudo foi conduzido em plantios clonais de um ano de idade localizados em Ortigueira, Paraná. As imagens de drone foram obtidas utilizando a plataforma Phantom e a plataforma Sequoia, ambos com sensor *Red, Green* e *Blue* (RGB). A partir dessas imagens, foram gerados o modelo digital de elevação, modelo digital de superfície e ortomosaico. Foram calculados os índices de uniformidade: PH25, PH50 e PH75, CV% e G. A comparação entre os índices obtidos do inventário tradicional e os obtidos por drone foi realizada por meio do teste de X^2. Foi possível estimar a uniformidade utilizando as imagens adquiridas por drone. Os índices de uniformidade obtidos por meio de drone não apresentaram diferença estatisticamente significativa em relação ao método tradicional de inventário. O índice PH25 pode levar a uma interpretação distorcida da uniformidade quando há uma alta taxa de mortalidade das árvores. A análise conjunta dos índices PH50 e PH75, CV% e G proporciona uma visão mais abrangente da uniformidade estrutural dos plantios.

Palavras-chave: Uniformidade estrutural; Plantios florestais; Modelo de razão

1 INTRODUCTION

In a clonal plantation, all plants are expected to have the same capacity to capture and use resources and convert them into biomass (Aspinwall et al., 2011); however, several factors can affect tree growth, resulting in stands with heterogeneous structures (Aspinwall et al., 2011). A heterogeneous plantation structure can contribute substantially to reduced growth and productivity when compared with more uniform structures (Hakamada et al., 2015a; Hakamada et al., 2015b; Resende et al., 2016; Yáñez et al., 2017; Soares et al., 2017; Sun et al., 2018; Resende et al., 2018).

Structural stand uniformity can be regarded as a reflection of the environmental conditions in which the plantation is established, the quality of the genetic material used, the quality of the silvicultural operations applied, and the interactions among these factors (Hakamada et al., 2015b; Soares et al., 2016; Sun et al., 2018). Therefore, it is important to determine structural uniformity within the first months of plantation development (Hakamada et al., 2015b; Soares et al., 2016; Sun et al., 2018), so that

the areas that require greater silvicultural management attention and immediate silvicultural interventions can be identified (McGown et al., 2016; Resende et al., 2016; Yáñez et al., 2017; Sun et al., 2018). Such measures can promote greater structural uniformity and, in turn, create conditions for the forest stand to reach its potential productivity (Luu et al., 2013).

The structural uniformity of plantations is determined by means of uniformity indices (UI), the most widely used of which in forestry are the coefficient of variation ($CV_{\%}$), the Gini coefficient (G), and the cumulative percentage of the variable of interest in the smallest 50% of planted trees (PV_{50}) (Hakamada et al., 2015b; McGown et al., 2016; Yáñez et al., 2017; Hentz et al., 2018).

These indices are generally calculated from sample data obtained by conventional forest inventory. However, for large or hard-to-access areas, data collection can become costly or even unfeasible. In this context, the use of drones has emerged as a potential alternative in the forest inventory process, owing to low operating costs, high spatial and temporal resolution, and high flexibility in image acquisition (Zhang and Kovacs, 2012; Salamí et al., 2014; Torresan et al., 2017; Almeida et al., 2021).

However, few studies have focused on obtaining uniformity measures from data collected with this airborne technology (Hentz et al*.,* 2018). Therefore, the objectives of this study were to: (a) investigate the feasibility of using drones to map the structural uniformity of plantations, and (b) demonstrate the applicability of uniformity indices for assessing the structure of young *Eucalyptus* plantations.

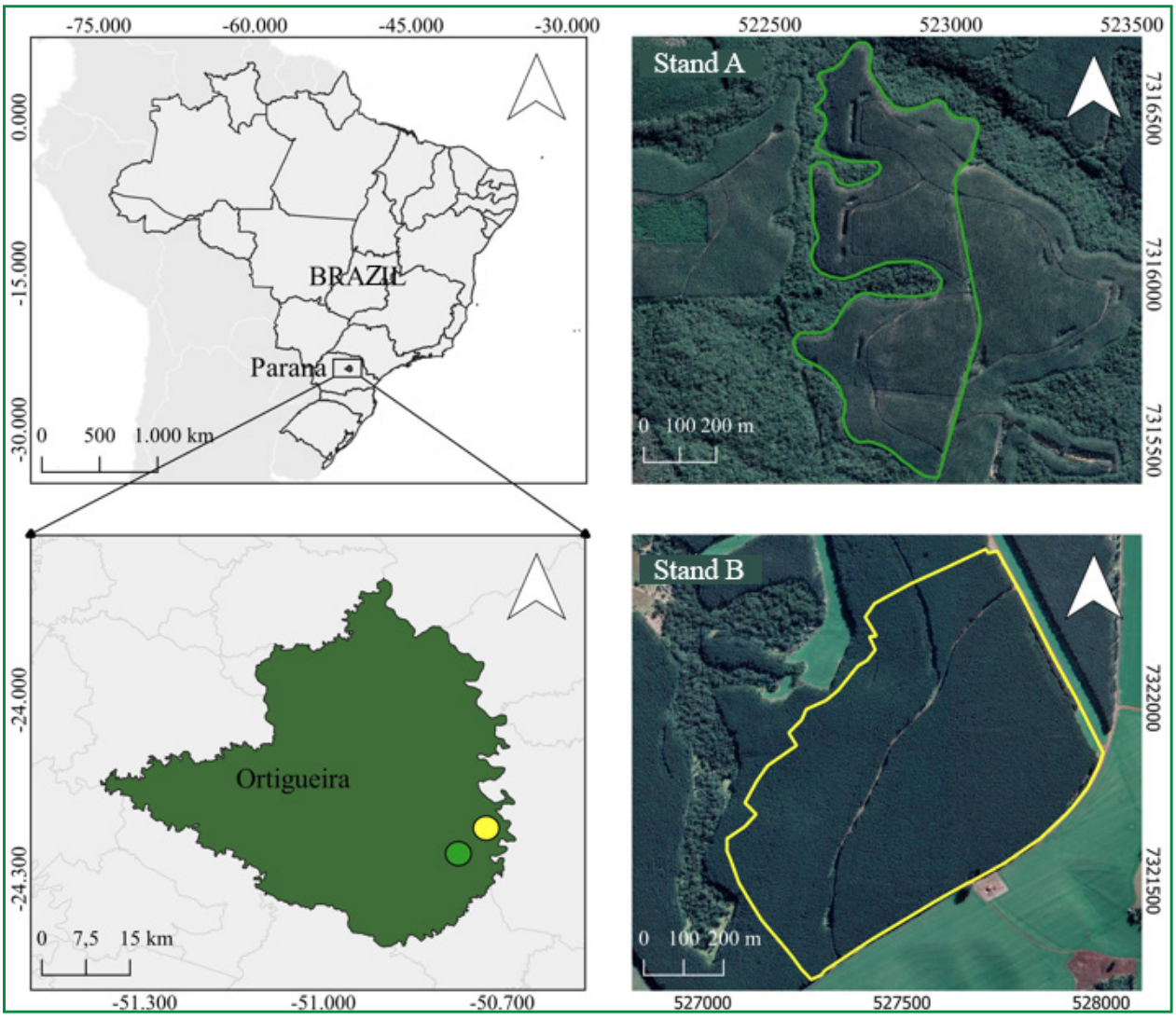
2 MATERIALS AND METHODS

2.1 Study area

The study area comprises two young plantations of the genus *Eucalyptus*, approximately one year old, selected and provided by the company Klabin S.A., in the municipality of Ortigueira, Paraná, southern Brazil (Figure 1). Plantation “A” is a monoclonal plantation of the species *Eucalyptus saligna* Sm., and plantation “B” is a monoclonal plantation of *E. grandis* W. Hill × *E. urophylla* S. T. Blake.

The productive area of plantation "A" is 38.39 ha, with Cambisols, whereas plantation "B" has a productive area of 54.19 ha and Ferralsols. At the time of the study, all plantations were approximately one year old, with crown overlap within the rows and partial overlap between the rows.

Figure 1 – Location of the study area in the municipality of Ortigueira, Paraná, Brazil



Source: Authors (2024)

2.2 Conventional forest inventory data acquisition

For this study, data from the Quality Forest Inventory (QFI) provided by the company Klabin S.A. were used. The plots were randomly allocated within the plantation and were rectangular, consisting of four rows with five trees each, totaling, on average, 20 trees (planting pits) per plot. The spacing between trees was 1.8 m × 3.3 m.

In the field data collection (QFI), the total height (h) of all trees in each plot was measured. In plantation "A", 261 trees were sampled in 13 plots, and in plantation "B", 222 trees in 11 plots. Total height was measured with a Haglöf Vertex IV® hypsometer at a distance of 20 m from the tree. In addition, the geographic position of each plot was recorded with a Garmin 62CSX GPS. According to the GPSMAP 62 series owner's manual, the margin of error for the exact location is ± 12 ft (or 3.66 m).

2.3 Drone data acquisition

Drone flights were carried out with the unmanned aerial platforms and sensors provided by Klabin S.A. In plantation "A", the *Phantom* platform was used with a visible-spectrum red, green, and blue (RGB) sensor, whereas in plantation "B", the *Parrot Disco* platform was used, equipped with the Sequoia multispectral sensor, which records the RGB, red-edge, and near-infrared bands (Table 1). The use of different platforms did not affect the generation of the cartographic products, since only the RGB bands of both sensors were used in image processing.

Table 1 – Flight information for the drone flights carried out in young Eucalyptus plantations

Information	Plantation "A"	Plantation "B"
Flight height (m)	120	120
Platform	Phantom	*Parrot Disco*
Sensor	RGB	Sequoia
Spatial resolution (cm)	3.0	4.5
Overlap (%)*	70 × 70	70 × 70

Source: Authors (2024)

In where: Overlap (%)* is the lateral and longitudinal overlap of the images.

The aerial drone images were acquired on clear-sky days and within the flight window, between 9:00 a.m. and 3:00 p.m. The flight pattern used was a single-grid acquisition, which consists of capturing images along parallel flight lines oriented in a single direction, with longitudinal and lateral overlap between images. The flight height was 120 m, in compliance with the regulations in force of the Agência Nacional de Aviação Civil (ANAC).

2.4 Processing of drone-collected data

The raw images from the drone flights were imported into the *PiX4D* software, where the following cartographic products were generated: a Digital Elevation Model (DEM/DTM); a Digital Surface Model (DSM); and an orthophoto mosaic, also called an orthomosaic. Then, in the *ArcGIS* software, version 10.4.1, the "DSM-DTM" subtraction was performed with the *Raster Calculator* tool, yielding the Canopy Height Model (CHM), or Normalized Digital Surface Model (nDSM), of each plantation.

Rectangular plots with the same size as the QFI plots were digitized on the orthomosaic. In Sampling 1, 13 and 11 plots were allocated in plantations "A" and "B", respectively, at the same locations as the QFI plots. In Sampling 2, an additional 17 and 19 plots were randomly allocated in plantations "A" and "B", respectively, at locations different from those of the QFI plots. Samplings 1 and 2 served as the basis for calculating the uniformity indices that were spatially mapped.

The tree location points were digitized by photointerpretation. With the positions of the trees within the plots on the CHM, tree heights were extracted using the *Extract Values to Points* tool of the *ArcGIS* software.

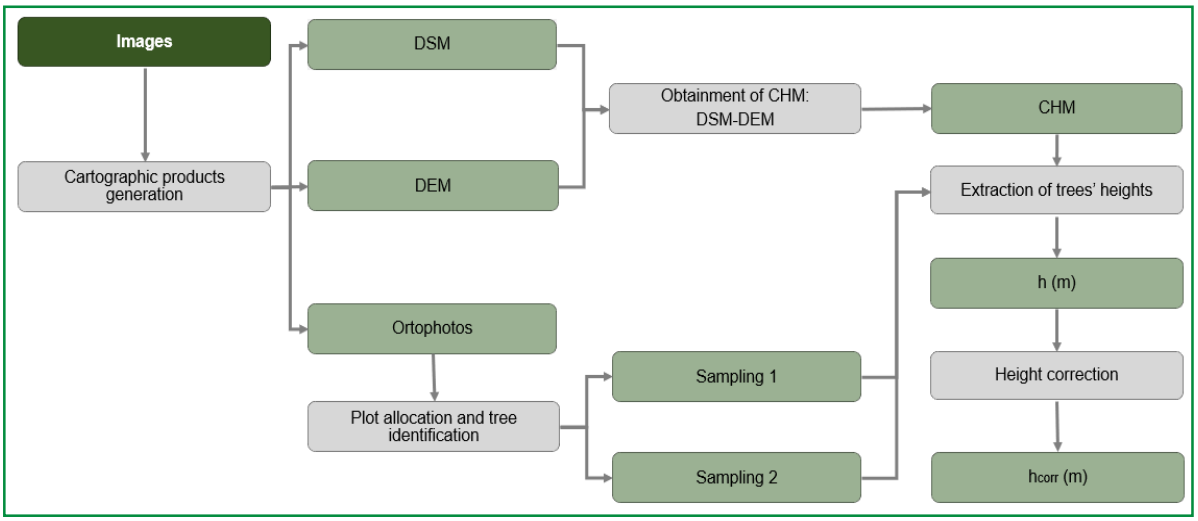
An exploratory data analysis revealed that the heights extracted from the drone images, when compared with the QFI heights, showed a systematic error with a tendency to underestimate the measurements. To overcome this limitation, the heights extracted from the drone images were subjected to a correction process based on the heights sampled in the QFI plots. For this purpose, correction factors by size class R_j, Equation (1), were first obtained, and the drone heights were then corrected using Equation (2). The methodological steps for obtaining the drone heights are presented in Figure 2.

$$R_j = \frac{\sum_{i=1}^{n_j} h_{oi}}{\sum_{i=1}^{n_j} h_{ei}} \quad (1)$$

$$h_{Corr} = h_{ei}\, R_j \quad (2)$$

In where: R_j is the ratio of class j; h_{oi} is the height obtained from the QFI in class j; and h_{ei} is the height extracted from the drone images in class j. h_{Corr} is the corrected height extracted from the drone images.

Figure 2 – Data processing steps for obtaining the drone heights



Source: Authors (2024)

2.5 Uniformity indices

In this study, the following uniformity indices were calculated: the cumulative percentage of the variable of interest in the smallest 50% of planted trees (PV_{50}) and its variations, such as PV_{25} and PV_{75}; the coefficient of variation ($CV_{\%}$); and the Gini coefficient (G).

PV_{50} is an index that treats planting gaps as part of the concept of stand uniformity (Hakamada *et al.,* 2015a). Thus, with the dataset of heights sorted in ascending order, the variations of PV_{50} were calculated, which was named PH_{50} because it uses the height variable in its calculation, according to equations (3), (4), and (5), respectively.

$$PH25_j = \frac{\sum_{i=1}^{\frac{n_j}{4}} x_i}{\sum_{i=1}^{n_j} x_i} \quad (3)$$

$$PH50_j = \frac{\sum_{i=1}^{\frac{n_j}{2}} x_i}{\sum_{i=1}^{n_j} x_i} \quad (4)$$

$$PH75_j = \frac{\sum_{i=1}^{\frac{3n_j}{4}} x_i}{\sum_{i=1}^{n_j} x_i} \quad (5)$$

In where: PH_{25j}, PH_{50j}, and PH_{75j} are the cumulative percentages of the height of the smallest 25%, 50%, and 75% of planted trees in plot j, respectively; is the value of the variable of interest; n_j = number of planted trees sorted in ascending order in plot j.

In calculating the coefficient of variation ($CV_{\%}$) and the Gini coefficient (G), all measurements in the dataset were used, except for planting gaps. $CV_{\%}$ was obtained using Equation (6), and G, Equation (7), was calculated using the statistical package *ineq* (Zeileis and Kleiber, 2014) in the R software.

$$CV_{\%j} = \frac{s_j}{\bar{x}_j} 100 \quad (6)$$

$$G_j = 1 - \sum_{i=0}^{n-1} (A_{j_{i+1}} - A_{j_i}) (D_{j_{i+1}} - D_{j_i}) \quad (8)$$

In where: G_j is the Gini coefficient of the dendrometric variable of interest in plot j; A_j = cumulative proportion of the number of trees in plot j; D_{ij} = cumulative proportion of the value of the dendrometric variable of interest in plot j; $CV_{\%j}$ is the coefficient of variation of the dendrometric variable of interest in plot j; is the standard deviation of the dendrometric variable of interest in plot j; is the mean of the dendrometric variable of interest in plot j.

2.6 Evaluation of the uniformity indices

The uniformity indices were compared (QFI × drone) by means of an X^2 test. For this purpose, the uniformity indices calculated from drone Sampling 1 and from the QFI plots were divided into three classes according to their range to determine the frequency of plots in each class.

Next, the plot frequencies for both evaluation methods (QFO and drone) were arranged in a table according to the source of variation and the classification of the indices. Given that the sources of variation (QFI and drone) and the classes are qualitative variables, the association between them was evaluated by means of the X^2 test, Equation (8):

$$X^2 = \frac{\Sigma (F_o - F_e)^2}{F_e} \quad (1)$$

In where: X^2 is the chi-square test statistic; F_o is the observed frequency; and F_e is the expected frequency.

To evaluate the association between the uniformity indices (QFI × drone), the following hypotheses were tested:

H_0: $F_e = F_o$; the plot frequency of the drone is not different from the plot frequency of the QFI when *p*-value ≥ α; thus, the methods do not differ statistically at the 5% significance level (α = 0.05).

H_1: $F_e \neq F_o$; the plot frequency of the drone differs from the plot frequency of the QFI when *p*-value < α; thus, the methods are statistically different at the 5% significance level (α = 0.05).

2.7 Spatial mapping of the uniformity indices

Based on Samplings 1 and 2, totaling 30 plots for each plantation, the uniformity indices $CV_{\%}$, G, PV_{25}, PV_{50}, and PV_{75} were calculated for these plots. For comparison purposes, the indices were standardized according to the expressions described in Table 2. Thus, the indices came to lie on a scale from 0 to 1, with values closer to 1 indicating greater uniformity. The standardized uniformity indices were imported into the *ArcGIS* software, where the uniformity surface of each index for each plantation was generated using the *Inverse Distance Weighting* (IDW) tool.

Table 2 – Standardization of the uniformity indices

UI	Lower Limit	Upper Limit	Standardization
PH_{25}	0	0.25	$x_{ip} = 4\ x_i$
PH_{50}	0	0.50	$x_{ip} = 2\ x_i$
PH_{75}	0	0.75	$x_{ip} = 4/3\ x_i$
CV%	∞	0	$x_{ip} = 4\ x_i$
G	1	0	$x_{ip} = x_{max} - x_i\ /\ x_{max}$

Source: Authors (2024)

In where: UI is the uniformity index; Upper limit corresponds to the value of maximum uniformity of the index, and Lower limit is the value corresponding to the absence of uniformity; x_{ip} is the standardized index value (0 to 1) in the plot; $x_{máx}$ is the maximum index value obtained in the plots of the plantations; and x_i is the index value obtained in the plot.

3 RESULTS

The uniformity indices were calculated based on the QFI heights (h) and on the corrected heights (h_{corr}) obtained from the drone. The descriptive statistics of these indices are shown in Table 3. There was no significant difference between the methods (QFI × drone) for any of the indices PH_{25}, PH_{50}, PH_{75}, $CV_{\%}$, and G (Table 4). Therefore, the uniformity indices calculated with the heights extracted from the drone images can be used, since they do not differ statistically from the indices calculated with the heights obtained in the field.

Table 3 – Descriptive statistics of the uniformity indices calculated from the height variable obtained from the QFI and from the drone in Eucalyptus sp. plantations located in the municipality of Ortigueira, east-central Paraná

Plantation	Index	QFI				Drone			
		Min.	Mean	Max	SD	Min.	Mean	Max.	SD
A	PH_{25}	0.13	0.21	0.23	0.03	0.01	0.11	0.23	0.08
	PH_{50}	0.41	0.45	0.48	0.02	0.17	0.33	0.47	0.10
	PH_{75}	0.68	0.71	0.74	0.02	0.41	0.60	0.72	0.09
	$CV_{\%}$	4.05	7.75	12.50	2.35	6.09	30.22	62.02	18.74
	G	0.02	0.04	0.06	0.01	0.03	0.16	0.34	0.10
B	PH_{25}	0.00	0.16	0.23	0.07	0.00	0.15	0.22	0.07
	PH_{50}	0.30	0.43	0.48	0.05	0.27	0.40	0.45	0.06
	PH_{75}	0.63	0.69	0.73	0.03	0.56	0.66	0.71	0.04
	$CV_{\%}$	5.43	8.28	14.46	2.78	8.19	16.66	43.13	9.51
	G	0.03	0.05	0.08	0.02	0.05	0.09	0.25	0.05

Source: Authors (2024)

In where: Min. is the minimum value; Mean is the mean value; Max. is the maximum value; SD is the standard deviation.

After calculating the uniformity indices for the higher sampling intensity (Sampling 1 + Sampling 2), the values were standardized to lie within the same interval of 0 to 1, with values closer to 1 corresponding to maximum plantation uniformity (Table 5).

Table 4 – Results of the X^2 test using the plot frequencies in the classes of the uniformity indices of Eucalyptus sp. plantations located in the municipality of Ortigueira, east-central Paraná

QFI × Drone	p-value	Test
PH_{25} × PH_{25}	0.3055	NS 5%
PH_{50} × PH_{50}	0.7236	NS 5%
PH_{75} × PH_{75}	0.1023	NS 5%
$CV_{\%}$ × $CV_{\%}$	0.1202	NS 5%
G × G	0.5524	NS 5%

Source: Authors (2024)

In where: NS is not significant.

Table 5 – Descriptive statistics of the uniformity indices calculated from the height extracted from the drone images, before and after standardization, in Eucalyptus sp. plantations located in the municipality of Ortigueira, east-central Paraná

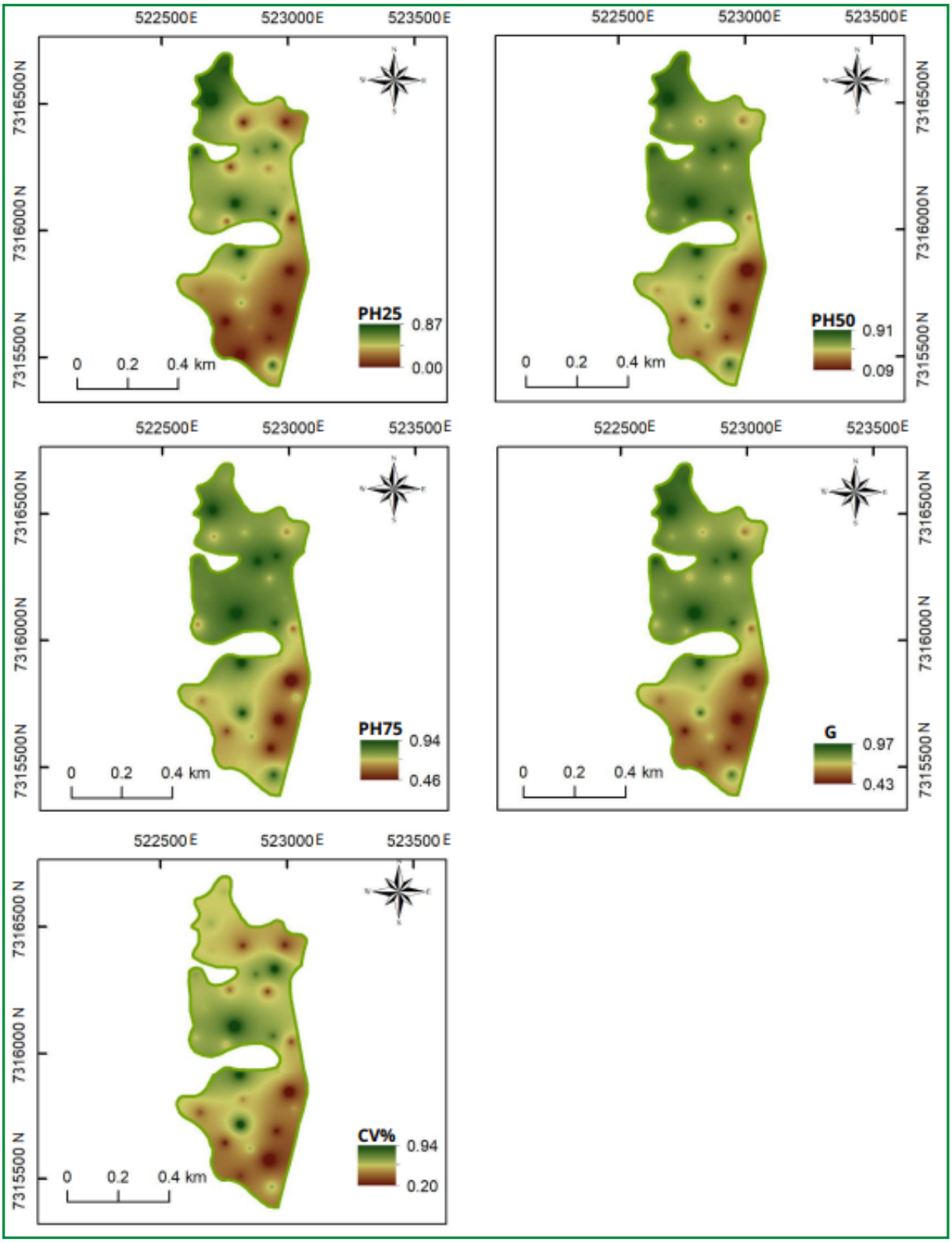
Plantation	Index	Index				Standardized index			
		Min.	Mean	Max.	SD	Min.	Mean	Max.	SD
A	PH_{25}	0.00	0.10	0.22	0.07	0.00	0.39	0.88	0.28
	PH_{50}	0.04	0.30	0.46	0.01	0.08	0.60	0.91	0.20
	PH_{75}	0.34	0.56	0.70	0.09	0.45	0.75	0.94	0.12
	$CV_{\%}$	5.62	45.06	77.36	18.11	0.20	0.53	0.94	0.19
	G	0.03	0.28	0.57	0.13	0.43	0.72	0.97	0.13
B	PH_{25}	0.00	0.12	0.21	0.07	0.00	0.48	0.85	0.29
	PH_{50}	0.06	0.35	0.44	0.10	0.12	0.70	0.89	0.20
	PH_{75}	0.26	0.63	0.71	0.09	0.35	0.84	0.94	0.12
	$CV_{\%}$	8.53	23.02	96.73	18.46	0.00	0.76	0.91	0.19
	G	0.05	0.20	0.61	0.13	0.39	0.80	0.95	0.13

Source: Authors (2024)

In where: Min. is the minimum value; Mean is the mean value; Max. is the maximum value; SD is the standard deviation.

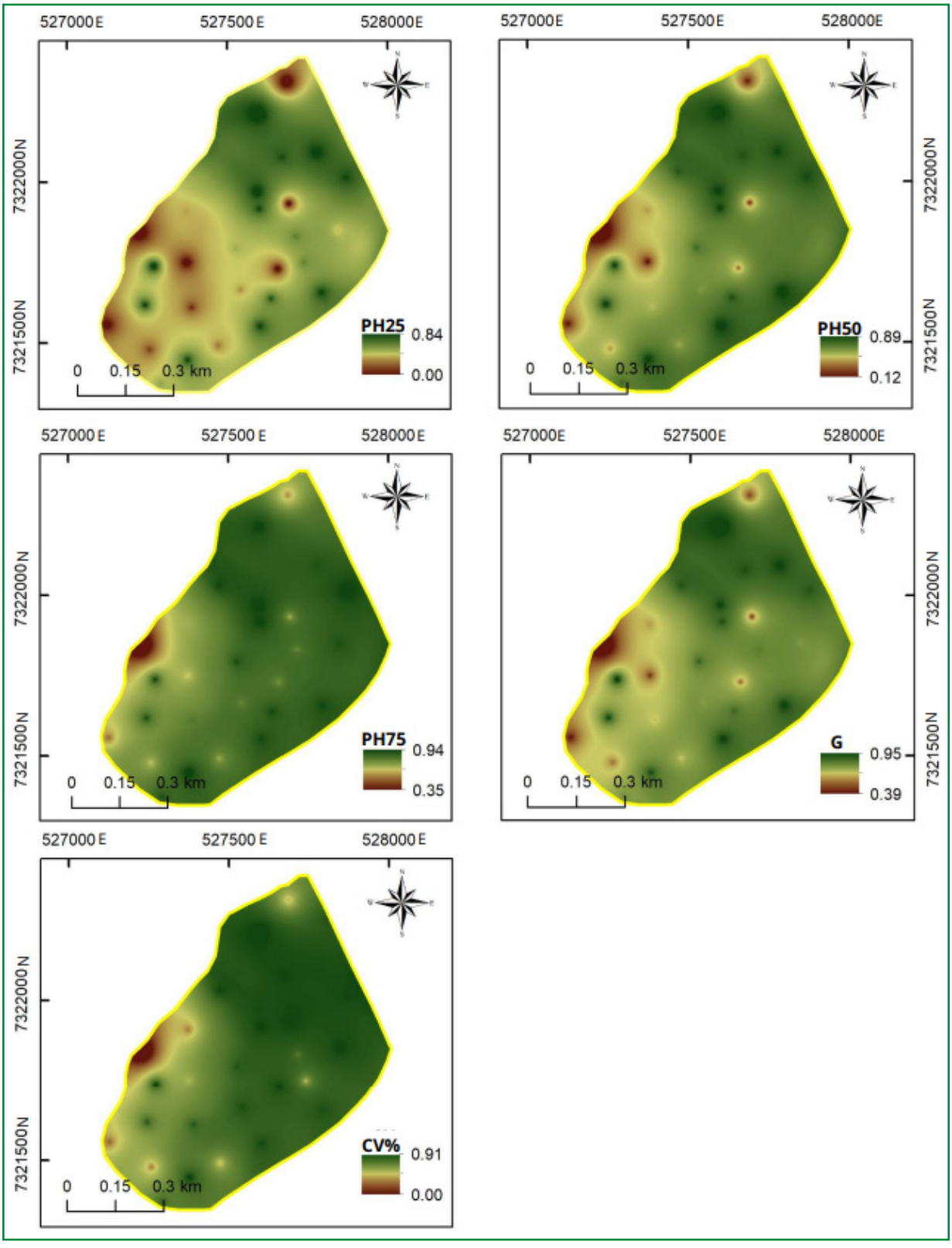
In Figures 3 and 4, the areas shown in green correspond to the regions of maximum plantation uniformity, whereas the areas shown in red correspond to regions of lower uniformity according to the index.

Figure 3 – Spatial mapping of the uniformity indices obtained for plantation "A" located in the municipality of Ortigueira, east-central Paraná



Source: Authors (2024)

Figure 4 – Spatial mapping of the uniformity indices obtained for plantation "A" located in the municipality of Ortigueira, east-central Paraná



Source: Authors (2024)

4 DISCUSSIONS

Obtaining accurate information on plantations is essential for the proper characterization and assessment of forest stands. Traditionally, such data are obtained through forest inventory, which allows the measurement of dendrometric variables such as total height, stem diameter, and crown diameter. From these variables, it is also possible to estimate attributes such as the volume and structural uniformity of plantations. However, the operational costs and the time required to carry out field surveys can limit the sampling intensity and, in certain situations, make it unfeasible to obtain this information adequately (Campos and Leite, 2006).

In this context, remotely piloted aircraft systems have stood out as complementary tools for the remote acquisition of dendrometric information (Silva et al., 2015). Among their main advantages are flexibility in data acquisition and the capture of images with high spatial and temporal resolution at relatively low cost (Lima Neto et al., 2012; Banu et al., 2016). Thus, technological advances have broadened the application of remote sensing as a tool to support forest inventory, contributing to faster, more comprehensive, and spatially detailed surveys.

The relevance of such surveys becomes even more evident given the relationship between structural uniformity in the early stages of development and the final productivity of stands. Stape et al. (2010) observed, in clonal *Eucalyptus* plantations, a positive relationship between tree uniformity at two years of age and stand productivity at six years. Similarly, Luu et al. (2013), evaluating a young *Eucalyptus* plantation in Espírito Santo, found that the reduction in the potential growth of trees ranged from approximately 2% at highly uniform sites to almost 10% at sites with low uniformity, resulting in an average reduction of 4.3% in the potential growth of the stand.

These results demonstrate that silvicultural practices aimed at promoting greater uniformity in tree size can contribute to gains of 5% to 15% in stand-level production, especially when they favor the balanced availability of resources and the

adequate development of individual trees (Luu et al., 2013). Conversely, increased structural heterogeneity can reduce production by 10% to 18% (Stape et al., 2010). This heterogeneity can become established as early as the initial stages of the plantation, when a partial or spatially uneven supply of resources intensifies differences in growth and competition among individuals (Stape et al., 2010). In this regard, early monitoring of uniformity, including through drone-derived data, can help identify heterogeneous areas and enable the timely targeting of silvicultural interventions.

In this study, the evaluation of the use of drones to obtain uniformity indices in young *Eucalyptus* plantations showed that the results derived from the images did not differ statistically from those obtained by the Quality Forest Inventory, QFI (Table 4). These results demonstrate the potential of drone imagery as a complementary data source for mapping the structural uniformity of forest plantations, especially because of the quality of the information obtained and the relatively low operating cost (Almeida et al., 2021).

A similar result was reported by Hentz et al. (2018), who estimated the uniformity of *Eucalyptus* spp. and *Pinus taeda* plantations based on heights derived from drone images. Although this approach may have limitations, the authors noted that these can be minimized by applying appropriate processing techniques. In addition, they found that the estimates derived from the images were close to the field measurements, confirming the potential of this technology for forest monitoring.

In the present study, the structural uniformity of the plantations was assessed using the indices PH_{25}, PH_{50}, and PH_{75}, $CV_{\%}$, and G. The use of different metrics is in agreement with McGown et al. (2016), who recommended the use of $CV_{\%}$ and G for assessing young plantations, as well as the joint analysis of more than one uniformity measure, in order to provide a more comprehensive characterization of stand structure.

In its original form, lower values of the Gini coefficient indicate greater uniformity, whereas higher values represent greater inequality among the individuals in the plantation. When the index is transformed into 1-G, as in the standardization

adopted in this study, this interpretation is reversed, so that values closer to 1 come to represent greater structural uniformity (Soares et al., 2016; Soares et al., 2017; Sun et al., 2018). However, Bendel et al. (1989) recommended caution in applying G to datasets with a high occurrence of null or near-zero values, owing to the sensitivity of the index to the mean of the distribution. Under these conditions, which are common in plantations with high mortality or a high incidence of gaps, the index may yield a distorted interpretation of uniformity.

Little et al. (2002) observed a high correlation between $CV_{\%}$ and G in the assessment of height and diameter at breast height (DBH). However, $CV_{\%}$ is sensitive to the magnitude of the mean and, when calculated only from the existing trees, does not directly incorporate planting gaps into the determination of the variance and standard deviation. For this reason, its isolated use may not adequately represent the distribution of all individuals originally planned for the plot. Despite this limitation, $CV_{\%}$ can contribute to a joint assessment with G, whose limits, defined between 0 and 1, facilitate comparison and the establishment of uniformity standards among plantations (Bendel et al., 1989).

The results showed that, among the indices PH_{25}, PH_{50}, and PH_{75}, PH_{25} had the lowest uniformity values. This behavior may be related to the inclusion of planting gaps, represented by null values, and to the small number of individuals that make up the lowest 25% of the distribution. Consequently, the occurrence of a few gaps or trees with reduced growth can have a strong influence on the index, resulting in a potentially distorted interpretation of plantation uniformity. According to Hakamada (2012), PH_{50} represents the proportion of the variable accumulated by the smallest 50% of trees relative to the plot total, dividing the distribution into the smallest 50% and the largest 50% of trees. This characteristic allows a more comprehensive representation of stand structure. In this study, the indices PH_{50} and PH_{75} showed similar patterns of spatial uniformity.

In the comparison between plantations "A" and "B" (Table 5), all indices evaluated indicated greater structural uniformity in plantation "B". Considering the mean standardized values, plantation "B" showed higher values for PH_{25} (0.48), PH_{50} (0.70), PH_{75} (0.84), G (0.80), and $CV_{\%}$ (0.76), compared with plantation "A", whose values were 0.39, 0.60, 0.75, 0.72, and 0.53, respectively.

The higher values of PH_{25}, PH_{50}, and PH_{75} observed in plantation "B" indicate that the trees in the smaller height classes accounted for a larger proportion of the total height of the stand. This behavior suggests less discrepancy between smaller and larger trees. Complementarily, the standardized values of G and $CV_{\%}$ indicate lower inequality and lower relative variability of heights in plantation "B".

The greater uniformity of plantation "B" suggests that its trees showed more homogeneous early development, whereas plantation "A" showed greater differentiation among individuals. This heterogeneity may be associated with variations in edaphic conditions, resource availability, the quality of the silvicultural operations, seedling survival, or the response of the genetic material to local conditions. However, since these factors were not individually assessed in this study, it is not possible to attribute the observed difference to a specific cause. Nevertheless, the results demonstrate that the joint analysis of the indices makes it possible to identify structural differences among plantations and to locate areas of greater heterogeneity, providing support for targeting field assessments and silvicultural management practices.

5 CONCLUSIONS

The analyses carried out led to the conclusion that drone imagery made it possible to estimate the structural uniformity of young *Eucalyptus* plantations, with no differences relative to the results from the conventional forest inventory. The PH_{25} index should be interpreted with caution in plantations with high mortality, because the presence of gaps can result in distorted estimates of uniformity. The joint analysis of the PH_{50}, PH_{75}, $CV_{\%}$, and G indices provided a more comprehensive assessment of the structure of the plantations than the use of a single measure alone. It is therefore recommended that the assessment of uniformity be accompanied by survival studies, in order to adequately account for the influence of mortality and planting gaps on the indices.

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