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Technical Note

Estimating Pasture Biomass and Canopy Height in Brazilian Savanna Using UAV Photogrammetry

Juliana Batistoti [1], José Marcato Junior [2,*], Luís Ítavo [1], Edson Matsubara [3], Eva Gomes [1], Bianca Oliveira [2], Maurício Souza [2], Henrique Siqueira [2], Geison Salgado Filho [2], Thales Akiyama [2], Wesley Gonçalves [2,3], Veraldo Liesenberg [4], Jonathan Li [5] and Alexandre Dias [1]

[1] Faculty of Veterinary Medicine and Animal Science, Federal University of Mato Grosso do Sul, Avenida Senador Filinto Muller 2443, Campo Grande 79074-960, MS, Brazil; juliana.batistoti@ufms.br (J.B.); luis.itavo@ufms.br (L.Í.); eva.gomes@ufms.br (E.G.); alexandre.menezes@ufms.br (A.D.)

[2] Faculty of Engineering, Architecture and Urbanism and Geography, Federal University of Mato Grosso do Sul, Av. Costa e Silva, s/n, Campo Grande 79070-900, MS, Brazil; bianca.garcia@ufms.br (B.O.); mauricio.souza@ufms.br (M.S.); henrique.siqueira@ufms.br (H.S.); geison.filho@ufms.br (G.S.F.); thales.akiyama@ufms.br (T.A.); wesley.goncalves@ufms.br (W.G.)

[3] Faculty of Computer Science, Federal University of Mato Grosso do Sul, Av. Costa e Silva, s/n, Campo Grande 79070-900, MS, Brazil; edsontm@facom.ufms.br

[4] Department of Forest Engineering, Santa Catarina State University (UDESC), Lages SC 88520-000, Brazil; veraldo.liesenberg@udesc.br

[5] Department of Geography and Environmental Management and Department of Systems Design Engineering, University of Waterloo, Waterloo, ON N2L 3G1, Canada; junli@uwaterloo.ca

* Correspondence: jose.marcato@ufms.br; Tel.: +55-67-3345-7731

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Abstract: The Brazilian territory contains approximately 160 million hectares of pastures, and it is necessary to develop techniques to automate their management and increase their production. This technical note has two objectives: First, to estimate the canopy height using unmanned aerial vehicle (UAV) photogrammetry; second, to propose an equation for the estimation of biomass of Brazilian savanna (Cerrado) pastures based on UAV canopy height. Four experimental units of *Panicum maximum* cv. BRS Tamani were evaluated. Herbage mass sampling, height measurements, and UAV image collection were simultaneously performed. The UAVs were flown at a height of 50 m, and images were generated with a mean ground sample distance (GSD) of approximately 1.55 cm. The forage canopy height estimated by UAVs was calculated as the difference between the digital surface model (DSM) and the digital terrain model (DTM). The R^2 between ruler height and UAV height was 0.80; between biomass (kg ha^{-1} GB—green biomass) and ruler height, 0.81; and between biomass (kg ha^{-1} GB) and UAV height, 0.74. UAV photogrammetry proved to be a potential technique to estimate height and biomass in Brazilian *Panicum maximum* cv. BRS Tamani pastures located in the endangered Brazilian savanna (Cerrado) biome.

Keywords: *Panicum maximum*; digital surface model; digital elevation model; crop surface models; herbage mass; forage canopy height

1. Introduction

The Brazilian territory contains nearly 160 million hectares of pastures which are located mainly in the North, Southeast, and Center-West regions [1]. One of the main activities developed in the country is livestock farming. The Brazilian cattle herd consists of approximately 226 million head [2], a large portion of which is reared on pasture [3], thus warranting efforts to optimize pasture management.

Therefore, determining biomass availability is an essential step in the adequate planning of pasture exploitation, since biomass-estimation strategies are aimed at defining the stocking rate of grazing systems, herbage growth, nutritional value, and defoliation regimes based on grazing activity and stocking methods [4].

Biomass measuring is described as an evaluation, the objective of which is to quantify the dry matter present above ground level per unit area [5]. Though thus involves simple techniques that can be performed in small areas, manual measurements require time and extensive labor. For this reason, research involving automated and non-destructive measuring approaches is still necessary [6].

Unmanned aerial vehicles (UAVs) are an adapted platform due to the diversity of sensors that allows them to be set up and flown to collect aerial images with high temporal and spatial resolution. Advances in precision, cost–benefit values, and the miniaturization of technologies such as computer processors and the global navigation satellite system (GNSS) has made the UAV a versatile platform, resulting in a tool capable of performing well in a wide range of applications [7,8], including soybean yield estimation, plant maturity prediction [9], and wheat plant density estimation [10].

Previous studies have shown the potential of UAVs for estimating the biomass of typical agricultural crops in Germany [11,12]; evaluating the applicability of images to model the height of eggplant, tomato, and cabbage plantations in India [13]; detecting weeds within rows in sunflower and cotton plantations in Spain; the monitoring of pastures [14]; the modeling of canopy height and biomass [15]; the estimation of biomass in temperate pastures in China [16]; the investigation of the utility of images acquired using UAVs to predict traces of vegetation in pastures [17]; the classification of species in mixed pasture in Canada [18]; and the estimation of biomass during the growth of the plants based on the residual heights of plants of crop surface models (CSM) [19].

Bendig [12] found a higher correlation between biomass and crop height when estimated by UAVs compared to spectral indices (estimated from the ratio between spectral bands). Moeckel [13] concluded that the manual measurement of plant height can be replaced by measurements obtained by UAV photogrammetry. Castro [20] reported that their used algorithm was able to identify each individual plant in their images, including weeds, and it was also able to accurately estimate plant height based on a digital surface model (DSM).

The previously mentioned studies were developed on different crops. In view of the scarcity of scientific data using UAVs to estimate height and biomass in Brazilian pastures, the present study investigates the use of UAV photogrammetry to estimate the pasture height and biomass of *Panicum maximum* cv. Tamani grass in the Brazilian state of Mato Grosso do Sul, Brazil. The adequate management of pastures enables the optimization of their uses and consequently contributes to significant environmental preservation, thus reducing pressure over forest remnants. There are several biomes in the Mato Grosso do Sul state, including Pantanal, which is considered by UNESCO (United Nations Educational, Scientific and Cultural Organization) to be one of the world heritage sites.

The study area is located in the Upper Paraguay Basin (UPB) that encompasses Pantanal, which is in the Brazilian savanna (Cerrado), and every environmental change in this area impacts on Pantanal. The main UPB rivers rise in the Cerrado and go towards the Pantanal. The intensive exploitation of the Cerrado by livestock and agriculture activities favors the occurrence of erosive processes. The use of soil conservation techniques and the management of the pastures contribute to the sustainability of the ecosystem.

2. Material and Methods

An experiment with *Panicum maximum* cv. BRS Tamani grass was undertaken at Fazenda Escola at the Federal University of Mato Grosso do Sul (Section 2.1). Herbage mass sampling, height measurements, and image capturing (using UAVs) were simultaneously performed and are described in Sections 2.2 and 2.3. After being collected on the field, the images were processed (Section 2.3). Lastly, regression and correlation analyses were performed to evaluate the results (Section 2.4).

2.1. Experimental Area

The experiment was conducted in the forage section (Figure 1) at Fazenda Escola, in the municipality of Terenos—Mato Grosso do Sul (MS), Brazil (latitude 20°26′34.31″S, longitude 54°50′27.86″W, altitude 530.7 m) (Figure 1). Before the implementation of the experiment, the samples of soil were collected from the 0–20 cm layer to determine fertility (Table 1). Dolomitic limestone was applied at the rate of 1.2 t ha^{-1} (total relative neutralizing power (TRNP) = 80%). Before planting, the area was fertilized with 100 kg ha^{-1} of P_2O_5, 100 kg ha^{-1} of N (in the form of urea), and 60 kg ha^{-1} of K_2O. The *Panicum maximum* cv. BRS Tamani grass was planted in November 2015.

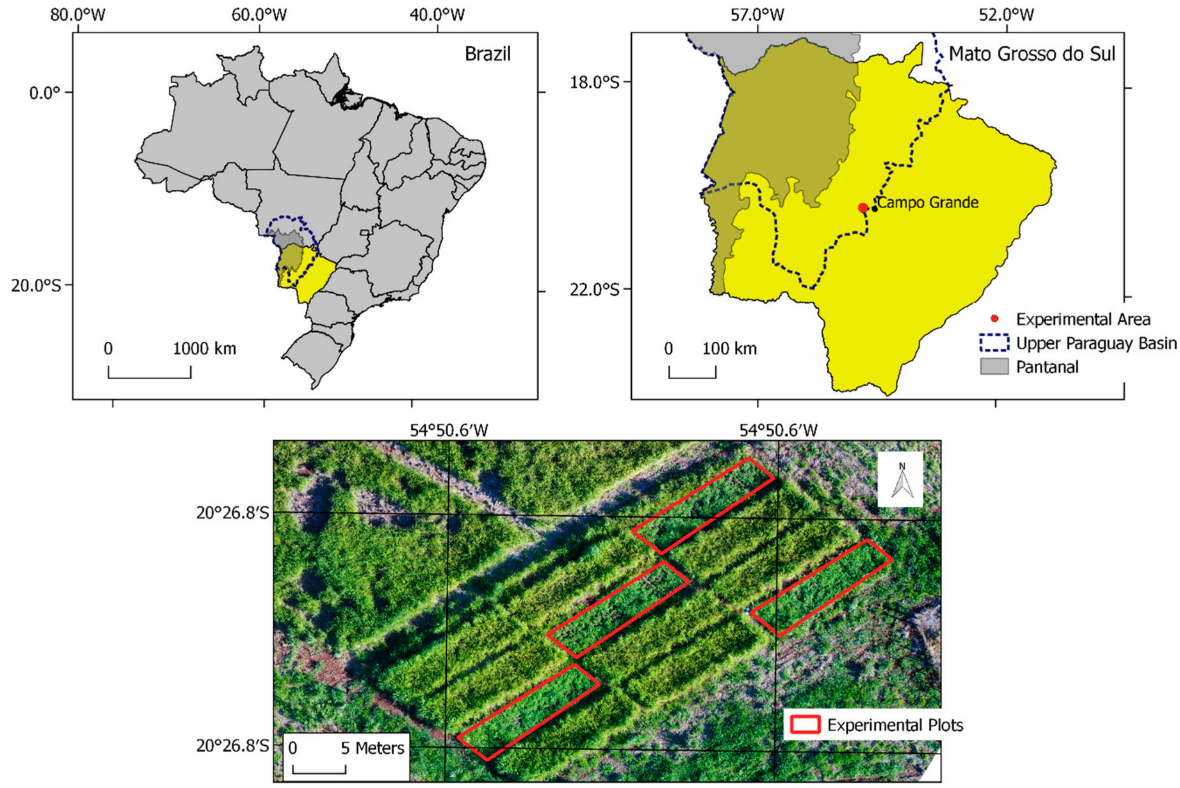

Figure 1. Localization of Fazenda Escola (study area) and experimental plots.

Table 1. Chemical characteristics of soil samples from the experimental area.

pH ($CaCl_2$)	pH (H_2O)	P	K	Ca	Mg	Ca + Mg	Al	H + Al	CEC	MO	V (%)
		cmol dm^{-3}								g dm^{-3}	
5.31	5.91	0.04	0.20	7.35	1.20	8.55	0.00	5.18	13.93	35.34	62.81

Cultivar BRS Tamani was implemented in four 3 × 12 m^2 experimental plots, which were subdivided into 3 × 3 m subplots, totaling 9 m^2 for each harvest age (21, 35, 49 and 63 days).

2.2. Biomass Sampling and Height

All the biomass present in the experimental units was quantified through harvesting at the height of 10 cm above the ground. Plant height was monitored at the time of harvest (21, 35, 49 and 63 day harvest intervals) (Table 2). In each experimental unit, measurements were taken at five representative points at the average height of the curvature of the upper leaves around the ruler, which was graduated in centimeters. Sampling (n = 66) took place on the same day the UAV was flown.

Table 2. Days in which field measurements and unmanned aerial vehicle (UAV) flights were carried out.

	Harvest Intervals			
	21 Days	**35 Days**	**49 Days**	**63 Days**
1st cut	30/10/17	13/11/17	29/11/17	12/12/17
2nd cut	17/11/17	17/12/17	15/01/18	09/02/18
3rd cut	12/12/17	22/01/18	05/03/18	-
4th cut	01/01/18	26/02/18	-	-
5th cut	22/01/18	02/04/18	-	-
6th cut	09/02/18	-	-	-
7th cut	05/03/18	-	-	-

2.3. Image Collection and Processing

RGB (Red, Green and Blue) images were collected by a Phantom 4 advanced (ADV) UAV. The UAV was flown before the biomass harvest and the height measurement. The camera has a 20-megapixel complementary metal-oxide semiconductor (CMOS), and each battery lasts 30 min at most.

The image processing was performed using Pix4D commercial software. This software can be used for interior and exterior parameter optimization, point clouds, and orthophotos generation. Several studies have assessed Pix4D, e.g., for the generation of surface models [21,22] and the estimation of plant height [23], as well as for the presentation of its basic concepts [24,25]. UAV photogrammetric software use computer vision methods, such as structure-from-motion (SfM) [26] and multi-view stereo (MVS) [27].

SfM enables the simultaneous estimation of interior and exterior orientation parameters and the coordinates of a sparse point cloud using images with overlap [25,28]. The scale invariant feature transform (SIFT) [29] method and its variants, in general, are used for image correspondence [25]. After that, the sparse point cloud is densified using MVS algorithms.

For the SfM method, five targets of approximately 50×50 cm were distributed in the experimental area. A previous study [30] showed the importance of ground control point (GCP) distribution for improving planimetry and altimetry accuracies. Therefore, five GCPs were used, as it was a small flat area. The target coordinates were estimated using a GS15 GNSS real-time kinematic (RTK) receiver of the LEICA VIVA GNSS GS15 line with a 3D precision of 5 mm. To assess the SfM method, the leave-one-out method, in which all the points were once considered check-points, was applied [31] (see Table 3).

The UAV was flown at a height of 50 m upon approval by the Department of Airspace Control (DECEA), which is responsible for the Brazilian airspace. Images were captured with longitudinal and lateral overlaps of 80% and 60%, respectively, and with a ground sample distance (GSD) of approximately 1.55 cm. The analysis of Table 3 shows that an accuracy of around 1 GSD was achieved in the X and Y coordinates, as well as 2.5 GSD in altimetry (Z).

To estimate pasture biomass and height with the UAV, the digital terrain model (DTM) was generated using at least 30 points per experimental plot surveyed using RTK (Figure 2) with the triangular irregular network (TIN) method. The digital surface model (DSM) (Figure 3a) was generated by applying the SfM and MVS methods in Pix4D software, with points over the pasture. Pasture height was calculated from the difference between the DSM and the DTM (Figure 3c).

Table 3. The leave-one-out method applied to assess the structure-from-motion (SfM) accuracy.

Check Point (Id)	Error X (m)	Error Y (m)	Error Z (m)
1	−0.0265	−0.0300	−0.0363
2	0.0066	0.0229	0.0312
3	−0.0336	−0.0041	−0.0445
4	0.0151	0.0038	−0.0386
5	0.0192	0.0039	0.0565
Mean	**−0.0038**	**−0.0007**	**−0.0063**
Sigma	**0.0210**	**0.0131**	**0.0402**
RMSE	**0.0222**	**0.0172**	**0.0423**

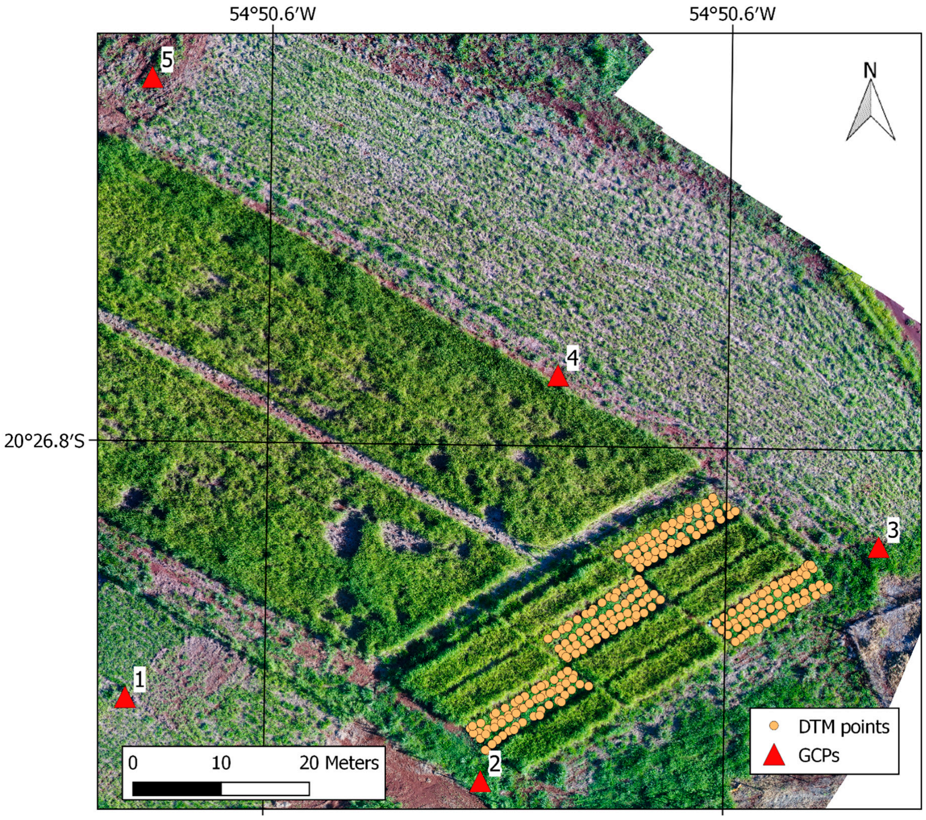

Figure 2. Distribution of digital terrain model (DTM) points and ground control points (GCPs), both collected with real-time kinematics (RTK).

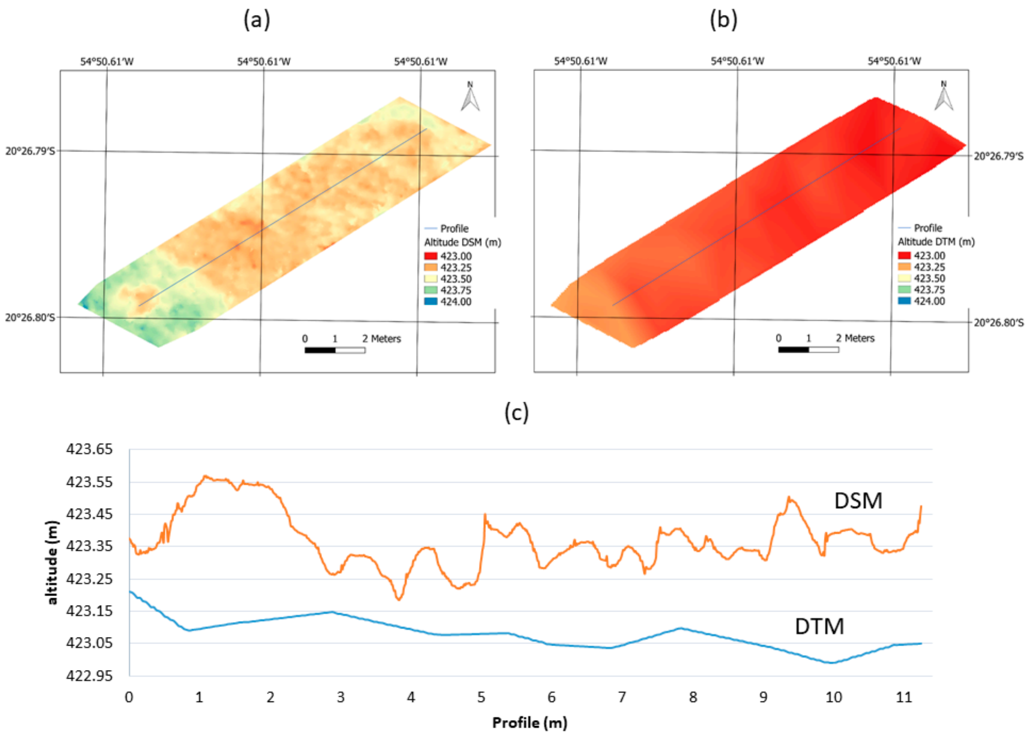

Figure 3. Generated models of the study area. (**a**) Digital surface model (DSM); (**b**) DTM generated using a Global Navigation Satellite System (GNSS) RTK receiver; and (**c**) elevation profile.

2.4. Statistical Analysis

In order to estimate accuracy, the normalized root mean square error (NRMSE) was estimated using the leave-one-out method [31]. In this method, the linear equation parameters were estimated without one point. After that, the discrepancy at this point was estimated. The NRMSE (%) was estimated by considering 66 discrepancies (n = 66) in the points left out.

Correlation and regression analyses were performed considering n equal to 66. The average canopy height per experimental unit, obtained by the UAV, was evaluated in comparison to the average canopy height, which was obtained from measurements taken using a ruler in the field. The result is presented in a scatter plot along with a linear regression equation.

To estimate herbage mass, linear regression equations were derived from the canopy height obtained by the UAV vs. green biomass and evaluated by their coefficient of determination (R^2).

3. Results and Discussion

The NRMSE estimated using the leave-one-out method was around 10.99% when considering the height measured with the ruler and by the UAV (Figure 3). There was a correlation between the height measured with the ruler and by the UAV (correlation coefficient (CC) = 0.89). The difference between the heights derived from UAV images and those measured by the ruler was approximately 8 cm, as can be observed in the regression equation shown in Figure 4. As the regrowth age advanced, this difference decreased. This can be explained by the fact that UAVs capture images from the total plot area, which may include uncovered soil areas. According to Geipel [32], a DSM may underestimate height in heterogeneous fields where soil spots are apparent, which might have occurred at the earlier ages due to a lower height and, consequently, a lower leaf area index.

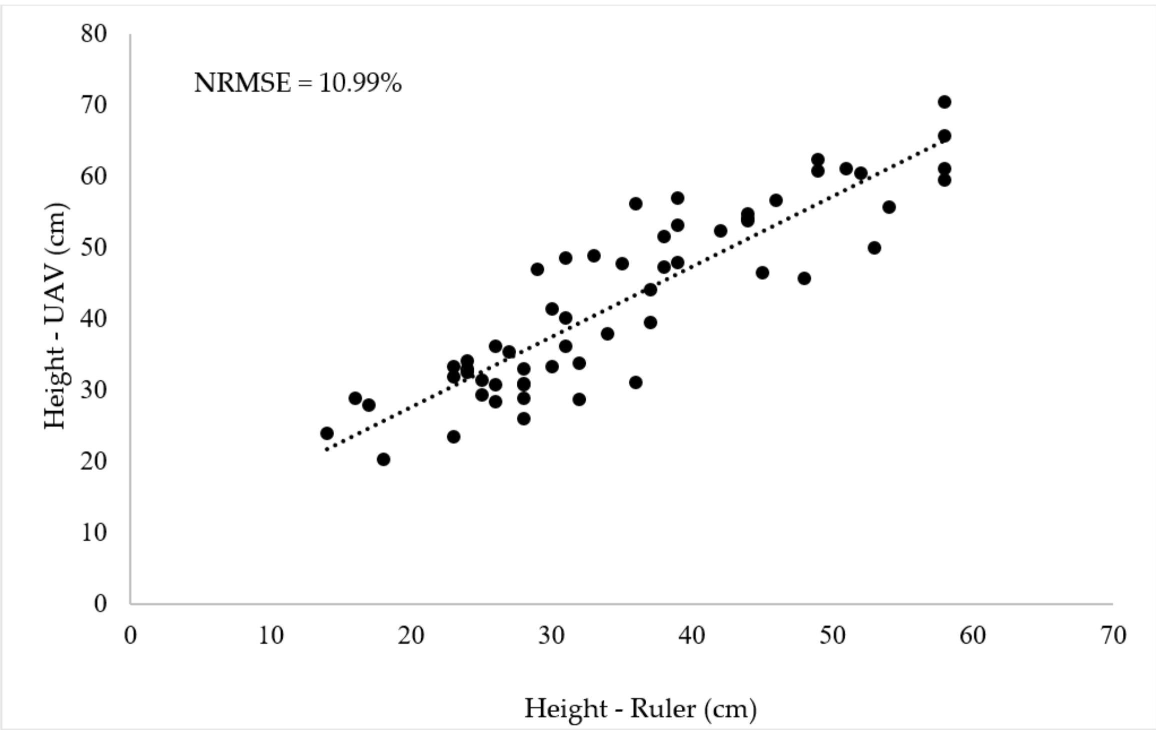

Figure 4. Relationship between the height estimated by the UAV and that measured with the ruler.

The CC between the height measured with the ruler and the biomass (Figure 5) was 0.90, indicating that these measurements were correlated. The NRMSE, when considering the height measured with the ruler and the biomass, was around 7.96%.

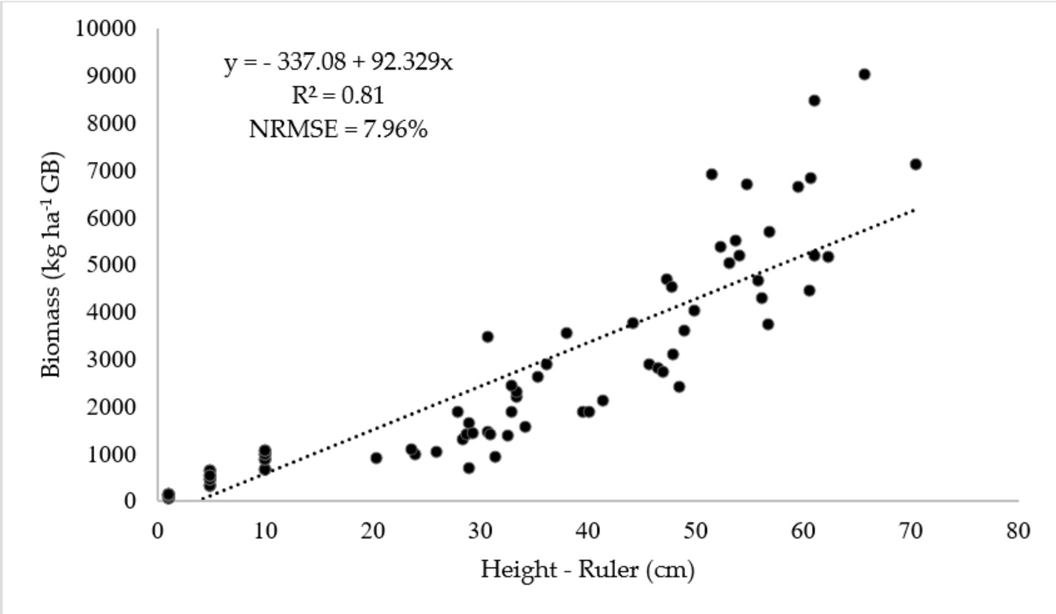

Figure 5. Relationship between biomass and height measured with the ruler.

The NRMSE was around 12.5% when considering the height measured by the UAV and herbage mass. There was a correlation between the height measured by the UAV and herbage mass (CC = 0.86) (Figure 6). Each additional centimeter in the height measured by the UAV represented an increase of approximately 88 kg ha^{-1} in green biomass for each experimental plot, i.e., herbage mass increased proportionally to the canopy height when measured by the UAV. This observation corroborates the reports of Terra Lopes [33] and Casagrande [34], who observed higher herbage allowances at greater heights.

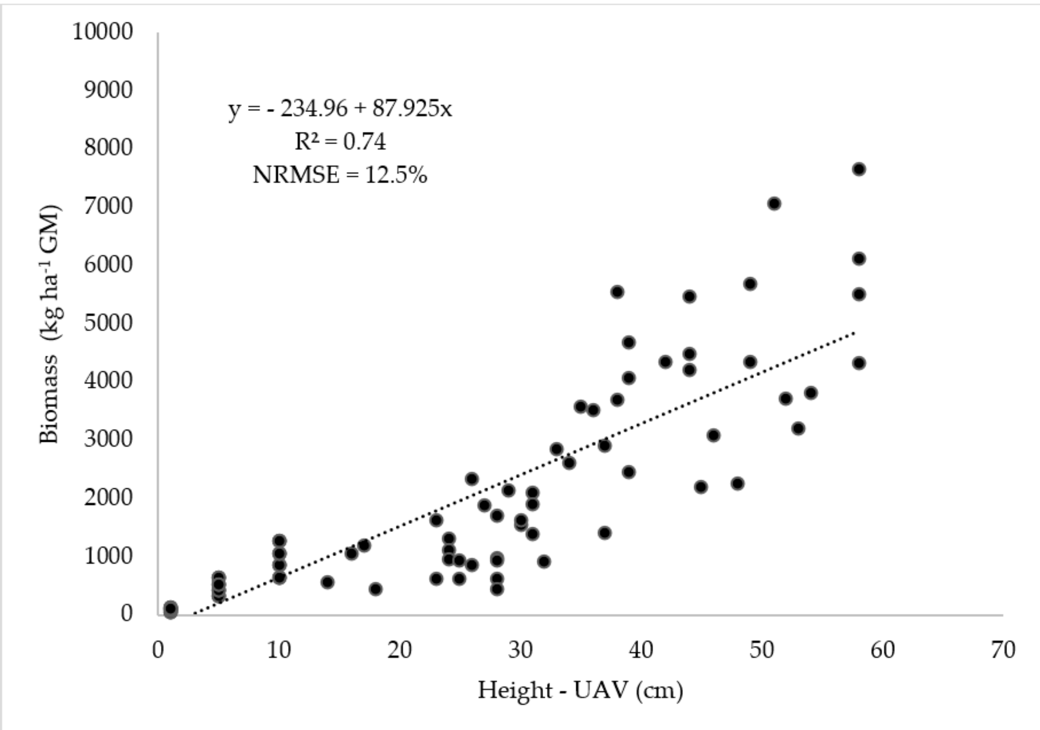

Figure 6. Relationship between the height estimated by the UAV and herbage mass.

According to the regression models, the determination coefficients for the biomass estimated by the UAV and the ruler were 0.74 and 0.81, respectively. These values are higher than the 0.72 and 0.71 found by Bendig [11], who estimated the biomass of barley using a DTM and a DSM from RGB images obtained with a UAV. This corroborates the findings of Ehlert [35] and Zhang and Grift [36], who stated that there is a very close relationship between biomass and height.

Each regrowth day corresponded to a 0.2422 m increase in height when measured by the ruler and 0.2098 m when calculated by the UAV (Figure 7). A similar regrowth trend was observed by Maranhão [37] and Ansah [38] that assessed the productive and structural characteristics of different cultivars submitted to different cutting intervals.

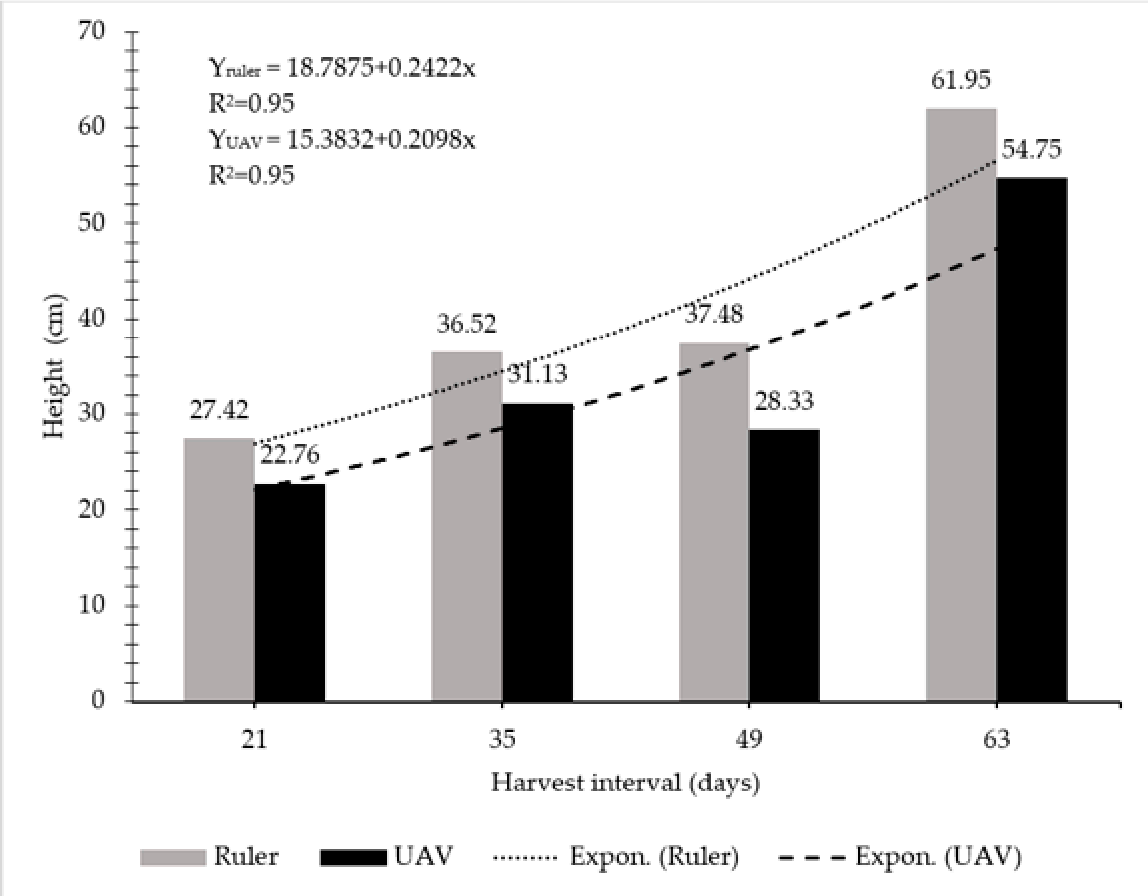

Figure 7. Height measured by the ruler and by the UAV at different harvest intervals.

As regrowth age advanced, herbage mass also increased. Biomass increased by 50.93 kg ha^{-1} GB (green biomass) with every regrowth day when estimated by the ruler and by 43.96 kg GB when the UAV was used (Figure 8). Increases in biomass were also found by Oliveira [39], Costa [40], Rodrigues [41], and Geleti and Tolera [42], who evaluated the forage yield in different cultivars and cutting intervals.

Due to the scarcity of studies regarding the use of UAVs to estimate biomass in Brazilian pastures, the present study investigated the use of UAV photogrammetry for this purpose in the Brazilian state of Mato Grosso do Sul, Brazil. In general, the obtained accuracy is consistent with what literature has obtained for other cultures in different areas of the world. The proposed equation for biomass was generated for a specific pasture by considering specific soil and conditions. The same soil type is very common in Brazil, and the same climate conditions occurs in many areas of the country. Consequently, it is possible to generalize the equation for certain regions in Brazil.

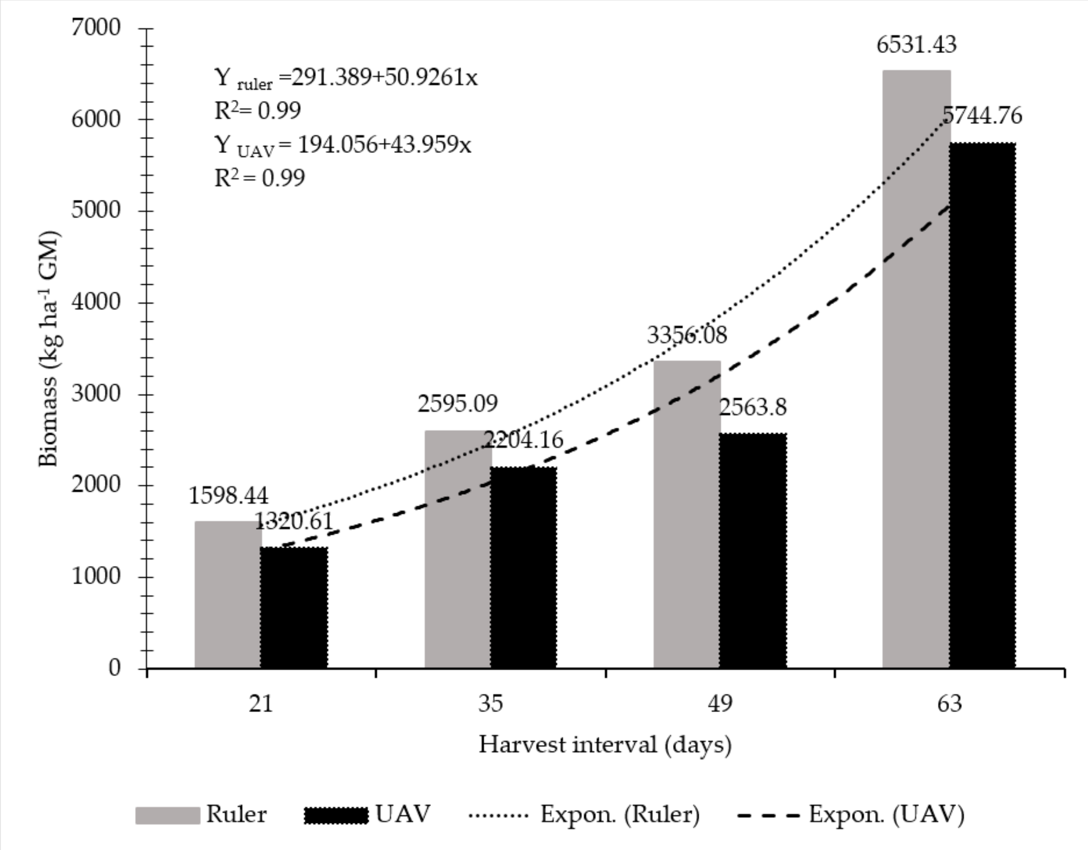

Figure 8. Biomass estimated by the ruler and by the UAV at different harvest intervals.

4. Conclusions

In this study, we examined the use of UAV photogrammetry to estimate biomass based on canopy height obtained with a digital elevation model and a digital surface model in Brazilian pastures. Firstly, we demonstrated that the applied technique is highly adequate for estimating canopy height.

Canopy height can be modeled with a high precision at different regrowth ages using high-resolution images obtained with a UAV (R^2 = 0.80). The DSMs cover more details than measurements taken with a ruler, which gives a lower average canopy height per experimental unit.

The coefficients of determination (R^2 = 0.74) and correlation (0.80) show that the canopy height obtained from images taken with a UAV is an adequate indicator for the estimation of herbage mass.

In order to provide an efficient management of the Brazilian pastures, the assessed technique should be performed considering a fixed-wing UAV. Such approaches enable the imaging of larger areas when compared to a multirotor UAV, which was used in the present work.

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Conflicts of Interest: The authors declare no conflict of interest.

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