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ANIMAL PRODUCTION

Canopeo and GreenSeeker applications as tools to support tropical pasture management

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ABSTRACT: This study determined whether Canopeo and GreenSeeker measurements in *Megathyrsus maximus* can estimate plant height, dry matter mass, morphological components, and content of crude protein and neutral detergent fiber at different days of growth. Five plots of 5 × 25m *M. maximus* grass were defined: subplots of 1×1m were evaluated every three days, in which the pasture shows 3, 6, 9, 12, 15, 18, 21, 24, 27, and 30 days of regrowth. The subplot was evaluated for canopy height and mass accumulation. The canopeo index (CI) obtained at a higher height was lower than those obtained at a smaller height. Higher measurement height increased the normalized difference vegetation index (NDVI) relative to 0.10 m. The highest indexes were observed since 18 d of regrowth. Except for the CI evaluated at 0.10 m of height, the indexes were not correlated to the chemical composition of the forage. The CI and NDVI were positively correlated to plant height, dry matter mass, and leaf index, whereas both were negatively correlated with stalk index. Thus, lower evaluation heights for CI and NDVI can be a good predictor of forage height. Values of 0.83 and 85.8 for NDVI and CI, respectively, indicated an appropriate time to start the grazing of *M. maximus*.
Key words: canopy height, *Megathyrsus maximus,* NDVI, optical sensor, ruminant.

Aplicativos Canopeo e GreenSeeker como ferramentas de apoio ao manejo de pastagens tropicais

RESUMO: O presente estudo teve como objetivo avaliar se os índices obtidos com Canopeo e GreenSeeker (NDVI) em *Megathyrsus maximum* são capazes de estimar altura de plantas, massa de matéria seca, componentes morfológicos e teor de proteína bruta e fibra em detergente neutro em diferentes dias de crescimento. Cinco parcelas de 5 × 25 m de capim *M.maximum* foram definidas: sub parcelas de 1 × 1 m foram avaliadas a cada três dias, nas quais a pastagem apresenta 3, 6, 9, 12, 15, 18, 21, 24, 27 e 30 dias de rebrota. A sub parcela foi avaliada quanto à altura do dossel e acúmulo de massa. O índice do Canopeo (IC) obtido em maior altura foi menor do que o obtido em menor altura. A maior altura de medição aumentou o NDVI em relação a 0,10 m. Os maiores índices foram observados desde 18 dias de rebrota. Exceto para o IC avaliado a 0,10 m de altura, os índices não foram correlacionados com a composição química da forragem. IC e NDVI correlacionaram-se positivamente com a altura da planta, massa de MS e índice foliar, e negativamente com o índice de colmos. Assim, menores alturas de avaliação para IC e NDVI podem ser um bom preditor da altura da forragem. Valores de 0,83 e 85,8 para NDVI e IC, respectivamente, indicam um momento adequado para o início do pastejo de *Megathyrsus maximum.*
Palavras-chave: altura do dossel, sensor óptico, *Megathyrsus maximum*, NDVI, ruminante.

INTRODUCTION

Pastures represent the most important source of livestock feeding for ruminants (BELLA et al., 2004). In this way, livestock systems need an accurate estimate of the biomass, canopy height, and nutritional value of the pastures to optimize pasture management, stocking rate, and animal productivity (CARDOSO et al., 2020). The vegetative mass is a function of canopy height (CH) and dry matter (DM) density (TUCKER 1980; MACHADO et al. 2002, FRICKE & WACHENDORF, 2013). Destructive sampling is the most accurate method to determine pasture availability (JÁUREGUI et al., 2019). Different methods have been developed to measure pasture production in the last two decades: rising plate meter and capacitance meter stick (SANDERSON et al., 2001). Traditional non-destructive methods have shown outstanding results in estimating green biomass locally (BELLA et al., 2004). However, with

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new technologies being developed, non-destructive sensing techniques can be used to evaluate pasture biomass, making it convenient for farmers.

Optical sensors that detect absorbed and reflected lights have been used to detect the qualitative differences among materials (KENYON, 2008). GreenSeeker® is one of these sensors that uses light-emitting diodes in the red (650 nm) and NIR (770nm) (CRAIN et al., 2012).The reflectance reading is calculated by an internal microprocessor, obtaining the normalized difference vegetation index (NDVI). The NDVI can be correlated with forage nitrogen uptake (FREEMAN et al., 2007). ANDERSSON et al. (2017) used a combination of NDVI and falling plate height index to estimate pasture biomass. CAMPANA (2017) also observed a linear increase of NDVI related to nitrogen doses and biomass yield in tropical pastures.

The Canopeo® mobile phone application is an image analysis tool developed in the MATLAB programming language (Mathworks, Inc., Natick, MA). The app can access the phone camera and analyze and classify all pixels in the image or video using color values in the red-green-blue system (PATRIGNANI & OCHSNER, 2015). It turns the color green into white with a smooth manual adjustment and produces the percentage of white pixels in a given frame (YELLAREDDYGARI & GUDMESTAD, 2017) that correspond to the pixels that meet the selection criteria (green canopy; PATRIGNANI & OCHSNER, 2015). Measuring the green color of an image's background by counting green pixels using digital image analysis may represent biomass (YELLAREDDYGARI & GUDMESTAD, 2017).

The Canopeo mobile device application was used to measure soybean canopy cover and showed promising results when compared with light interception measurements. The app showed to be very fast and valuable for this parameter (SHEPHERD et al., 2018). CHUNG et al. (2017) used the same application to evaluate sorghum biomass and concluded that the application could replace hand data collection of plant height, considering it as an easily accessible high-throughput phenotyping tool for quantifying biomass.

This evidence indicates a potential for Canopeo® and GreenSeeker® to be used as a tool to estimate biomass, light interception, and nitrogen of forage crops provided that proper calibration is done. Pastoral farming requires fast, reliable, and farmer-friendly methods to determine pasture availability, which is crucial to increasing the farm's profitability (JÁUREGUI et al., 2019). The present study hypothesizes that Canopeo and GreenSeeker, regardless of height measurement, provide similar estimates, which is positively associated with the biomass and chemical composition of *M. maximus* tropical pasture. The present study determined whether Canopeo and GreenSeeker measurements in *M. maximus* can estimate plant height, DM mass, morphological components, crude protein, and neutral detergent fiber at different days of growth.

MATERIALS AND METHODS

The trial was performed in the Grupo de estudos e Trabalhos em Agropecuária (GETAP), Universidade Federal de São Carlos (UFSCar), from December 2017 to February 2018. Before the trial, five plots of 5 × 25 m of a long-term managed *M. maximus* grass were defined. The pasture of each plot was mowed at 40-cm height 30, 24, 18, 12, and 6 days before the first sampling.

The first sampling was performed on December 09th, 2017. Sampling from each plot was performed every three days throughout the season. After 30 days of regrowth, the plot pasture was mowed at a height of 0.40-cm, and another cycle began. It resulted in ten samples for each plot in each cycle. Moreover, it was evaluated in three subsequent cycles in the present study. The experimental period finished on February 19th, 2018.

Plant height, Canopeo Index, NDVI, and destructive methods

Plot pasture was evaluated during each sampling day using non-destructive methods, such as plant height, CI, and NDVI, and destructive methods, such as "cut and weight." First, the pasture height was evaluated using a graduated ruler. The Canopeo was free obtained at Google Play Store®. Then, in the same plot, images were taken before cutting using a mobile phone to obtain CI and NDVI measurements using a GreenSeeker® crop sensing system (Trimble, CA, USA) at 16:00 h. Pictures were taken at 0.10, 0.20, 0.30, 0.60, and 0.90 m above the plants' canopy height using a monopod with a scale (Figure 1). Canopeo evaluates fractional green canopy cover (CI) based on color ratios in the picture. GreenSeeker® was used at 0.10, 0.20, and 0.30 m above canopy height. The GreenSeeker® sensor captures incident and reflected light from plants at 660 ± 15 nm (red) and 770 ± 15 nm (NIR). Five points were evaluated in each parcel. Normalized difference vegetation index was calculated according to the following equation (MULLA, 2013):

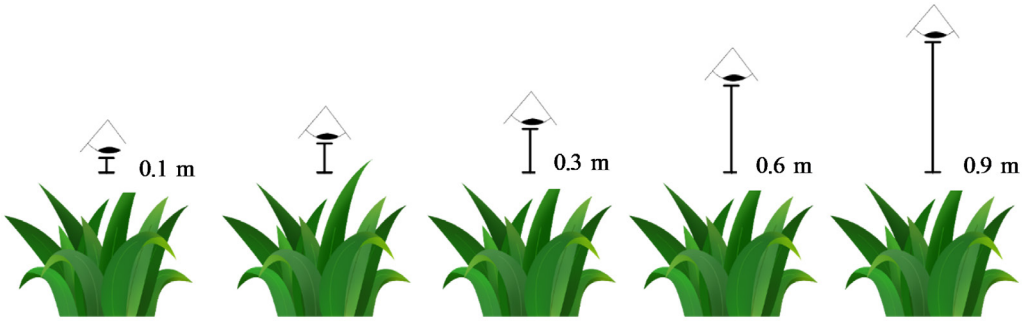

Figure 1 - Representation of height of evaluation.

$$NDVI = \left(\frac{NIR - Red}{NIR + Red}\right)$$

Pasture biomass (i.e., accumulated biomass above 0.40-cm height level) was determined by cutting 1 m² from each same plot (PENATI et al., 2005). Fresh mass was weighed, and a sample was used to assess the morphological composition, which was evaluated by the manual separation of the leaf lamina and stem. After these evaluations, each sample was dried for 72 h in a forced-air oven at 60 °C and ground in a knife mill (SL-31, Solab Científica, Piracicaba, Brazil) through a 1-mm sieve. Moreover, the samples were analyzed for DM (method 950.15,AOAC International, 2016), crude protein (CP; N × 6.25; method 984.13, AOAC International, 2016; Kjeldahl method), and neutral detergent fiber (aNDF-NDF) using α-amylase, without the addition of sodium sulfite, and expressed including residual ash (VAN SOEST et al., 1991).

Data analysis

The subplot measure was considered independent and defined as the experimental unit. Different height measurements were considered as measurements in the same experimental unit. Therefore, CI and NDVI were evaluated using the PROC MIXED of SAS 9.4, considering the following statistical model:

$$Y_{ijk} = \mu + T_i + \omega_{ii} + H_k + e_{iik}$$

With $\omega_{j:i} \approx N(0, \sigma^2_\omega)$ and $e_{ijk} \approx NRM(0, R)$, in which Y_{ijk} is the observed value of the dependent variable; μ is the overall mean; T_i is the fixed effect of time (i = 1–10) and the random error associated with each sample (j = 1–75); H_k is the fixed effect of height (k = 1–3 for NDVI and 1–6 for CI); e_{ijk} is the experimental error; N stands for Gaussian distribution; $\sigma_\omega^2$is the variance associated with the random error of experimental units; *NRM* stands for approximately normal multivariate distribution; and R is a matrix of variance and covariance due to repeated measures in the same experimental unit. CS, CSH, AR (1), ARH(1), TOEP, TOEPH, UN, and FA(1) matrixes were evaluated considering the Bayesian method.

Plant weight, mass, and chemical composition data were analyzed considering the following model:

$$Y_{ijk} = \mu + T_i + e_{ij}$$

with $e_{ij} \approx N(0, \sigma_i^2)$, in which Y_{ij} is the observed value of the dependent variable; μ, T_i, and N were previously defined; and e_{ij} is the experimental error and the variance associated with residual for each time of plant regrowth. Differences among the evaluation times were studied using Fisher's means test at 5% of probability.

Pearson correlations between the indexes (Canopeo and NDVI) obtained at different heights and plant information (plant height, DM mass, morphological and chemical composition) were obtained using PROC CORR. Significant correlations were studied with simple linear regression using PROC REG. For all statistical analyses, a 5% level of significance was considered.

RESULTS

CI and NDVI

Height and age of plant interaction showed no significant effect (P = 0.99) on the CI and NDVI (Table1). The CI obtained at higher heights (0.60 and 0.90 m) was lower (P ≤ 0.05) than that

Table 1 - Canopeo and Green Seeker (GS) index of *Panicum maximum* grass at different evaluation height (mean ± SE).

Item	----------Evaluated height (m)----------					----------Probabilities[1]----------		
	0.10	0.20	0.30	0.60	0.90	Height	Age	Height×Age
Canopeo	79.2±1.55^{ab}	79.8±1.56^{a}	79.2±1.50^{ab}	77.5±1.55^{bc}	75.8±1.55^{c}	<0.01	<0.01	0.99
GS	0.777±0.0078^{b}	0.790±0.0077^{a}	0.800±0.0078^{a}	-	-	<0.01	<0.01	0.99

[1]Probabilities: Height of evaluation; Age of regrowth (3, 6, 9, 12, 15, 18, 21, 24, 27, and 30 days); Height and age interaction effect.

obtained at smaller heights. Conversely, higher height measurements (0.20 and 0.30 m) increased ($P \leq 0.05$) the NDVI relative to 0.10 m. Days after the harvest affected ($P < 0.01$) both indices (Figures 2 and 3). The lowest ($P \leq 0.05$) indices were observed at 3 and 6 days of growth. The highest ($P \leq 0.05$) indices were observed since 18 days of regrowth, whereas intermediary values were observed between 9 and 15 days.

Forage mass, height, and chemical composition during growth

Plant height and DM mass increased ($P \leq 0.05$) almost linearly up to 30 after harvest (Figures 4 and 5). At 18 days of growth, the plants showed 2920 kg ha^{-1} of available forage and a height of 0.903 m. Throughout the cycle, time showed no effect ($P \geq 0.36$) on the plants' CP and NDF content (Figure 6). However, at a higher age (21 and 30 days), the plants had a higher ($P \leq 0.05$) DM content than the younger ones. The highest NDVI was observed since 18 days of regrowth. The NDVI value was 0.83, CI was 85.8, and CH was 0.903 m at 18 days of pasture regrowth.

Pearson correlation between indices (NDVI and CI) and chemical composition

The CI measurements at different heights did not correlate ($P \geq 0.23$) with the DM and NDF content of plants (Table 2). However, a positive correlation was observed ($R = 0.32$ and $P = 0.04$) between CI measured at 0.10 m of height and the CP content of pasture. Moreover, no correlation was observed ($P \geq 0.14$) between CP content and CI measurements obtained at the highest heights (≥ 0.20 m). In addition, there was no correlation effect ($P \geq$

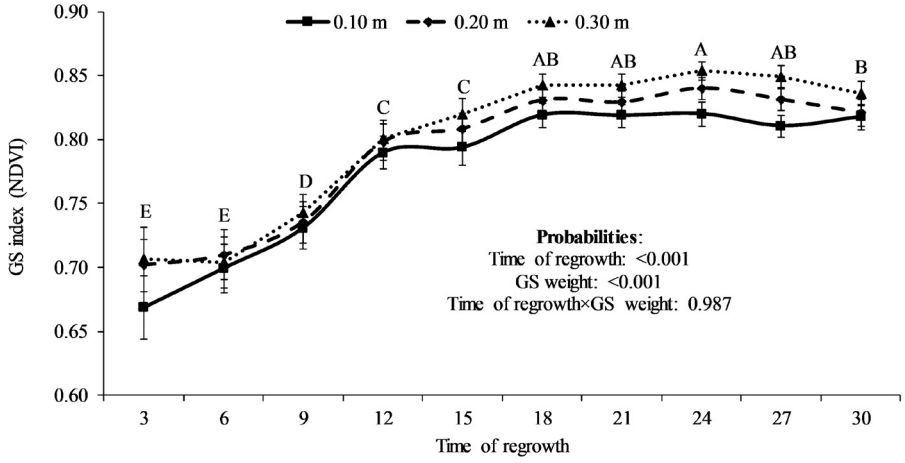

Figure 2 - GreenSeeker index (NDVI) of *Megathirsus maximum* grass at different time of growth and evaluation height.

[A-E]Fisher means test at 5% of probability. Bars are standard error of means.

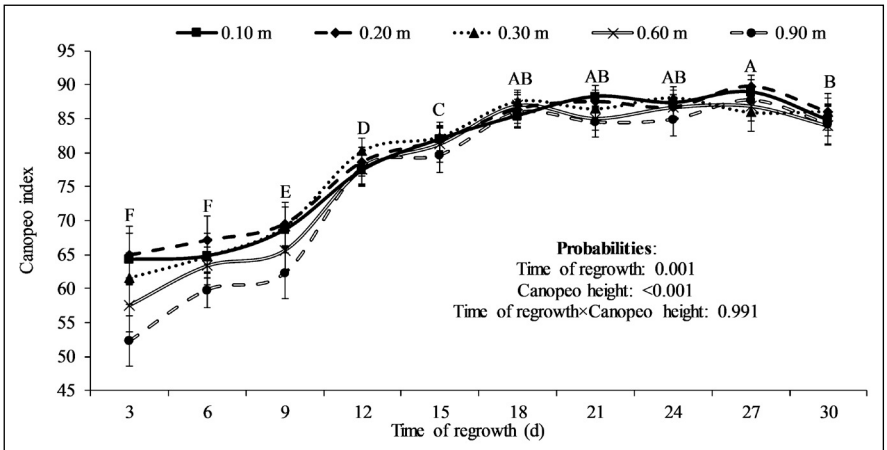

Figure 3 - Canopeo index of *Megathirsus maximum* grass at different time of growth and evaluation height.

[A-F]Fisher means test at 5% of probability. Bars are standard error of means.

0.19) between NDVI and DM, CP, and NDF content of the forage.

Pearson correlation between indexes (NDVI and CI) and height, DM mass and indexes of stalk and leaves of forage, and regressions

Both indices (NDVI and CI) showed a significant ($P < 0.001$) correlation with plant height, DM mass, and indices of stalk and leaves (Table 3). The correlations between indices and plant height range from 0.53 to 0.57. Higher height (≥0.30 m) of CI measurement showed a higher correlation (0.54–0.56) than that observed using a lower height of measurement or NDVI (0.47–0.49).

The stalk index was more correlated with the CI (−0.42–−0.40) than the NDVI (−0.34 and −0.33). Finally, the NDVI showed a lower correlation

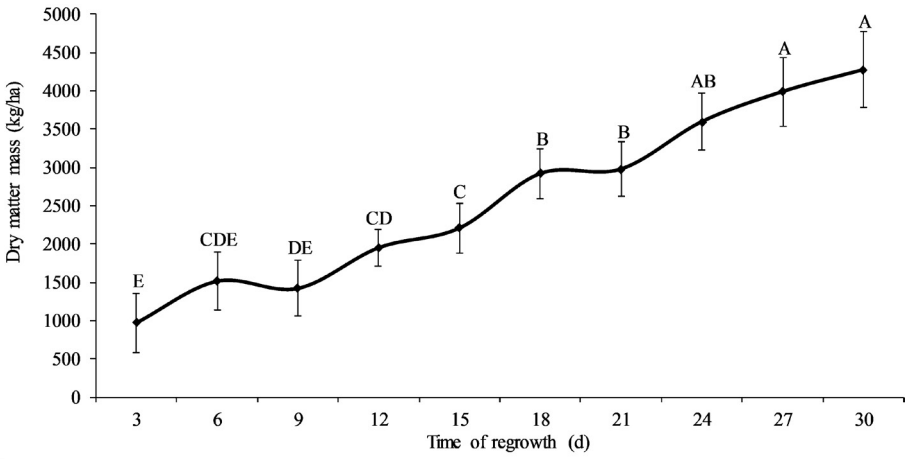

Figure 4 - *Megathirsus maximum* grass dry matter mass at different time of growth.

[A-E]Fisher means test at 5% of probability. Bars are standard error of means.

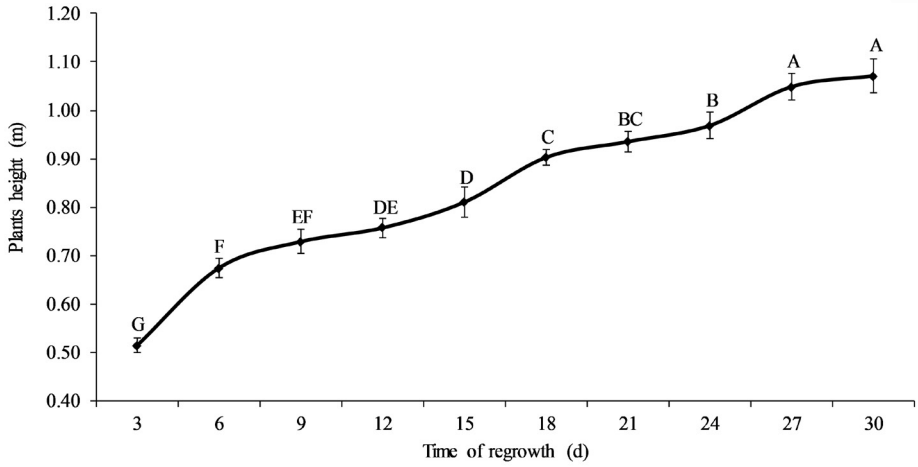

Figure 5 - *Megathirsus maximum* grass height at different time of growth.

[A-E]Fisher means test at 5% of probability. Bars are standard error of means.

(0.33–0.34) with a leaf index than CI (0.39–0.44). In regression equations (Table 4), it is possible to observe that increased height of CI and NDVI evaluation showed a positive effect on intercept estimation and reduced slope estimation when estimating plant height, DM mass, and leaf index.

DISCUSSION

The CI was reduced with increasing height evaluation from the canopy, whereas the more considerable distance between the GreenSeeker device and canopy increased the NDVI values.

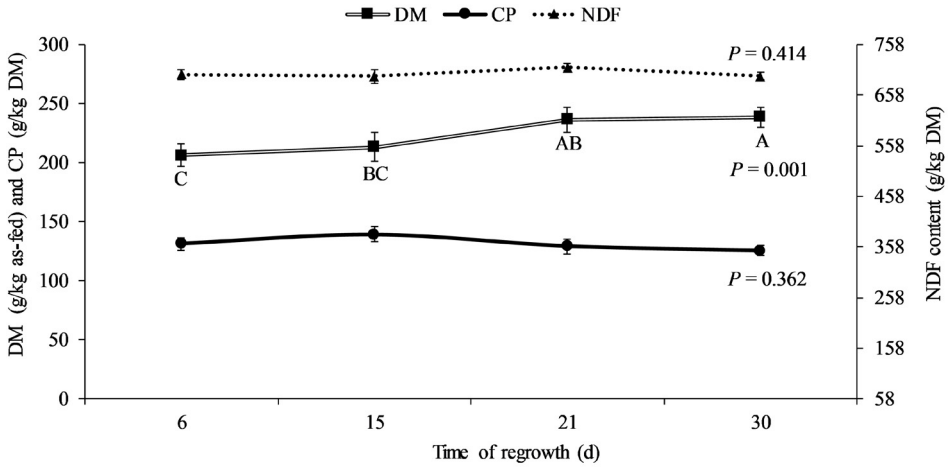

Figure 6 - *Megathirsus maximum* grass DM, CP, and NDF content at different time of growth.

[A-C]Fisher means test at 5% of probability. Bars are standard error of means.

Table 2 - Pearson correlation of CI and NDVI index of *Megathirsus maximum* grass at different evaluation height with dry matter (DM), crude protein (CP), and neutral detergent fiber (NDF) content [R (Probability)].

Index and height	DM	CP	NDF
----------Canopeo (CI)----------			
0.10 m	-0.19 (0.23)	0.32 (0.04)	-0.09 (0.58)
0.20 m	-0.19 (0.23)	0.23 (0.14)	-0.07 (0.67)
0.30 m	0.05 (0.65)	0.04 (0.73)	-0.05 (0.70)
0.60 m	-0.10 (0.38)	0.11 (0.32)	-0.06 (0.60)
0.90 m	-0.06 (0.62)	0.15 (0.20)	-0.02 (0.88)
----------GreenSeeker (NDVI)----------			
0.10 m	-0.06 (0.63)	0.12 (0.31)	-0.07 (0.56)
0.20 m	-0.15 (0.19)	0.13 (0.25)	-0.09 (0.45)
0.30 m	-0.14 (0.23)	0.13 (0.28)	-0.11 (0.35)

Canopeo initially was tested with a camera kept at about 1.5 m from the top of the canopy using a 1.5 m monopod (PATRIGNANI & OCHSNER, 2015), but like any other measurement tool, it depends on the end user's operation and cannot compensate for some operational errors by the user. A limitation of Canopeo is the need to always keep the camera at an appropriate height above of the canopy (PATRIGNANI & OCHSNER, 2015). We decided to try different heights from the top of the canopy because tropical pastures can be naturally high. However, the NDVI value is obtained using the energy relation reflected light or irradiated in the infrared and red near the canopy. Contrary to our findings, MARTIN et al., (2012) observed that a distance between GS and canopy reduces the NDVI values. Lower heights are also more attractive for the user because less effort is required to hold, finding good NDVI values for a height of 31 cm (MARTIN et al., 2012).

The light interception (LI) of *M. maximus* cv. Mombaça is 95% with a height of 0.90 m (CARNEVALLI et al., 2006). The height of 0.90 m for Mombaça is well documented for its high correlation

Table 3 - Pearson correlation of CI and NDVI of *Megathirsus maximum* grass at different evaluation height with plants height, DM mass, and index of stalk and leaf.

Index and height	Plant height	DM mass	Stalk index	Leaf index
----------Canopeo (CI)----------				
0.10 m	0.53	0.49	-0.41	0.41
0.20 m	0.54	0.49	-0.41	0.42
0.30 m	0.56	0.56	-0.44	0.44
0.60 m	0.54	0.55	-0.40	0.39
0.90 m	0.56	0.54	-0.42	0.41
----------GreenSeeker (NDVI)----------				
0.10 m	0.54	0.47	-0.34	0.34
0.20 m	0.56	0.49	-0.33	0.33
0.30 m	0.57	0.49	-0.33	0.33

*Probabilities (P) < 0.001 for all correlations.

Table 4 - Regression of plant height, DM mass and leaf index of *Megathirsus maximum* in function of CI and NDVI evaluated at different height.

Item	Intercept		Slope		R^2	RMSE[1]
	Estimate	SE	Estimate	SE		
Plant height, cm						
Canopeo (CI)						
0.10 m	1.82×10^{-1}	1.02×10^{-1}	8.48×10^{-3}	1.32×10^{-3}	0.29	0.177
0.20 m	1.54×10^{-1}	1.06×10^{-1}	8.77×10^{-3}	1.36×10^{-3}	0.29	0.176
0.30 m	2.13×10^{-1}	6.94×10^{-2}	7.94×10^{-3}	8.63×10^{-4}	0.31	0.167
0.60 m	3.03×10^{-1}	6.23×10^{-2}	6.95×10^{-3}	7.88×10^{-4}	0.29	0.169
0.90 m	3.35×10^{-1}	5.54×10^{-2}	6.67×10^{-3}	7.13×10^{-4}	0.32	0.166
GreenSkeeker (NDVI)						
0.10 m	-1.92×10^{-1}	1.20×10^{-1}	1.33	1.54×10^{-1}	0.29	0.168
0.20 m	-2.71×10^{-1}	1.22×10^{-1}	1.41	1.53×10^{-1}	0.31	0.167
0.30 m	-2.51×10^{-1}	1.16×10^{-1}	1.37	1.44×10^{-1}	0.33	0.163
DM mass, kg/há						
Canopeo (CI)						
0.10 m	-1.30×10^{3}	557	39.9	7.16	0.24	928
0.20 m	-1.40×10^{3}	569	40.9	7.27	0.24	926
0.30 m	-2.90×10^{3}	609	69.5	7.55	0.31	1438
0.60 m	-2.13×10^{3}	547	61.1	6.89	0.30	1455
0.90 m	-1.63×10^{3}	496	55.7	6.36	0.29	1459
GreenSkeeker (NDVI)						
0.10 m	-5.41×10^{3}	1.12×10^{3}	1.03×10^{4}	1.43×10^{3}	0.22	1530
0.20 m	-5.97×10^{3}	1.13×10^{3}	1.08×10^{4}	1.43×10^{3}	0.24	1516
0.30 m	-5.67×10^{3}	1.09×10^{3}	1.03×10^{4}	1.35×10^{3}	0.24	1512
Leaf index (%)						
Canopeo (CI)						
0.10 m	68.2	5.16	2.94×10^{-1}	6.63×10^{-2}	0.16	8.60
0.20 m	66.9	5.26	3.07×10^{-1}	6.71×10^{-2}	0.17	8.56
0.30 m	73.0	3.07	2.52×10^{-1}	3.81×10^{-2}	0.19	7.25
0.60 m	77.2	2.78	2.05×10^{-1}	3.51×10^{-2}	0.16	7.41
0.90 m	77.9	2.49	1.98×10^{-1}	1.96×10^{-2}	0.17	7.34
GreenSkeeker (NDVI)						
0.10 m	66.3	5.57	34.3	7.11	0.11	7.63
0.20 m	65.8	5.69	34.4	7.15	0.11	7.60
0.30 m	66.8	5.49	32.7	6.80	0.11	7.63

[1]Root of means square error.

with the time of the start of grazing. Values of 0.83 for NDVI and 85.8 for CI allow predicting LI and the height of the forage. Values above those previously mentioned for NDVI and CI allow deducing an increased forage growth. NDVI has a high correlation with forage height and is related to forage yields. A low NDVI occurs because lower forage has a low percentage of vegetal coverage of the soil, and of the reflected energy, part of it comes from the soil and the other part of the plant with a lower NDVI.

BÜCHI et al. (2018) and SHEPHERD et al. (2018) reported a correlation between canopy

cover and height using Canopeo and other methods of measurements. CHUNG et al., (2017) reported significant correlations between green pixel percentage and plant height. Mostly, Canopeo can correctly measure the fractional coverage of the green canopy (JÁUREGUI et al., 2019). Eighteen days of regrowth possibly have an excess of green resulted in the fast and effective classification by the Caponeo. Likewise, Canopeo had fewer problems with the small size of the seedlings, which may explain the CI's low values for the age of 3–6 days (PATRIGNANI & OCHSNER, 2015). CANO et al. (2004) reported an increase in Tanzania grass height and DM mass almost linearly until 30 days after harvest, which is similar to our results. However, older plants had a higher DM content than younger plants resulting from advancing age where in CH increases resulting in dead material due to changes in the green leaf and green stem portions of the plants and in senescent material related to physiological factors that are linked to the death and beheading of tillers (BARBOSA et al., 2002).

Although, no correlation was observed between the height content of DM and NDF of the pasture for the NDVI and CI, a positive correlation (R = 0.32) can be observed between the CP and the CI measured at 10 cm; the excess of the green index in forages in the position (height: 10 cm) for taking pictures can be related to the protein content. Moreover, at a height of 10 cm, the Caponeo App can classify the values of red, green, and blue colors, and the pixels can be analyzed based on a ratio of red for green and blue for green pixels, which is interpreted as a green index (PATRIGNANI & OCHSNER, 2015).

Both indexes (NDVI and CI) showed a significant correlation with plant height, DM mass, and indexes of stalk and leaves, but the increase in height level leads to an increase in the intercept and a reduction in the slope for the CI and NDVI, showing a lower response of the model to predict grass height for both the CI and NDVI. Lower height assessments for the CI and NDVI can be a good predictor of forage height, and further research is needed to assess the different types of heights using the Canopeo and GreenSeeker device applications in the different classes of forage to produce more concrete conclusions. However, it is essential to emphasize that Canopeo is faster in calculating canopy cover percentage, can be easily applied in the field (SHEPHERD et al., 2018), and has a low-cost and easy operation (CHUNG et al., 2017).

CONCLUSION

Values of 0.83 and 85.8 for NDVI and CI, respectively, indicate an appropriate moment for the start of the grazing of *M. maximus*. Lower height measurements from the top of the canopy for CI and NDVI better predict forage height. Canopeo and GreenSeeker can be a powerful, accessible, and easy-to-use tool for farmers to facilitate tropical pasture management.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; and in the decision to publish the results.

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AUTHORS' CONTRIBUTIONS

All authors contributed to the conception and writing of the manuscript and critically revised the manuscript and approved of the final version.

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