RGSA – Revista de Gestão Social e Ambiental
ISSN: 1981-982X
Submission date: 5/1/2025
Acceptance date: 7/1/2025
DOI: https://doi.org/10.24857/rgsa.v19n8-025
Organization: Interinstitutional Scientific Committee
Chief Editor: Ana Carolina Messias de Souza Ferreira da Costa
Assessment: Double Blind Review pelo SEER/OJS

# METHODOLOGY FOR USING GEOREFERENCED DIGITAL MAPS TO MANAGE THE CANOPY HEIGHT OF ELEPHANT GRASS GENOTYPES

Walter Coelho Pereira de Magalhães Jr. [1]
Ricardo Guimarães Andrade [2]
Marcos Cicarini Hott [3]
Cristiano Amancio Vieira Borges [4]
Francisco Jose da Silva Ledo [5]
Domingos Savio Campos Paciullo [6]
Carlos Augusto de Miranda Gomide [7]
Wadson Sebastião Duarte Rocha [8]
Pérsio Sandir D'Oliveira [9]
Matheus Bertolino Motta [10]

**ABSTRACT**

**Objective:** The objective of this study was to develop a methodology to accurately report the average canopy height formed by elephant grass genotypes, without carrying out numerous field evaluations.

**Theoretical Framework:** The research is based on the concepts of digital agriculture and photogrammetry for the potential use of remotely piloted aircraft (RPAs), which are low-altitude remote sensing platforms. These platforms, equipped with several high-precision sensors, can be used to obtain diverse information about elephant grass.

**Method:** The methodology adopted for this research involves aerial mapping of elephant grass patches in the José Henrique Bruschi experimental area, Coronel Pachecho, MG – for data collection using a PRA. Photogrammetric processing of the aerial images, statistical analysis of the data and the maps generated were performed.

**Results and Discussion:** According to the results obtained, it is clear that the height of elephant grass can be estimated well using precision GPS and ARP images. The correlation of 0.9 observed between the average heights obtained demonstrates that the methodology using ARP and precision GPS has the potential to replace or complement, efficiently and accurately, measurements using a graduated ruler.

[1] Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Juiz de Fora, Minas Gerais, Brasil.
E-mail: walter.magalhaes@embrapa.br Orcid: https://orcid.org/0000-0003-2765-2706
[2] Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Juiz de Fora, Minas Gerais, Brasil.
E-mail: ricardo.andrade@embrapa.br Orcid: https://orcid.org/0000-0002-8595-5038
[3] Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Juiz de Fora, Minas Gerais, Brasil.
E-mail: marcos.hott@embrapa.br Orcid: https://orcid.org/0000-0003-0653-5877
[4] Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Juiz de Fora, Minas Gerais, Brasil.
E-mail: cristiano.borges@embrapa.br Orcid: https://orcid.org/0000-0001-8120-3288
[5] Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Juiz de Fora, Minas Gerais, Brasil.
E-mail: francisco.ledo@embrapa.br Orcid: https://orcid.org/0000-0001-6378-8905
[6] Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Juiz de Fora, Minas Gerais, Brasil.
E-mail: domingos.paciullo@embrapa.br Orcid: https://orcid.org/0000-0002-1016-328X
[7] Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Juiz de Fora, Minas Gerais, Brasil.
E-mail: carlos.gomide@embrapa.br Orcid: https://orcid.org/0000-0002-0537-7021
[8] Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Juiz de Fora, Minas Gerais, Brasil.
E-mail: wadson.rocha@embrapa.br Orcid: https://orcid.org/0000-0003-3024-3487
[9] Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Juiz de Fora, Minas Gerais, Brasil.
E-mail: persio.oliveira@embrapa.br Orcid: https://orcid.org/0000-0002-4007-4536
[10] Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora, Minas Gerais, Brasil.
E-mail: matheus.bertolino.motta@gmail.com Orcid: https://orcid.org/0000-0003-0013-0318

**Research Implications:** The practical and theoretical implications of this research are discussed, providing insights into how the results can be applied in the field of PRA use. Their use in agricultural systems is increasingly important in crop monitoring, being relevant to the environment and agriculture.

**Originality/Value:** This study contributes to the literature by presenting a methodological proposal to accurately report the average canopy height of elephant grass genotypes. The relevance and value of this research are evidenced by showing that the proposed methodology was more representative than the average height obtained by the field method.

**Keywords:** Elephant Grass, Canopy Height, Digital Agriculture, Drone, RPA.

## METODOLOGIA PARA UTILIZAÇÃO DE MAPAS DIGITAIS GEORREFERENCIADOS NO MANEJO DA ALTURA DO DOSSEL DE GENÓTIPOS DE CAPIM-ELEFANTE

## RESUMO

**Objetivo:** O objetivo deste estudo foi desenvolver uma metodologia para informar com precisão a altura média do dossel formado por genótipos de capim-elefante, sem a realização de numerosas avaliações de campo.

**Referencial Teórico:** A pesquisa se fundamenta conjuntamente nos conceitos da agricultura digital e fotogrametria para o uso potencial de uma aeronave remotamente pilotada (ARP), que são plataformas de sensoriamento remoto de baixa altitude. Estas plataformas, equipadas com diversos sensores de alta precisão, podem ser utilizadas para obter diversas informações acerca do capim-elefante.

**Método:** A metodologia adotada para esta pesquisa compreende o mapeamento aéreo das pacelas de capim-elefante, na área exeprimental José Henrique Bruschi, Coronel Pachecho, MG – para coleta de dados por meio de uma ARP. Foram realizados o processamento fotogramétrico das imagens aéreas, análise estatística dos dados e dos mapas gerados.

**Resultados e Discussão:** De acordo com os resultados obtidos é evidente a boa estimativa da altura do capim-elefante com uso de GPS de precisão e imagens ARP. A correlação de 0,9 observada entre as alturas médias obtidas, demonstra que a metodologia com uso de ARP e GPS de precisão tem potencial para substituir ou complementar, de forma eficiente e precisa, as medições por meio de régua graduada.

**Implicações da Pesquisa:** As implicações práticas e teóricas desta pesquisa são discutidas fornecendo insights sobre como os resultados podem ser aplicados no campo do uso de ARPs. O uso destas nos sistemas agrícolas são cada vez mais importantes no monitoramento das lavouras, sendo relevantes ao meio ambiente e à agricultura.

**Originalidade/Valor:** Este estudo contribui para a literatura ao apresentar uma proposta metodológica para informar, com precisão, a altura média do dossel de genótipos de capim-elefante. A relevância e o valor desta pesquisa são evidenciados por mostrar que a metodologia proposta mostrou mais representativa que a altura média obtida pelo método de campo.

**Palavras-chave:** Capim-Elefante, Altura do Dossel, Agricultura Digital, Drone, ARP.

## METODOLOGÍA PARA EL USO DE MAPAS DIGITALES GEORREFERENCIADOS PARA LA GESTIÓN DE LA ALTURA DEL DOSEL DE GENOTIPOS DE PASTO ELEFANTE

## RESUMEN

**Objetivo:** El objetivo de este estudio fue desarrollar una metodología para reportar con precisión la altura promedio del dosel de los genotipos de pasto elefante, sin realizar numerosas evaluaciones de campo.

**Marco teórico:** La investigación se basa en los conceptos de agricultura digital y fotogrametría para el uso potencial de aeronaves pilotadas remotamente (RPA), que son plataformas de teledetección de baja altitud. Estas plataformas, equipadas con varios sensores de alta precisión, permiten obtener información diversa sobre el pasto elefante.

**Método:** La metodología adoptada para esta investigación consiste en el mapeo aéreo de parches de pasto elefante en el área experimental José Henrique Bruschi, Coronel Pachecho, MG, para la recopilación de datos mediante un PRA. Se realizó el procesamiento fotogramétrico de las imágenes aéreas, el análisis estadístico de los datos y los mapas generados.

**Resultados y Discusión:** De acuerdo con los resultados obtenidos, es evidente que la altura del pasto elefante puede estimarse adecuadamente utilizando imágenes de GPS y ARP de precisión. La correlación de 0,9 observada entre las alturas promedio obtenidas demuestra que la metodología que utiliza ARP y GPS de precisión tiene el potencial de reemplazar o complementar, de forma eficiente y precisa, las mediciones con una regla graduada.

**Implicaciones de la Investigación:** Se discuten las implicaciones prácticas y teóricas de esta investigación, proporcionando perspectivas sobre cómo los resultados pueden aplicarse en el campo del uso de PRA. Su uso en sistemas agrícolas es cada vez más importante para el monitoreo de cultivos, siendo relevante para el medio ambiente y la agricultura.

**Originalidad/Valor:** Este estudio contribuye a la literatura al presentar una propuesta metodológica para reportar con precisión la altura promedio del dosel de los genotipos de pasto elefante. La relevancia y el valor de esta investigación se evidencian al demostrar que la metodología propuesta fue más representativa que la altura promedio obtenida por el método de campo.

**Palabras clave:** Pasto Elefante, Altura del Dosel, Agricultura Digital, Drones, RPA.



## 1 INTRODUCTION

Elephant grass (*Pennisetum purpureum Schum.*) is a forage with high production potential and good nutritional value at a certain stage of plant development, being widely used in cattle feed, either in the form of weeding, grazing or silage (Coser *et al.*, 2002). In field evaluations, different methods can be used to measure the average forage height from sampling points. However, conventional direct sampling techniques can be laborious and present large sampling errors. In the case of elephant grass, estimates may be even less accurate due to its erect growth characteristics (Coser *et al.*, 2002).

It should be noted that while the number of sampling points can vary considerably in the methods of evaluation in the field, there are already techniques based on remote sensing that allow the realisation of these measurements. These, made from the digital images generated by remotely piloted aircraft (RPA), make it possible to measure and analyse objects on the surface through aerial photographs. In this case, digital surface and terrain models of very high resolution (2 cm pixel) are generated. These digital models make it possible to estimate the height of the forages or the area of the vegetative canopy of interest in a much more precise manner.

In the scope of the present study, digital agriculture represents the set of digital technologies used, interconnected by state-of-the-art equipment and software that contribute to obtaining data and information in order to optimise the management of elephant grass genotypes, either for the purpose of genetic improvement or for pasture production.

In view of the above, the objective was to develop a methodology in digital media, to more accurately inform the average height of the canopy formed by different elephant grass genotypes, discarding the need to carry out a sequence of numerous evaluations in the field, throughout the growing season, using a graduated ruler (Rodrigues *et al.*, 2023).

## 2 THEORETICAL FRAMEWORK

The research is based on the concepts inherent in digital agriculture (Ribeiro *et al.*, 2024; Massruhá *et al.*, 2023; Torres-Sánchez *et al.*, 2021) in association *with the photogrammetry technique (Perereira et al.*, 2024; Aasen & Bareth, 2021) to effectively enjoy the potential offered by the aircraft's cutting-edge technologies.

Considered as a low-altitude remote sensing platform, a Remotely Piloted Aircraft (RPA), drone or Unmanned Aerial Vehicle (UAV) can carry cameras with different types of high-precision sensors (Tsouros *et al.*, 2021), which can be selected according to the desired estimates, related to the structural and productive characteristics of elephant grass genotypes.

Multispectral sensors (Mendes et al., 2024) can accurately identify areas of greater or lesser plant vigour (Andrade et al., 2021; Hott et al., 2019), guide application at varying rates of agrochemicals and water, estimate the percentage of soil cover (Andrade et al., 2021) and biomass production achieved by a cultivar (Ferreira et al., 2022; Andrade et al., 2022a,b; Bendig et al., 2020), accurately identifying and accounting for areas affected by disease or disease pests (Moraes et al., 2024; Sujatha et al., 2022). Although they can also be used in these estimates, high-precision RGB sensors are usually used to identify planting failures, stand or number of plants per unit area and in the measurements of area, extension, perimeter, volume and height of plants (Rocha *et al.*, 2024; Santos *et al.*, 2024; Ota *et al.*, 2021).

## 3 METHODOLOGY

### 3.1 EXPERIMENTAL AREA AND EVALUATION PERIOD

The experiment was carried out at the José Henrique Bruschi Experimental Field, belonging to Embrapa Gado de Leite, in the municipality of Coronel Pacheco-MG, between February and May 2022, and the measurements coincided with the samplings of 15/02 and 17/05/2022. The UTM coordinates of the site are: 23k 679911.00 m E; 7614932.00 m S. Five elephant grass genotypes were evaluated, managed with two residue heights (25 and 45 cm), arranged in three blocks, with ten plots of 4 x 3m, observing the distance of 1m between plots and 2m between the blocks, in a total area of 19 x 19 m. The genotypes 2111, 2035, 1810 and 2022, belonging to the Elephant Grass Genetic Improvement Programme for Embrapa Forage Use, besides the BRS Kurumi cultivar, were evaluated.

Figure 1 illustrates the experimental planting area of elephant grass genotypes with identification of elephant grass plots (P01 to P30), blocks (B01 to B03) and the distribution of genotypes 2111, BRS Kurumi, 2035, 1810 and 2022 belonging to PMGCE.

**Figure 1**

*Experimental area used.*


### 3.2 MAIN FEATURES OF THE PRA USED

The aerial mapping or aerial survey of the elephant grass plots in the experimental area was carried out by a professional quadcopter-type rotary wing ARP, model DJI Inspire 1 Pro, which allows the exchange of cameras equipped with RGB, multispectral or thermal sensors. The stabilisation of flights and the on-board camera, offered by this type of aircraft, is of fundamental importance to increase the accuracy of the estimates to be made through aerial photographs. To develop this work, a multispectral camera, Sentera Multispectral Double 4K Gimbaled model, was used, which made it possible to image the genotypes in the spectral bands of red, green, blue, near infrared (NIR) and red edge (red edge).

Through the RGB bands (Red-Green-Blue), a set of aerial images was generated containing the experimental area of the elephant grass plots, which was used as a basis to estimate the canopy height by digital means. The *technical quality and the spatial resolution of the generated images are primordial factors for obtaining accurate estimates, which are respectively related to the quality of the set of lenses and the size of the pixels of the images (Silva et al.*, 2023; Oliveira *et al.*, 2023; Ribeiro *et al.*, 2024).

## 3.3 FLIGHT PLANNING

In order to maintain consistency between canopy height evaluations, performed by the field method with graduated rulers and the proposed methodology through aerial images, flights with the ARP used were programmed to be performed on the same day or on dates close to the evaluations performed by the field method, avoiding that a differentiated growth of plants could significantly affect the comparison between the methods. The sun's position is another important factor to consider, because of the size of the shadows it provides. The shadows directly interfere with the accuracy of the estimates. For this reason, flights have always been scheduled around noon, at which time the shadows are usually lower.

Flight planning with the aircraft used was carried out in a standardised way by the FieldAgent TM software owned by the American company Sentera, adopting the parameterisation presented in Table 1.

**Table 1**

*Parameterisation of flight planning.*

| Parameter | Definition | Parameter | Definition |
|---|---|---|---|
| Coordinate system | UTM | Datum | SIRGAS 2000 |
| Camera | Double 4K | GSD | 0.5 in/px (1.59 cm²) |
| Altitude | 140 ft (42.6 m) | Photos | 61 |
| Speed | 10 mph (16 km/h) | Duration | 6 min |
| Overlap | 75% | Aircraft Heading | Nadir |

The Universal Transverse Mercator – UTM coordinate system (Pereira & Martins, 2021) was adopted because it uses the metric scale as the unit of measurement. In accordance with the location of the experimental area, the SIRGAS 2000 datum (IBGE, 2005) was used because it was more precise and indicated for South America. GSD stands for *Ground Sample Distance* or ground sample at a distance, and corresponds to the pixel size of aerial images, determined primarily by the height of flight. Although there are lower and upper limits for determining the aircraft's flight height, in principle, the lower the flight height, the lower the GSD and the greater the accuracy of the metrics performed by digital means for estimates of area, extension, perimeter, volume and height. Ground objects smaller than the GSD obtained cannot be observed or measured by aerial photographs. The Overlap corresponds to the percentage of frontal and lateral overlap of the photos and the Nadir positioning informs that the camera of the aircraft must be inclined orthogonally to the ground, in order to shoot the photos during the execution of the flight. More information on parameterisation and flight planning with remotely piloted aircraft can be observed in (Martins *et al.*, 2024; Rocha *et al.*, 2024; Santos *et al.*, 2024)

## 3.4 DEMARCATION OF GROUND SUPPORT POINTS

The aircraft used has a Global Navigation Satellite System (GNSS), connected to the GPS, BeiDou, Glonass and Galileo constellations, which is used to correct the positioning of the aircraft during flight and record the coordinates of each pixel of the aerial images, in accordance with the format of the configured coordinate system. Although suitable to conduct the aircraft throughout the planned flight, this navigation system is not suitable for measuring objects on the ground, because it presents positioning errors or noises, which can be corrected by using demarcation of ground support points and high-precision GPS equipment.

Ground support points are markings made at strategic locations in the area to be mapped by the aircraft, which serve as a positional reference so that a high-precision geodetic GNSS can be used to correct the pixel coordinates of the images, informed by the aircraft's navigation system. Technically, ground support points are subdivided into control and verification points (Madeira *et al.*, 2020), which are, respectively, used to correct the pixel coordinates of the images in the x, y and z directions, and to determine the positional error in these directions after correction. However, by maximising the positional accuracy (Almeida & Silva, 2023) of the objects contained in the images, the demarcation of the ground support points with high-precision GNSS also contributes to improve the geometric accuracy (Pereira & Oliveira, 2023) of the georeferenced digital maps, making it possible to achieve a better definition of the objects present in these maps and to obtain more reliable measurements at the planimetric and altimetric level.

A high-precision geodetic GNSS, Real Time Kinematic (RTK), GTRi model with 10mm+1 ppm precision (https://www.techgeo.com.br), was used to correct the planimetric and altimetric coordinates of the aerial images obtained in the flight of May 17-2022. The unit in ppm means that the error increases by 1mm for every 1km of aircraft movement. Figure 2 illustrates the landmark locations of the support points in the experimental area of the elephant grass plots, subdivided into control (PC-n) and verification (PV-n) points, informing the location of the RTK base.

**Figure 2**

*Identification of the landmarks of the support points in the experimental area of the plots of elephant grass, subdivided into control points (PC-n) and verification (PV-n), informing the positioning of the RTK base.*

## 3.5 PHOTOGRAMMETRIC PROCESSING OF AERIAL IMAGES

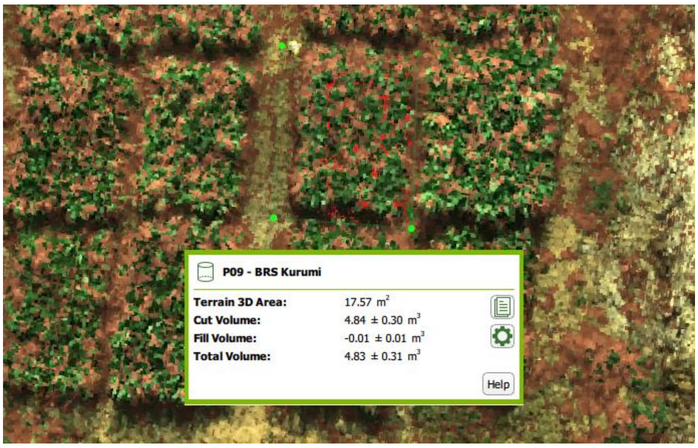
Photogrammetric processing (Lima *et al.*, 2024) of the aerial images of elephant grass genotypes was performed by the Pix4D Mapper Pro software v. 4.1.25, (https://www.pix4d.com/). The maps called ortomosaic, dense point cloud and digital surface model (DSM) were used to estimate the canopy height of elephant grass genotypes in the plots of the experimental area.

Through the orthomosaic, one can accurately estimate the dimensions of different areas, extensions and perimeters located in the area of interest (Ferreira *et al.*, 2024; Santos *et al.*, 2024). The dense point cloud and the DSM are digital maps generated in 3D format, which have the ability to inform the height and volume of objects located on the surface, making it possible to generate altimetric profiles (Jia *et al.*, 2020; Walter *et al.*, 2021; Sosa *et al.*, 2021). It is noteworthy that in the photogrammetry technique, the measurements made through the 3D maps used, should consider the soil around the canopy as an altimetric reference.

Figure 3 illustrates the technique of estimating the average height of the canopy formed in plot P09 with the BRS Kurumi genotype, through the dense point cloud generated by the Pix4D Mapper Pro software v. 4.1.25, considering the volume reached by the genotype and having the soil around the plot as an altimetric reference.

**Figure 3**

*Illustration of the technique used with Pix4D Mapper Pro v. 4.1.25 software to estimate the average height of the canopy formed in plot P09 with BRS Kurumi genotype, by measuring the volume reached by the genotype based on the dense point cloud of the experimental area.*



### 3.6 GEOPROCESSING OF GEOREFERENCED DIGITAL MAPS

The geoprocessing step of the georeferenced digital maps, generated by the photogrammetric processing software, was carried out by GIS - Geographic Information System (Tomlinson, 2020) software, specifically ArcGIS 10.5 (https://www.esri.com/en-us/home) and Global Mapper Pro v. 20 (https://www.bluemarblegeo.com/global-mapper/).

### 3.7 STATISTICAL ANALYSIS

Statistical analysis was performed using covariance analysis models (ANCOVA), separately for the two evaluation moments performed on February 15-2022 and May 17-2022. To adequately represent the experimental factors (block and gen) in the regression matrix of the models, the deviation coding was adopted in relation to the general average, also called "effect coding", in which the codes (1, 0, -1) are used to identify their levels, as suggested by HUITEMA (2011) and also indicated by KUTNER *et al*. (2005). Starting from the adjustment of the complete model, containing both the main effects of the experimental factors and the covariate (alt_via_drone), and the effect of the gen*alt_via_drone interaction (to allow different inclinations between the genetic materials, if significant), the terms were tested individually through the General Linear F Test of regression models, composing type II tests, according to the terminology of FOX and WEISBERG (2019), in order to control for the presence of the others. This approach consists in the comparison of a more general model (the "complete" model) with a smaller model (the "reduced" model), which is a particular case of the former, resulting from the removal of the term to be proved. Thus, the order in which the regressors are tested is of no importance, since the individual contribution of each one is tested assuming that all the others are already included in the model, except for the interaction terms that involve it. Thus, each main effect is easily interpreted as the unique contribution of that predictor. When not significant, the terms were removed, one by one, always starting at the highest descriptive level (p-value), iteratively reducing the initial model until obtaining the final model.

The analyses were performed in the statistical programming environment R (R Core Team, 2024), using the lm function, from the basic stats package, for the adjustment of the models; the Anova function of the car library (Fox & Weisberg, 2019), with the default option 'type = II', for the individual general linear F tests; and the ggplot function, from the ggplot2 library, for the generation of the graphs of the adjustment lines. In all tests, a significance level of 0.05 was adopted.

## 4 RESULTSS AND DISCUSSÕES

In the field method, using a ruler graduated in centimetres, the average canopy height of elephant grass genotypes was estimated from three evaluations carried out at representative points of the canopy height of each plot, randomly selected by the evaluators in the field. Considering the two instants of evaluations and the 30 experimental units, 180 height evaluations were carried out, with 60 average heights in total.

In the proposed methodology, using the drone, the number of evaluations to find the average canopy height occurred fundamentally as a function of the size of each pixel or GSD of the digital maps used. Considering the GSD of 1.59 cm² obtained during the standardised aerial surveys with the ARP, it can be stated that to determine the 60 average estimates, about 75,471 pixels were consulted to generate the canopy height evaluations in each plot of 12 m², totalling approximately 4,528,301 pixels consulted to generate the evaluations in both instants.

As expected, the value of the average height estimated by the proposed methodology is lower than the value estimated by the field method, because it considers not only the most representative points of the canopy, but the altimetry of all points represented at each 1.59 cm² of pixel that contribute to the formation of the canopy, including those with lower heights, usually located near the edges of the canopy.

Regarding the incorporation of a high-precision geodetic GNSS to correct the pixel coordinates of the images and improve the geometric accuracy of the digital maps used in the height estimates, Table 2 presents the result of the two instants of evaluation of the average canopy height of the elephant grass genotypes, performed by the field method and the proposed methodology. Following the February 15-2022, the methodology considered only the use of the aircraft's native GNSS, while on May 17-2022 the correction of the pixel coordinates, obtained with the native GNSS, was performed using the technique of demarcation of ground support points with high precision GNSS RTK.

**Table 2**

*Results of the two instants of evaluation of the average canopy height of elephant grass genotypes, carried out on 15-February-2022 and on 17-May-2022 by the field method and the proposed methodology.*

| | | | Elephant grass - Average canopy height | | | |
|---|---|---|---|---|---|---|
| | | | 15-February-2022 | | 17-May-2022 | |
| Plot | Block | Genotype | Field Method | Native GNSS Methodology | Field Method | Methodology with GNSS RTK |
| 1 | 1 | 2111 | 112 | 45 | 90.3 | 69.6 |
| 2 | 1 | Kurumi BRS | 92 | 29 | 54 | 43.8 |
| 3 | 1 | 2035 | 115 | 48 | 78 | 56.9 |
| 4 | 1 | 1810 | 113 | 36 | 88.3 | 65.8 |
| 5 | 1 | 2022 | 79 | 41 | 47.7 | 37.3 |
| 6 | 1 | 2111 | 92 | 17 | 64 | 47.1 |
| 7 | 1 | 2022 | 95 | 1 | 49 | 30.9 |
| 8 | 1 | 2035 | 89 | 20 | 60.7 | 39.5 |
| 9 | 1 | Kurumi BRS | 117 | 42 | 53.3 | 38.3 |
| 10 | 1 | 1810 | 87 | 34 | 55.3 | 49.5 |
| 11 | 2 | 2035 | 118 | 28 | 73.7 | 54.8 |
| 12 | 2 | Kurumi BRS | 87 | 22 | 44 | 30.4 |
| 13 | 2 | 1810 | 77 | 11 | 54 | 37.9 |
| 14 | 2 | 2022 | 96 | 1.08 | 45.3 | 35.5 |
| 15 | 2 | 2035 | 85 | 29 | 61.7 | 39.2 |
| 16 | 2 | Kurumi BRS | 112 | 27 | 55.6 | 32.9 |
| 17 | 2 | 2111 | 93 | 17 | 58 | 42.9 |
| 18 | 2 | 1810 | 100 | 35 | 64.3 | 46 |
| 19 | 2 | 2111 | 114 | 43 | 76 | 57.7 |
| 20 | 2 | 2022 | 94 | 36 | 57 | 45.2 |
| 21 | 3 | 2035 | 109 | 27 | 72 | 52 |
| 22 | 3 | 2022 | 95 | 33 | 60 | 28.6 |
| 23 | 3 | 1810 | 89 | 33 | 62 | 56.3 |
| 24 | 3 | Kurumi BRS | 87 | 19 | 44 | 30.1 |
| 25 | 3 | 2111 | 85 | 27 | 62 | 43.5 |
| 26 | 3 | 1810 | 79 | 35 | 50.3 | 31 |
| 27 | 3 | Kurumi BRS | 109 | 50 | 57.7 | 44.9 |
| 28 | 3 | 2022 | 86 | 1.06 | 44 | 29.2 |
| 29 | 3 | 2035 | 76 | 21 | 62 | 44.6 |
| 30 | 3 | 2111 | 111 | 46 | 80 | 67.8 |

Table 3 presents the analysis of variance tables of the complete, initial model, adjusted separately to the data obtained in the first and second evaluation moments. At any time, it was verified the non-significance of the interaction term between the different genetic materials and the digitally estimated height ($p = 0.067$ and $p = 0.43$, respectively). The iterative reduction of this model, eliminating one by one the non-significant terms, always starting with the one with the highest descriptive level, led, in both cases, to the same final model, containing only the covariate, and the terms involving block effect or genetic material were discarded.

**Table 3**

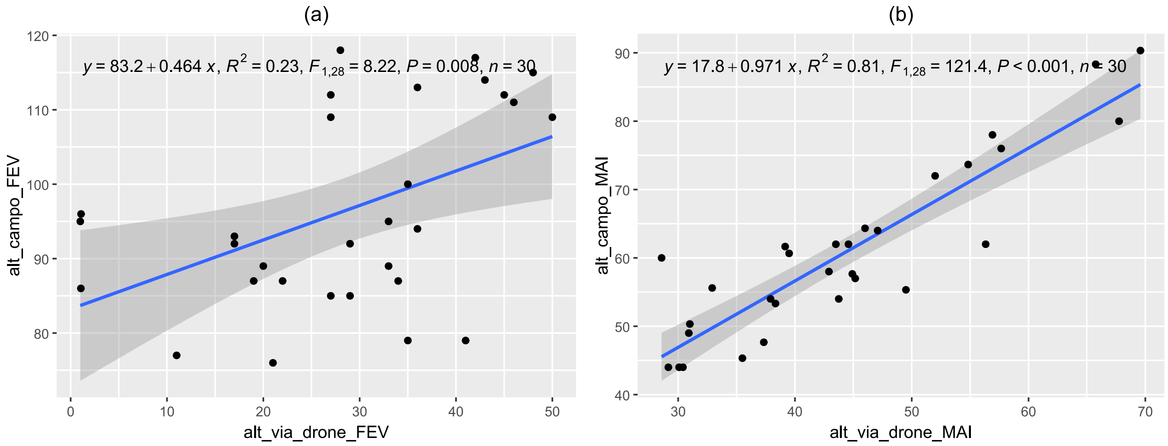
*Variance analysis tables of the complete model for the evaluation moments, using the sum of type II squares, according to the nomenclature of FOX & WEISBERG (2019).*

| Trial instant | Variance source | GL | SQ | QM | Estat. F | Pr. (F > Ftab) |
|---|---|---|---|---|---|---|
| | Block | 2 | 397.8 | 198.9 | 1.76 | 0.20 |
| | Genotype (G) | 4 | 391.9 | 98.0 | 0.86 | 0.50 |
| 15-February-2022 | Alt. via drone (A) | 1 | 932.6 | 932.6 | 8.23 | 0.010 |
| | G x A | 4 | 1201.3 | 300.3 | 2.65 | 0.067 |
| | Error | 18 | 2039.6 | 113.3 | - | - |
| | Block | 2 | 14.6 | 7.3 | 0.23 | 0.80 |
| | Genotype (G) | 4 | 157.7 | 39.4 | 1.24 | 0.33 |
| 17-May-2022 | Alt. via drone (A) | 1 | 1522.7 | 1522.7 | 47.72 | < 0.0001 |
| | G x A | 4 | 127.6 | 31.9 | 1.00 | 0.43 |
| | Error | 18 | 574.4 | 31.9 | - | - |

The regression equations and corresponding adjustment graphs of the final models are reported in Figure 4. Although the same final model was obtained for both instants, there is a huge discrepancy between the goodness of fit achieved with the data of each one. While for the data of the first instant in 15-February-2022, the final model was extremely ill-adjusted, explaining a very small portion of the variability of the response variable ($R^2$ = 0.23) and with the vast majority of the points being very out of the confidence band (Figure 4a), for the data of the second instant in 17-May-2022, the same model reached the most satisfactory quality of adjustment, with $R^2$ = 0.81 and with the points best arranged around the adjustment line, even when not covered by the confidence band (Figure 4b). Since the only methodological and experimental difference between the two collections consisted in the use of the landmark marking technique in the soil, combined with the use of a high-precision GNSS RTK in the second moment of evaluation, the results indicate the size of the impact that the correction of the positioning of the sampling points can generate in the canopy height estimates obtained by the georeferenced digital maps.

**Figure 4**

*Regression adjustments of the final models for the evaluation moments performed on 15-February-2022 (a) and 17-May-2022 (b), in both cases contemplating only the digitally estimated height as a predictor, with the respective confidence bands of 95% confidence level.*




Regarding the strength of a correlation, EVANS (1996) recommends classes from 0.00 to 0.19; 0.20 to 0.39; 0.40 to 0.59; 0.60 to 0.79 and from 0.80 to 1.00 giving rise to the categories "very weak", "weak", "moderate", "strong" and "very strong", while recently RUMSEY (2023) suggests cuts in 0, 0.3, 0.5, 0.7 and 1 for the categories "no correlation", "weak", "moderate", "strong" and "perfect". Although there is no consensus regarding the strength of a correlation, the authors classify a correlation of 0.48 as weak or moderate, for the coefficient of determination $R^2$=0.23 illustrated in Figure 4a and 0.9 as strong or very strong for the coefficient $R^2$=0.81 illustrated in Figure 4b.

Regarding the use of technologies embedded in remotely piloted aircraft in agricultural systems, the authors (Embrapa Instrumentation, 2021) state *that the use of tools, such as unmanned aerial vehicles (UAVs), are increasingly incorporated into crop monitoring, transform the countryside landscape and change the way to manage them, bring positive economic and environmental impacts to agriculture.* They are able to observe and collect information with their embedded sensors, replace visual inspections, which are more laborious and time-consuming, streamline tasks and decision making. This is what the so-called disruptive technologies do, which cause a rupture with the standards or models already established, and bring improvements in the cost-benefit ratio of the processes and their performance. Finally, the authors in SAUSEN *et al.* (2020) add that the adoption of disruptive technologies is a no-return path for the rural sector, since, in addition to adding value to production, they provide more environmental, social and economic sustainability to agricultural systems.

## 5 CONCLUSION

When considering the entire canopy length, the average height estimation obtained by the proposed methodology proved to be more comprehensive and representative than the average height obtained by the field method. In addition, the 0.9 correlation observed between the average heights obtained supports the adoption of this methodology in the field, provided that a set formed by knowledge and fundamental technical details is respected, specifically related to: (i) technological capacity of the ARP, such as aircraft stabilisation power and embedded camera, quality of the set of lenses and the precision of the embedded RGB sensors; (ii) standardisation and adequate flight planning, aiming that the images present reliable technical quality and a GSD appropriate to the metric scale to be used; (iii) adoption of the UTM coordinate system and the datum SIRGAS2000 or equivalent, according to the region of the aerial surveys; (iv) demarcation of ground support points to perform the planimetric and altimetric correction of the pixel coordinates of the images through a high GNSS RTK precision or, alternatively, use a professional PRA with embedded RTK technology that dispenses with the need to use ground support points; (v) configuration and execution of flight planning software, photogrammetric processing and geoprocessing of georeferenced digital maps; (vi) use of the ground as an altimetric reference in height and volume estimates; (vii) proving the positional accuracy of the metrics performed by digital means, through the technical quality reports generated by the photogrammetric processing software.

## ACKNOWLEDGMENTS

We thank FAPEMIG (project APQ-00657-17) and Embrapa Gado de Leite, in the context of the CAPIM-ELEFANTE (MON: 20.20.01.010.00.00) and ZOPEC-LEITE (MON: 10.19.03.064.00.00) projects.

## REFERENCES

Aasen, H.; Bareth, G. Spectral and geometric plant traits derived from UAVs for precision agriculture: A review of methods. Remote Sensing, v. 13, n. 5, p. 949, 2021.

Almeida, J. S.; Silva, T. R. Acurácia posicional em mapeamento aéreo com drones. Revista Brasileira de Cartografia, v. 75, n. 1, p. 123-139, 2023.

Andrade, R. G.; Hott, M. C.; Magalhaes Junior, W. C. P. de; Machado, J. C.; Borges, C. A. V. Unmanned aircraft for monitoring elephant grass genotypes in energy biomass production. International Journal of Advanced Engineering Research and Science, v. 9, n. 1, p. 70-76, 2022.

Andrade, R. G.; Hott, M. C.; Magalhaes Junior, W. C. P. de; Oliveira, P. S. d'; Oliveira, J. S. e. Monitoramento do desenvolvimento do milho por meio do VANT. In: HOTT, M. C.; ANDRADE, R. G.; MAGALHAES JUNIOR, W. C. P. de (org.). Geotecnologias: aplicações na cadeia produtiva do leite. Ponta Grossa: Atena, 2022. p. 91-95.

Andrade, R. G.; Hott, M. C.; Magalhaes Junior, W. C. P. de; Paciullo, D. S. C.; Gomide, C. A. de M. Estimate of vigor classes of Brachiaria ruziziensis using sensors boarded on UAV plataform. International Journal of Advanced Engineering Research and Science, v, 8, n. 12, p. 365-370, 2021.

Balafoutis, A. T.; Kakogiannakou, S.; Fountas, S.; Tzanakis, I.; Bochniak, A.; Vazquez-Aure, D. Use of UAV thermal imagery for identifying water stress at different crop stages in maize. Sensors, v. 21, n. 4, p. 1278, 2021.

Ben-Dor, E.; Levin, N.; Oren, A.; Chudnovsky, A. Thermal remote sensing for precision agriculture: The use of UAV thermal imagery to detect water stress in crops. Remote Sensing of Environment, v. 249, p. 112026, 2021.

Bendig, J.; YU, K.; Aasen, H.; Bolten, A.; Bareth, G. Combining UAV-based plant height from crop surface models, visible, and near-infrared vegetation indices for biomass monitoring in barley. International Journal of Applied Earth Observation and Geoinformation, v. 88, p. 102065, 2020.

Cóser, A. C.; Martins, C. E.; Carvalho, C. A. B.; Gerônimo, O. J.; Freitas, V. P.; Salvati, J. A. Avaliação de metodologias para a estimativa da disponibilidade de forragem em pastagem de capim-elefante. Ciênc. agrotec., Lavras, v.26, n.3, p. 589-597, mai./jun., 2002

EMBRAPA INSTRUMENTAÇÃO. Tecnologias disruptivas impactam o agro brasileiro. São Carlos, 2021. Notícias. https://www.embrapa.gov.br/web/portal/instrumentacao/busca-de-noticias/-/noticia/60653569/tecnologias-disruptivas-impactam-o-agro-brasileiro?p_auth=fkW5cqc7. Acesso em: 30 set. 2024.

Evans, J. D. Straightforward statistics for the behavioral sciences. Pacific Grove, CA: Brooks/Cole Publishing, 1996.

Ferreira, F. M.; Leite, R. V.; Malikouski, R. G.; Peixoto, M. A.; Bernardeli, A.; Alves, R. S.; Magalhaes Junior, W. C. P. de; Andrade, R. G.; Bhering, L. L.; Machado, J. C. Bioenergy elephant grass genotype selection leveraged by spatial modeling of conventional and high-throughput phenotyping data. Journal of Cleaner Production, v. 363, 132286, 2022.

Ferreira, J. A.; Silva, P. H.; Oliveira, R. T. Geração de ortomosaicos com drones para mapeamento de áreas agrícolas. Revista Brasileira de Cartografia, v. 76, n. 2, p. 202-215, 2024.

Fox J.; Weisberg S. An R Companion to Applied Regression, 3rd ed. Sage, Thousand Oaks CA, 2019.

Hott, M. C.; Andrade, R. G.; Magalhaes Junior, W. C. P. de; Benites, F. R. G. Uso de veículo aéreo não tripulado (VANT) para estimativa de vigor e de correlações agronômicas em genótipos de capim Cynodon. In: SILVA, H. C. da (Org.). Engenharia Sanitária e Ambiental. Ponta Grossa, PR: Atena Editora, 2019. p. 235-244.

Huitema, B. The Analysis of Covariance and Alternatives: Statistical Methods for Experiments, Quasi-Experiments, and Single-Case Studies, 2nd ed. John Wiley & Sons, 2011.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). SIRGAS 2000: uma introdução ao sistema de referência geocêntrico para as Américas. Rio de Janeiro: IBGE, 2005.

Jia, H.; Shang, J.; Liu, J.; Martin, K.; Mcnairn, H.; Zhu, B. Crop height sensing using digital surface models from UAV SAR images. Remote Sensing of Environment, v. 245, p. 111828, 2020.

Kutner, M. H.; Nachtsheim, C. J.; Neter, J.; Li, W. Applied Linear Statistical Models, 5th ed. Boston: McGraw-Hill Irwin, 2005.

Lima, F. P.; Gomes, R. S.; Almeida, J. F. Processamento fotogramétrico com drones para mapeamento de áreas rurais: técnicas e precisão. Revista Brasileira de Cartografia, v. 76, n. 4, p. 301-315, 2024.

Madeira, S. S.; Gomes, F. B.; Sousa, A. M. O. UAV photogrammetry for agricultural monitoring: The importance of GCP for precision agriculture. Remote Sensing Applications: Society and Environment, v. 19, p. 100351, 2020.

Martins, R. L.; Pereira, L. S.; Gonçalves, J. T. Padronização de voos com drones para mapeamento de áreas agrícolas: Impacto na qualidade dos dados. Ciência e Sensoriamento Remoto, v. 14, n. 2, p. 102-115, 2024.

Massruhá, S. M. F. S.; Leite, M. D. A.; Bolfe, E. L. Agro 4.0: o papel da pesquisa e perspectivas para a transformação digital na agricultura. 2023.

Mendes, R. T.; Albuquerque, J. P.; Carvalho, A. L. Agricultura de precisão com uso de drones: Monitoramento multiespectral em lavouras de cana-de-açúcar. Journal of Agricultural Science, v. 12, n. 4, p. 50-63, 2024.

Moraes, J. S.; Almeida, G. V.; Silva, T. M. Agricultura digital e sensoriamento remoto: Aplicações de drones na detecção de pragas em cultivos de café. Ciência Rural, v. 54, n. 2, p. 1-9, 2024.

Oliveira, L. F.; Santos, V. R.; Costa, M. J. Comparação de métodos para avaliar a qualidade das imagens obtidas por drones em diferentes altitudes. Journal of Photogrammetry and Remote Sensing, v. 12, n. 1, p. 55-67, 2023.

Oliveira, J. P.; Sousa, R. C.; Santos, F. A. Métodos estatísticos para análise da correlação e sua força: uma revisão aplicada. Revista Brasileira de Estatística, v. 35, n. 2, p. 123-136, 2023.

Ota, T.; Oishi, M.; Akiyama, Y.; Nakamura, H.; Takahashi, H. Estimation of crop height and yield in maize using UAV-based RGB imaging. Plant Production Science, v. 24, n. 3, p. 195-208, 2021.

Pereira, L. F.; Oliveira, R. M. Análise da acurácia geométrica em ortofotos obtidas por drones. Geospatial Research, v. 12, n. 2, p. 45-60, 2023.

Pereira, M. J.; Ferreira, G. R.; Mendes, F. L. Aplicação de drones e fotogrametria digital na geração de modelos 3D de plantações florestais. Journal of Photogrammetry and Remote Sensing, v. 17, n. 2, p. 90-102, 2024.

Pereira, J.; Martins, C. Sistema UTM e suas aplicações na agricultura de precisão. Porto Alegre: Editora Agrícola, 2021.

R Core Team. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, 2024.

Ribeiro, A. P.; Pereira, R. T.; Moraes, J. S. Fatores que influenciam a qualidade técnica de imagens aéreas capturadas por drones. Ciência e Geoinformação, v. 8, n. 2, p. 33-47, 2024.

Ribeiro, C. A.; Gonçalves, F. P.; Teixeira, L. R. Drones na agricultura digital: Uso de veículos aéreos não tripulados para análise de variabilidade espacial em culturas de algodão. Precision Agriculture, v. 26, p. 42-58, 2024.

Rocha, A. F.; Almeida, V. M.; Ferraz, G. R. Diretrizes para padronização de parâmetros de voo com drones em estudos ambientais. Boletim de Geociências, v. 11, n. 3, p. 45-58, 2024.

Rocha, V. P.; Gomes, F. L.; Vasconcelos, D. P. Avaliação da biomassa em pastagens utilizando imagens RGB obtidas por drones. Boletim de Ciências Agrárias, v. 11, n. 1, p. 10-22, 2024.

Rodrigues, P.R.; Paciullo, D.S.C.; Soares, N.A.; Gomide, C.A.M.; Morenz, M.J.F.; Lopes, F.C.F.; S. Sobrinho, F. ; Lana, Â.M.Q. Productive traits and nutritional value of Urochloa ruziziensis submitted to different planting densities and defoliation intensities. ARQUIVO BRASILEIRO DE MEDICINA VETERINÁRIA E ZOOTECNIA, v. 75, p. 1005-1015, 2023.

Rumsey, D. J. Statistics for dummies. 4. ed. Hoboken: Wiley Publishing, 2023.

Santos, L. F.; Melo, R. P.; Gomes, F. V. Avaliação de precisão na geração de ortomosaicos com veículos aéreos não tripulados em áreas urbanas e rurais. Journal of Geospatial Information Science, v. 9, n. 1, p. 45-58, 2024.

Santos, P. R.; Oliveira, M. C.; Pereira, J. A. Uso de drones com sensores RGB para avaliação de desempenho vegetativo em culturas de milho. Revista Brasileira de Engenharia Agrícola e Ambiental, v. 28, n. 2, p. 145-152, 2024.

Santos, P. T.; Souza, D. A.; Carvalho, F. J. Impacto da padronização de voos com drones na coleta de dados multiespectrais. Revista Brasileira de Sensoriamento Remoto, v. 32, n. 1, p. 150-163, 2024.

Sausen, Darlene *et al*. Agrotecnologias disruptivas. Revista Eletrônica Competências Digitais para Agricultura Familiar, v. 6, n. 2, p. 41-68, 2020.

Sentera. Key Specs for the Double 4K. 2025. Disponível em: https://senterasensors.com/hardware/sensors/double-4k/. Acesso em: 14 abr. 2025.

Silva, T. R.; Mendes, P. H.; Almeida, J. F. Avaliação da qualidade técnica de imagens geradas por drones para monitoramento agrícola. Revista Brasileira de Engenharia Agrícola e Ambiental, v. 27, n. 3, p. 215-223, 2023.

Sosa, J. J.; Cifuentes, C. M.; Colorado, J. UAV-based high-throughput phenotyping to estimate plant height using photogrammetric point clouds and machine learning in maize crops. Drones, v. 5, n. 1, p. 8, 2021.

Sujatha, R.; Chatterjee, J. M.; PATIL, S. Drones in agriculture: A systematic review. Agronomy, v. 12, n. 5, p. 1223, 2022.

Tomlinson, R. F. Geographic Information Systems (GIS): Techniques and applications. International Journal of Geographical Information Science, v. 15, n. 3, p. 177-191, 2020.

Torres-Sánchez, J.; Peña, J. M.; De Castro, A. I.; López-Granados, F. Multi-temporal mapping of the vegetation fraction in early-season wheat fields using images from UAV. Precision Agriculture, v. 22, n. 2, p. 500-519, 2021.

Tsouros, D. C.; Tsagkas, V.; Batsaris, M.; Bibikas, D.; Sarris, A. UAV remote sensing for precision agriculture: A comparison between different sensors and multi-sensor data fusion approaches. Agronomy, v. 11, n. 2, p. 366, 2021.

Walter, V.; Liebisch, F.; Hund, A. Plant height estimation using photogrammetric point clouds from UAV imagery and crop surface models for applications in breeding trials. Plant Methods, v. 17, p. 77, 2021.