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ORIGINAL ARTICLE

FOR A GREATER EFFICIENCY OF THE BRAZILIAN PASTURES: ANALYSIS OF GROSS PRIMARY PRODUCTIVITY WITH CASA-SEBAL MODEL AND SATELLITE DATA

Por uma Maior Eficiência das Pastagens Brasileiras: Análise da Produtividade Primária Bruta com o Modelo CASA-SEBAL e Dados de Satélite

Gabriel Alves Veloso
Universidade Federal do Pará – UFPA, Brazil
Laboratório de Geografia Física e Cartografia - LAGEO
gveloso@ufpa.br

Manuel Eduardo Ferreira
Universidade Federal de Goiás – UFG, Brazil
Laboratório de Processamento de Imagens e Geoprocessamento - LAPIG
manuel@ufg.br

Bernardo Barbosa da Silva
Universidade Federal de Campina Grande – UFCG, Brazil
bbdasilva.ufpe@gmail.com

Lucas Augusto Pereira da Silva
Universidade Federal Uberlândia – UFU, Brazil
lucasagusto@ufu.br

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Abstract
Climate change, induced by human activities, is already a reality in the most diverse environments on Earth. Therefore, modelling forage capacity for herds has become an important management strategy, aiming to reduce environmental impacts and increase efficiency in meat production. This work aimed to estimate the Gross Primary Productivity (GPP) in pasture areas in savanna environments (locally known as Cerrado) of the State of Goiás, Brazil, with specific parameterization data for Brachiaria species. The experiment was carried out in pasture areas in the Rio Vermelho hydrographic basin (BHRV), in the western portion of Goiás, using Landsat 8 OLI / TIRS sensor satellite images, in which the variation in the GPP was recorded in 22 images in the period from October 2014 to May 2018. This parameter was estimated by coupling the SEBAL algorithms to estimate evapotranspiration, combined with the CASA model, which, together with surface data, calculates the GPP. Furthermore, for this same area, an adaptation of the GPP product methodology obtained by MOD17A2H was also carried out for Landsat 8 images to understand better the variation in GPP in medium spatial resolution images (30 m). Among the results, the SEBAL / CASA method proved to be more efficient among the methods applied in this research, following the climatic seasonality of the region and its influences on the pasture areas, with a variation of 0.10 to 5 g C m-2. Therefore, the estimate of the GPP aiming at a reading of the pasture and local climatic data presented better results with the calibration of the models with specific data.

Keywords: Carbon Sequestration; livestock; Remote sensing.

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Resumo
As mudanças climáticas, induzidas pelas atividades antrópicas, já são uma realidade nos mais diversos ambientes da Terra. Modelar a capacidade de forragens para rebanhos passou a ser uma estratégia de manejo importante, visando reduzir impactos ambientais e aumentar a eficiência na produção de carne. Este trabalho teve como objetivo estimar a Produtividade Primária Bruta (GPP) em áreas de pastagens no Cerrado goiano, com dados de parametrização específicos para pastagens da espécie Brachiaria. O experimento foi realizado em áreas de pastagem na bacia hidrográfica do Rio Vermelho (BHRV), na porção oeste de Goiás, utilizando imagens de satélite do sensor Landsat 8 OLI / TIRS, em que a variação do GPP foi registrada em 22 imagens no período de outubro de 2014 a maio de 2018. A estimativa deste parâmetro foi obtida através do acoplamento dos algoritmos SEBAL para estimar a evapotranspiração, combinados com o modelo CASA, que, juntamente com os dados de superfície, calcula o GPP. Além disso, para esta mesma área, também foi realizada uma adaptação da metodologia do produto GPP obtida pelo MOD17A2H para imagens Landsat 8 para entender melhor a variação do GPP em imagens de resolução espacial média (30 m). Dentre os resultados, o método SEBAL/CASA demonstrou ser mais eficiente entre os métodos aplicados nesta pesquisa, acompanhando bem a sazonalidade climática da região e suas influências nas áreas de pastagem, ao apresentar uma variação de 0,10 a 5 g C m^{-2}. Portanto, a estimativa da GPP visando uma leitura da pastagem e dados climáticos locais, apresentou melhores resultados com a calibração dos modelos com dados específicos.

Palavras-chaves: Sequestro de Carbono; Pecuária; Sensoriamento Remoto.

1. INTRODUCTION

In the last decade, the issue of climate change has been widely debated by research centers and the international press. Since then, greenhouse gases (GHG) resulting from anthropogenic activities have been identified as mainly responsible for climate change, with an emphasis on carbon dioxide (CO_2) and methane (CH_4). Although unanimity on such emissions as the cause of the intensification of the global average temperature is incomplete, heads of State and scientists are mobilized to develop public policies and technologies for the mitigation of emissions and reabsorption of atmospheric carbon (SILVA *et al.*, 2013).

One alternative for reducing CO2 emissions is the control and increase of gross primary productivity (GPP) of natural and artificial systems by recovering degraded areas (SILVA *et al.*, 2013). This parameter is considered a fundamental property, as it represents the sequestration of atmospheric carbon by converting it into organic matter through photosynthesis and storing it in vegetation and soil. Furthermore, the indication of GPP becomes an excellent parameter to attest to the quality of such systems and, indirectly, their efficiency, as in the case of pastures (i.e., high GPP throughout the year, higher quality, and capacity for nutritional support for herds).

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In this context, Brazil has a prominent position on the world stage due to its natural potential to fix carbon from the atmosphere, with greater significance for the two largest biomes in South America, the Amazon rainforest and the Cerrado (savanna). Nevertheless, unfortunately, the country also stands out for the continuous increase in GHG emissions due to deforestation and changes in land use, characterized by the expansion and intensification of agriculture and pastures in Cerrado areas (ROSA and SANO, 2013).

In return, the Brazilian government has been developing mechanisms to mitigate GHG emissions, especially since 2010, with the creation of the ABC (Low Carbon Agriculture) plan, prepared following Article 3 of Federal Decree No. 7,390 / 2010, whose purpose is the organization and planning of actions to be carried out to adopt sustainable production technologies. The ABC Plan, developed for the agribusiness sector, aims to provide credit to rural producers to adopt technologies to reduce/mitigate GHG emissions. One of the main goals established in this program is the recovery of 15 million hectares of degraded pastures and the implantation of 4 million hectares destined for crop-livestock-forest integration (ILPF) (CNA, 2014). According to the Food and Agriculture Organization of the United Nations (FAO, 2009), the recovery of degraded pastures has been cited as one of the most critical agricultural policies for mitigating climate change, as it significantly contributes to the sequestration of atmospheric carbon, and it also boosts the production of animal protein without the need to expand the agricultural frontier (DIAS-FILHO, 2011). These measures are also crucial for the growing demand for food, which is estimated to be twice as high as today's by 2050 (FAO, 2009). Therefore, the big challenge is producing more, causing less environmental damage.

It is, therefore, of significant importance to know the real potential of pasture areas in Brazil (the largest producer of beef in the world) to expand the sequestration of carbon (and other gases, such as methane and nitrous oxide), as well as supplying the demand for animal protein. Only then will it be possible to adopt strategic planning actions and preventive and/or corrective measures in environmental terms.

In this context, remote sensing (RS) is an essential tool in monitoring land use and can be used to identify changes in different areas of the Earth's surface. Another advantage of RS is the multiple spatial and temporal resolutions of the other sensors onboard satellites, which allows a better understanding of the various biophysical phenomena resulting from the interaction of solar radiation with the various types of ground cover. Unfortunately, traditional methods can hardly obtain such land cover

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parameters (although of great importance). Therefore, these are restricted to small areas, as is the case of micrometeorological towers and other classic techniques.

In this context, several orbital sensors have been used to determine gross primary productivity, including the Enhanced Thematic Mapper Plus - ETM + (Landsat 7 platform), Thematic Mapper- TM (Landsat 5 platform), Moderate Resolution Imaging Spectroradiometer - MODIS sensors (Terra and Aqua platforms) and, more recently, Operation Land Imager - OLI and Thermal Infrared Sensor - TIRS sensors (Landsat 8 platform). As an example, there is the work of Silva *et al.* (2013), who estimated the GPP in the irrigated perimeter of São Gonçalo with images from the Landsat 5 TM satellite, and Danelichen *et al.* (2015), who performed the GPP estimate in a transition area between the Amazon rainforest and the cerrado, with images from Landsat and MODIS.

Methods were developed to use RS images to determine the GPP and some complementary surface meteorological data. One of the outstanding methodologies is the one that resulted in the product MOD17A2H (based on data from the MODIS orbital sensor), which provides data on gross primary productivity for various terrestrial ecosystems, with a spatial resolution of 1 km (for MOD17A2, collection 5) and 500 meters (for MOD17A2, collection 6), the same being generated for eight days based on RS data and meteorological data from reanalysis. Another similar methodology was developed by Bastiaanssen and Ali (2003). They adapted the method for estimating radiation and energy balances, derived from the Surface Energy Balance Algorithm for Land (SEBAL) algorithm, coupling the biomass production model and the efficiency model for the use of light and giving rise to the Carnegie Ames Stanford Approach (CASA) algorithm, based on the perspective of using remote sensing as data input (parameters) for the global analysis of gross primary productivity.

Estimating these biophysical parameters, such as GPP, in sensors with better spatial resolution becomes a critical challenge due to the significant variability of pasture areas and the intense and dynamic use of Cerrado areas. In this case, the application of these methodologies in medium-high spatial resolution images, such as the Landsat 8 OLI / TIRS sensor, can contribute to the understanding of these parameters on a regional or even local scale (at the level of rural properties) and can assist in the management and planning of these areas to make them more productive and environmentally sustainable.

Based on the above, this research elaborates a strategy for quantifying GPP in pasture areas, having as reference/test area the Rio Vermelho Hydrographic Basin (BHRV), as part of a long-term research project (PELD) in the Midwestern region of Brazil.

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It is located in the western part of the State of Goiás, Brazil, and is very important for national livestock and as one of the main tributaries of the Araguaia-Tocantins River. Currently, 68% of this basin's surface is under agricultural production (VIEIRA, 2015). Thus, this work aims to estimate the GPP in pasture areas in BHRV, using images from the Landsat 8 satellite OLI / TIRS sensors, using specific biophysical parameters of *Brachiaria brizanta* and local climatic data.

The relevance of this study is to generate new information about GPP in pasture areas in a more dynamic way and with greater spatial precision (i.e., greater detail), using remote sensing data and local surface climatic data. The results obtained in this research will contribute to 1) Subsidizing decisions regarding management actions in degraded pasture areas (less nutritional support capacity for cattle), to improve the efficiency of the production chain by increasing production without the need to expand the agricultural frontier (that is, with new deforestation); 2) Generating more detailed spatial and temporal data for the GPP, helping to understand carbon sequestration in such areas, thus contributing to the monitoring of areas favoured by plans to reduce greenhouse gas emissions; 3) Supporting research on a local and regional scale, which requires information on the spatial distribution of GPP in pasture areas.

2. MATERIAL AND METHODS

2.1. Study Area

The hydrographic basin of the Rio Vermelho (BHRV) is located in the western portion of the State of Goiás, between parallels 14° 55' and 16° 20' South and meridians 50° 00' and 51° 30' West (Figure 01). It comprises an area of 10,824.60 km², covering territory from 11 municipalities in Goiás, partially and/or completely (Goiás, Aruanã, Matrinchã, Britânia, Jussara, Santa Fé de Goiás, Fazenda Nova, Novo Brasil, Buriti de Goiás, Faina and Itapirapuã) (VIEIRA, 2013; SANTOS, 2014).

The BHRV plays a vital role in the State of Goiás from a historical, cultural, and political point of view, as it was on its banks that gold exploration began. As a result, the development of provinces or villages culminated in the formation of the State's first capital in 1732 (remaining there until 1942, in the city of Goiás, when the administrative headquarters was transferred to the new capital, Goiânia). Currently, economic development is based on agribusiness, associated with the intense use of the soil, with high conversion rates of the native Cerrado into pasture areas (most) and crops.

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At the state level, this basin represents human occupation of more than 160,000 people (± 3.7% of the total population of the State), with the municipalities of Goiás and Jussara having a higher occupation rate, with 1/4 of the people of the basin (IBGE, 2010).

The Rio Vermelho has its source in the Serra Dourada Formation (approximately 17 km from the city of Goiás), debouching into the emblematic Rio Araguaia (in Aruanã - GO), covering an extension of about 120 km. Among its main tributaries on the right bank, the rivers Bugres and Ferreira stand out, while on the left bank, it flows into Ribeirão da Água Limpa, Ribeirão Samambaia, Rio Itapirapuã, Ribeirão do Capim, Ribeirão da Bocaína, and the Rio Uvá.

The litho-geomorphological aspects of the Rio Vermelho basin are characterized by the formations of the Araguaia Group (Quaternary) and Cachoeirinha Formation (Tertiary), with planing surfaces distributed in the south, southeast, north, northwest, and northeast, and folded and raised structures hills spread over all portions, including river plain and alluvial bands in the valleys of the main watercourses. The soils are categorized as Oxisols, Argisols, Gleisols, Cambisols, Plintosols, and Quartzarenic Neosols (VIEIRA *et al.*, 2015; DEL' ARCO *et al.*, 1999). The BHRV is fully integrated into the Cerrado biome, presenting forest phytophysiognomies (e.g., dry and gallery forests), arboreal (e.g., Cerradão and Cerrado *sensu stricto*), and shrub-grass (e.g., Campo Sujo and Campo Limpo). The Campo Cerrado class, also present in the basin, has transition characteristics between tree and shrub physiognomies. Some areas are still used as native pastures, such as the Campo Sujo physiognomy, although most are cultivated fields (SANTOS, 2014).

The Cerradão class, as described by Moysés (2008), represents vegetation with the presence of *sclerophilia* with forest physiognomy, its elements having a greater development, thanks to soil conditions, favored by shading and humidity, forming important components in the decomposition of organic matter used by plants. The Cerrado has three strata: upper (trees between 10 and 12 meters high, and some with 15 to 18 m); medium, with more or less dense shrubs, which can reach up to 3 meters in height; and lower, with a lower number of species, lower in height (GUIMARÃES *et al.*, 2006). The Campo Cerrado class, on the other hand, corresponds to a low to medium vegetation type, exhibiting a herbaceous-grassy set with sub-shrubs and well-spaced shrubs. Examples are grass-arrow (*Tristachya leiostachya*), cinnamon-ema (*Vellozia squamata* Pohl), murici (*Byrsonima crassifólia* - L- Rich), and red cherry (*Eugenia calycina*) (MOYSÉS, 2008). The canopy of Campo Cerrado is well spread, with an average of 10% coverage. Some species, exceptionally, reach 10 meters in height, such as gomeira (*Vochysia thyrsoidea*). Occasionally, herbaceous plants have a high density, emphasizing grasses (GUIMARÃES *et al.*, 2006). As for the variability of climatic conditions, the BHRV has the same climatic characteristics as the State of Goiás, characterized as a semi-humid tropical climate, with two distinct rainfall periods: dry (May to September) and rainy (October to April). However, January generally presents an excellent rainfall discharge in the basin, with records of up to 335 mm (SANTOS and FERREIRA, 2017).

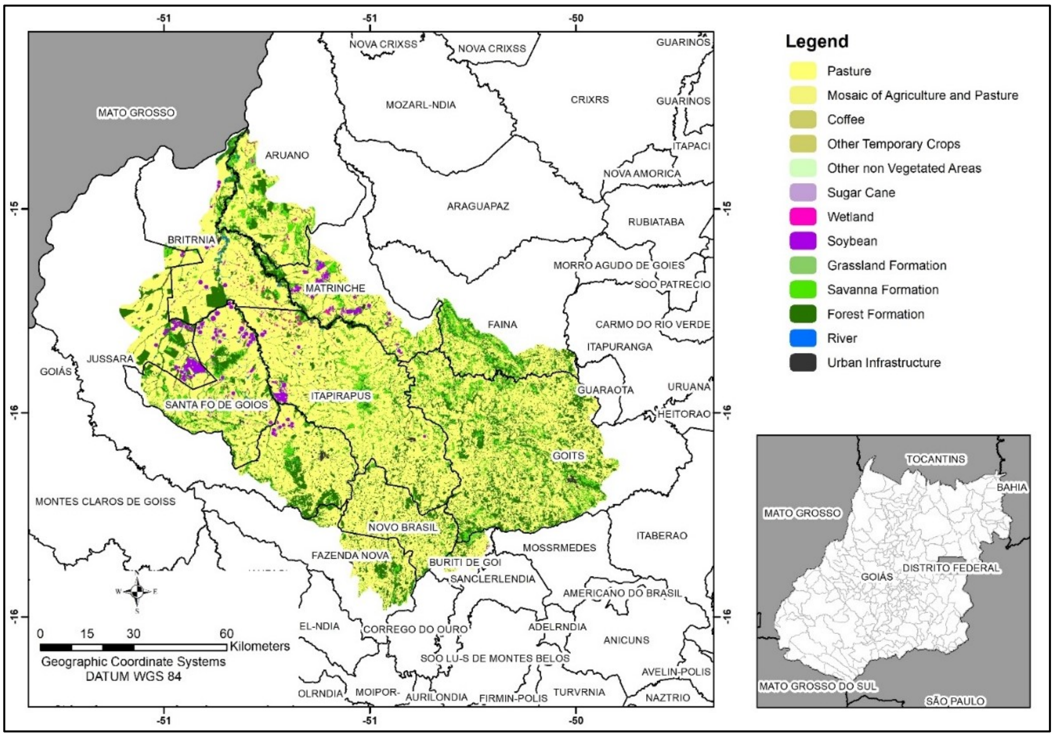

Figure 01 - Location map of the study area in the Rio Vermelho Hydrographic Basin.

In the specific case of the BHRV, Vieira *et al.* (2014) state that one of the main characteristics of the climate is the presence of high temperatures throughout the year, with monthly averages ranging from 23 to 28 ºC (with minimum and maximum temperatures of 20 and 32 ºC, respectively). There are habitual and exceptional precipitations. The exceptional rainfalls are characterized as intense and localized, capable of saturating the soils and causing a significant volume of water in the rivers. For example, the Rio Vermelho's striking flooding (municipality of Goiás) in December 2001 stands out. Furthermore, precipitation during the rainy season can be irregular, with days of heavy rain interspersed with short periods of drought.

The natural characteristics associated with the accelerated process of colonization/occupation of the region in the mid-1970s and 1980s caused a series of

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changes in the original configurations of the BHRV (VIEIRA, 2015). The productive regional bias is mainly in cattle ranching (occupying more than 53% of the basin), mechanized agriculture (with rainfed and irrigated areas), and, in certain parts, the production of subsistence fruit and vegetables (SANTOS, 2014). This socioeconomic and environmental condition is subsidized by essential physical-biotic aspects, which characterize the primary contribution of the productive system, among them the pedological (predominance of soil classes of Oxisols and Argisols), topographic (medium-high slope) and climatic (with good rainfall distribution) characteristics, associated with technological and financial inputs by producers in the region.

2.2. Digital Processing of Landsat 8 OLI / TIRS Images (CASA-SEBAL)

The above-ground GPP estimate, obtained by remote sensing, can be made by combining the model of estimation of photosynthetically active radiation absorbed by vegetation (APAR) (proposed by MONTEITH, 1972), together with the model of efficiency of the use of light in photosynthesis (presented by FIELD *et al.*, 1995). Furthermore, Bastiaanssen and Ali (2003) consider that the water factor in the model by Field *et al.* (1995) can be represented by the evaporative fraction, which integrates the set of procedures of the SEBAL algorithm to estimate evapotranspiration through the quantification of the energy balance components.

For this methodological procedure, the following cartographic bases were used to calculate the GPP for the study area: a) MODISQ1H and MOD15A2H images from the MODIS sensor, made available by the North American Geological Service (USGS) and Image Processing and Geoprocessing Laboratory (LAPIG) online platforms; b) MOD17A2H images from the MODIS sensor, made available by the USGS; c) OLI / TIRS images from the Landsat 8 satellite for the BHRV, made available by the USGS; d) Time series of meteorological data from meteorological stations available on the website of the National Meteorological Institute (INMET) for parameterization of the algorithms; e) Mapping of pasture areas, made available by LAPIG, for the Rio Vermelho Hydrographic Basin.

Thus, OLI / TIRS - Landsat 8 images, corresponding to orbit 223 / point 71, were processed over three years, selecting those with lesser atmospheric contamination, in which 22 images were obtained between October 2014 and May 2018. In addition to these

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images, meteorological data from the Goiás automatic station (A014), located in the BHRV, were used under the responsibility of the National Meteorological Institute (INMET).

The following meteorological data were used to obtain the GPP by coupling the CASA algorithm in SEBAL: temperature and relative humidity, global solar radiation, wind speed, and atmospheric pressure. In the SEBAL algorithm, the energy balance equation was used to estimate the latent heat flow (LE) as a residue of the other components: Soil heat flow (G), sensitive heat flow (H), and the balance radiation (Rn), according to the equation below:

$$LE = Rn - H - G \quad (01)$$

With the components of the energy balance, the evaporative fraction was estimated based on the following equation:

$$FE = \frac{LE}{(Rn - G)} \quad (02)$$

Details of the estimate of the radiation balance and energy balance components can be found in Veloso *et al.* (2020). The evaporative fraction was used to estimate the GPP, using the methodology proposed by Bastiaanssen and Ali (2003), with Photosynthetically Active Radiation (PAR, in Wm^{-2}) first. For the PAR estimate, the value of 0.58 was adopted as a factor for harnessing sunlight. The specialized literature estimated that the fraction of PAR used by vegetation in its photosynthesis process is approximately 50%. However, Galvani (2009) indicated ratios between 44% and 69%, while Silva *et al.* (2013) pointed out that, for the Cerrado region, the value of photosynthetically active radiation represents 58% of the global radiation, applicable for the dry and rainy seasons. These authors used data from the SONDA Project to carry out the research. For this reason, the same utilization factor (i.e., 58%) was followed, obtained by Silva *et al.* (2013). Thus, the PAR was calculated according to the equation:

$$PAR = 0.58 * Rsolar \quad (03)$$

In turn, it is known that only part of the photosynthetically active radiation (PAR) is absorbed by vegetation (FPAR), found in the visible light spectrum range between 0.4 and 0.7 µm. Several studies have demonstrated a high relationship between FPAR and some vegetation indexes, especially NDVI (SELLERS *et al.*, 1992; POTTER *et al.*, 1993; SELLERS *et al.*, 1997; DEFRIES *et al.*, 1997; FRIEDL, 1997; DEFRIES and Los, 1999;

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GOETZ *et al.*, 1999). In addition, this relationship has been observed in tropical forest areas in Sumatra (GUILLEVIC and GASTELLU-ETCHEGORRY, 1999). Therefore, for the FPAR estimate of this research, the correlation between FPAR and NDVI was performed in pasture areas in 2014 using the products MOD13Q1H (NDVI) and MOD15A2 (FPAR). The coefficients obtained in this relationship were used to estimate the FPAR with the NDVI images from Landsat 8 OLI / TIRS in the BHRV.

The correlation coefficient for the rainy season was r = 0.6108 and p-value> 0.0001. This result is associated with the interference of the atmosphere, which in the case of the MOD13Q1 and MOD15A2 images, even with the pixel quality filters (to avoid clouds), presents much noise in this period. For the drought period, with little interference from the atmosphere, the NDVI and FPAR values showed a high correlation, obtaining the coefficient of determination in the order of 0.8178 and p> 0.0001, demonstrating the feasibility of estimating the FPAR with NDVI images. Thus, the FPAR for pasture can be estimated according to the vegetation index by normalized difference (NDVI), according to Equation 04, for the rainy season and Equation 05 for the dry season.

$$FPAR = 0.0564 + 0.8198 * NDVI\ (W\ m^{-2}) \quad (04)$$

$$FPAR = 0.004 + 0.9843 * NDVI\ (W\ m^{-2}) \quad (05)$$

Therefore, the APAR estimate consists of the product of PAR and FPAR, according to the equation:

$$APAR = FPAR * PAR \quad (06)$$

Then, the temperature scale T1 and T2 calculations were performed, given by equations 07 and 08 (FIELD *et al.*, 1995).

$$T_1 = 0.8 + 0.02\ T_{opt} - 0.0005 T_{opt}^2 \quad (07)$$

$$T_2 = \frac{1}{1+\exp\ (0.2T_{opt} - 10 - T_{day})} \cdot \frac{1}{1+\exp[0.3\ (-T_{opt} - 10 + T_{day})]} \quad (08)$$

T_{opt} is the average air temperature (ºC) of the month of maximum NDVI, and T_{day} is the average daily air temperature (ºC). The efficiency of the use of light, ε (g C MJ^{-1}), can be quantified by the model of Field *et al.* (1995), modified by Bastiaanssen and Ali (2003), according to the equation:

$$\varepsilon = \varepsilon'. T_1. T_2. FE \quad (09)$$

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LUEmax represents maximum efficiency for converting photosynthetically active radiation into biomass, being considered in this research with a value equal to 0.5 g C MJ^{-1}. Rosa and Sano (2013) studied *Brachiaria brizantha* pasture areas in the Cerrado of Minas Gerais state and found maximum efficiency values in the order of 0.46 g C MJ^{-1}. Fonseca *et al.* (2006) found values and efficiency in using radiation ranging from 0.09 to 0.51 g C MJ^{-1} in field experiments, for field vegetation, in the Campos Sulinos biome. Machado (2014), in an experiment developed with *Brachiaria brizantha* pasture at the Embrapa Cerrados unit in Planaltina (Federal District), found maximum efficiency values of 0.5 g C MJ-1. In this context, it was decided to use the efficiency factor from Machado (2014) in this research. With the determination of ε, GPP was obtained in g C m^{-2} day^{-1}, based on the equation:

$$\text{GPP} = APAR.\varepsilon'.T_1.T_2.FE \quad (10)$$

2.3. Analysis approaches

After estimating the pasture GPP using the multispectral model, the estimated values were compared with a polynomial regression model. Next, the GPP data obtained by Finally, linear regression analyses were performed between the estimated values, in addition to error analysis, quantifying the mean absolute error (EAM) (Equation 11), the root of the mean square error (REQM) (Equation 12), and the Willmott agreement index (d) (Equation 13).

$$\text{EMA} = \frac{1}{N}\sum_{i=1}^{n}[X_1 - X_2] \quad (11)$$

$$\text{REQM} = \left(\sum_{i=1}^{N}\frac{(X_1 - X_2)^2)}{N}\right) \quad (12)$$

$$d = 1 - \frac{\sum_{i=1}^{N}(X_1 - X_2)}{\sum_{i=1}^{N}(|X_1 - \overline{X_2}\,)^2)} \quad (13)$$

Where: X1 is the value obtained in the field, X2 is the value estimated by the standard model, and X is the average of the observed values

3. RESULTS AND DISCUSSION

GPP (Gross Primary Productivity) is considered a fundamental variable of ecosystems for sequestering atmospheric carbon and making it available to ecophysiological metabolic processes. It can be regarded as the sum of photosynthesis

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performed by all leaves on an ecosystem scale. Furthermore, it results from the time scale integration of days per year, measured in units of mass per area per time (e.g., g C m^{-2} day^{-1}) (CHAPIN *et al.*, 2011).

For estimating GPP in pasture areas in the BHRV, the CASA-SEBAL model methodology was used, and the application of part of the MOD17A2 methodology in Landsat 8 images. The difference lay in the fact that this study examined the efficiency of use of the maximum light (LUE) specific for *Brachiaria brizanta*, as well as local climatic data, with a simplification of the FPAR estimate based on NDVI images, as detailed in the materials and methods.

The complementary data to the Landsat 8 OLI / TIRS images for the GPP estimate are shown in Table 01. It is observed that the photosynthetically active radiation (PAR) remained between 7.75 and 16.68 MJ m^{-2} day^{-1}, corresponding to April 12, 2015, and October 7, 2016, respectively, showing significant variation in the days analyzed. The parameters T1 and T2 reflect the temperature contribution in the LUE by the plants, ranging between 0.981 and 0.739, the first being related to the image of February (with the highest NDVI values) parameters used in the calculation of the LUE in the CASA-SEBAL model. The parameters Tmin Scalar and VPD Scalar are factors for attenuating the LUE of the pasture, the first being related to temperature and the second to the vapor pressure deficit; these parameters were used to calculate the LUE in the "MOD17 / Landsat 8" method (or MOD17 (L8)).

Figure 02 shows the variation of the LUE calculated by these methods, referring to the year 2015; this period was chosen for analysis due to the representativeness of images in both the dry and rainy periods. Thus, the values varied between 0.3096 g C MJ day^{-1} (April 12) and 0.4650 g C MJ day^{-1} (September 3) in the MOD17 (L8) method, and 0.1888 g C MJ day^{-1} (August 18) and 0.4105 g C MJ day^{-1} (April 12) in the CASA-SEBAL method.

It is observed in the graph of Figure 02 that the variation of the LUE by the CASA-SEBAL method followed the variation of precipitation closely; the MOD17 (L8) method, on the other hand, presents higher values in the dry season (mainly in July and August) than the first method, overestimating the GPP for this period. This same pattern occurred in the images of the years 2016, 2017, and 2018, and this result may be related to the representation of the water factor in each model, in which the evaporative fraction represents the CASA-SEBAL methodology, while in the model of MOD17A2H, this factor is not expressly described.

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Liu *et al.* (2011) argue that the methodology used by the MOD17A2H model may present an overestimation of GPP in areas of water restriction due to the explicit lack of representativeness of water in the soil in the system. Therefore, the CASA-SEBAL method showed greater efficiency in demonstrating the water stress suffered by the pasture areas in the dry season, in which the GPP estimate for this model accounts for the water factor in the process of carbon fixation by the pasture, using its method the estimate of the evaporative fraction (SEBAL methodology), with spatial variation (dimensionless) according to the stage of development of the plant.

Table 01: Dates of the Landsat 8 OLI / TIRS, T1, and T2 images, referring to the days selected for the research, TMIN_Scalar, VDP_Scalar, Daily photosynthetically active radiation (PAR) (MJ m^{-2} day^{-1}).

Field Collection Date	Date of Satellite Passage	T_1	T_2	TMIN Escalar	VDP Escalar	PAR 24h
02/10/14	18/10/14	0.988	0.739	1	0.882	12.95
06/01/15	06/01/15	0.988	0.939	1	0.712	13.75
23/02/15	23/02/15	0.988	0.951	1	0.654	14.75
12/04/15	12/04/15	0.988	0.957	1	0.619	7.75
24/05/15	30/05/15	0.988	0.951	1	0.738	11.09
21/06/15	15/06/15	0.988	0.959	1	0.779	10.92
27/07/15	17/07/15	0.988	0.953	1	0.861	11.29
14/08/15	18/08/15	0.988	0.943	1	0.877	11.80
06/09/15	03/09/15	0.988	0.888	1	0.930	14.28

Figures 3, 4, and 5 show the thematic maps of the GPP estimated by the CASA-SEBAL methodology for the days analyzed, with a variation between ≤ 0.10 and 5.0 g C m^{-2} day^{-1}. The GPP values estimated by the MOD17 methodology with Landsat 8 OLI / TIRS images (MOD17 (L8)) showed a variation of 0.50 and 6.0 g C $m^{-2}day^{-1}$.

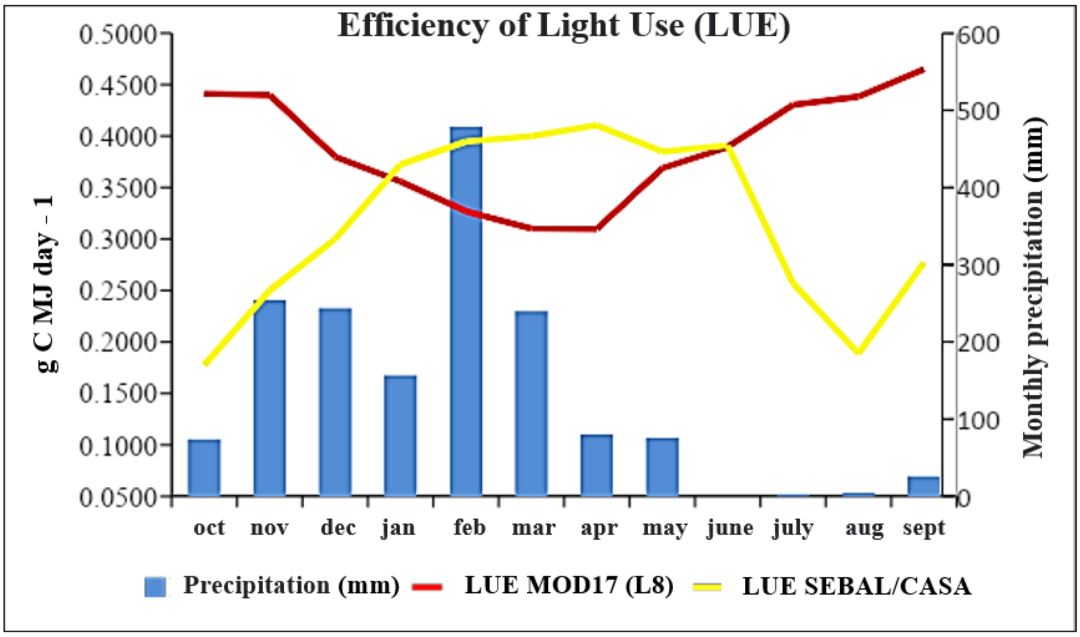

Figure 02 – Efficiency of using light measured by the MOD17 (L8) and CASA-SEBAL method.

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In the CASA-SEBAL methodology, the LUE estimate closely followed the water restrictions in the soil in the months of greater drought prolongation (July and August), presenting values of LUE with average variations in the studied period from 0.18 to 0.39 g C MJ day^{-1}, with the highest values in the rainy season (October to March) and the lowest in the dry season (April to September).

This result indicates that the water factor significantly affects the assimilation of carbon by the plant. The values of LUE estimated by the MOD17 method (L8) demonstrated less variability in the analyzed period, with variation between 0.3096 g C MJ day^{-1} (April 12) and 0.4650 g C MJ day^{-1} (September 3), as shown in the graph on Figure 02. The highest values of GPP were obtained on February 23, 2015, in the CASA-SEBAL methodology, with a predominance of the class of 3 to 4.6 g C m^{-2} day^{-1}, corresponding to approximately 70% of the pasture areas. This result was associated with high values of NDVI, incident solar radiation, and evaporative fraction, as well as high values of LUE, with average values of 0.4 g C m^{-2} day^{-1} observed for this day. Besides, this day corresponds to the rainy season, characterized by good water availability and a higher incidence of photosynthetically active radiation (PAR) (14.75 MJ m^{-2} day^{-1}).

It is known that green vegetation has high radiation absorption in the red wavelength range due to chlorophyll in the green leaves and high reflectance in the near-infrared range. For that same day, the MOD17 (L8) methodology showed predominance in the class of 2 to 3 g C m^{-2} day^{-1}, corresponding to approximately 70% of the pasture areas. However, the highest PAR value of the period was observed on October 7, 2016 (16.68 MJ m^{-2}), with mean values of GPP at 1.07 g C m^{-2} day^{-1}. This low GPP result may be related to the low rainfall in September (67 mm) this year, in which pasture areas are still under water stress due to prolonged drought.

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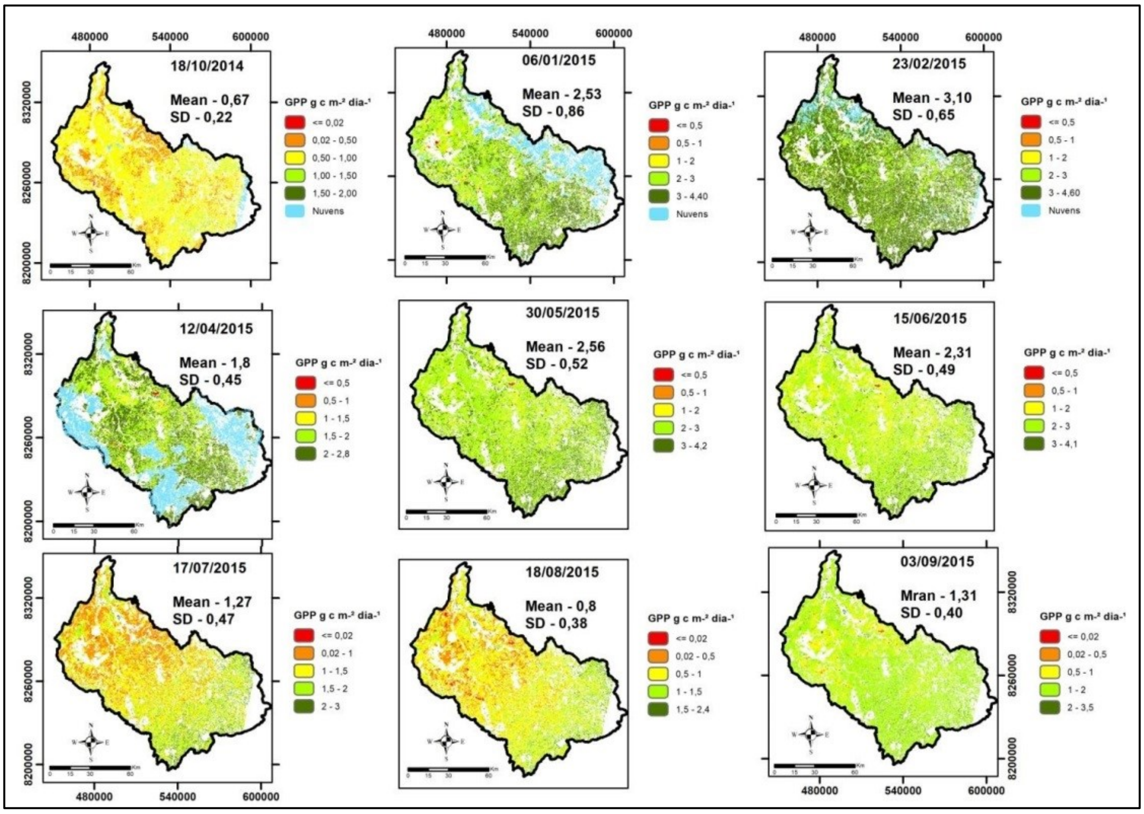

Figure 03 – Gross Primary Productivity for BHRV in g C m^{-2} day^{-1}, using the SEBAL/CASA model.

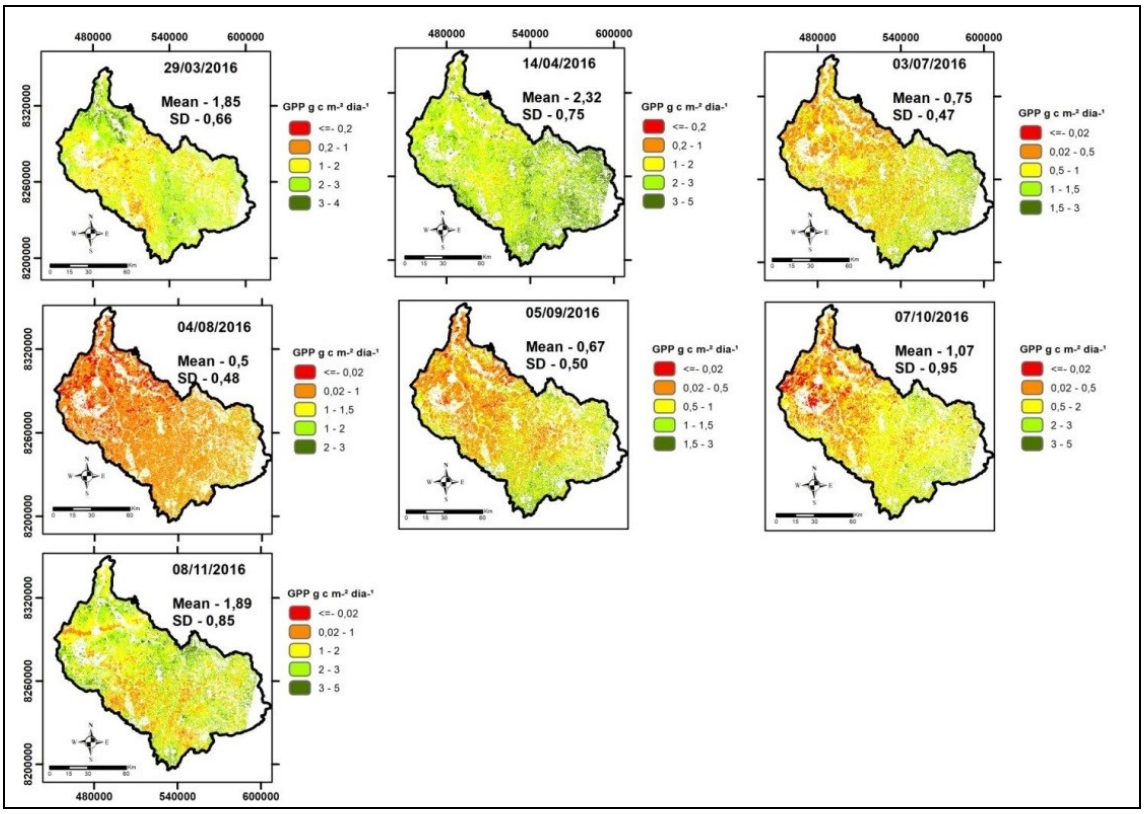

Figure 04 – Gross Primary Productivity for BHRV in g C m^{-2} day^{-1}, using the SEBAL/CASA model.

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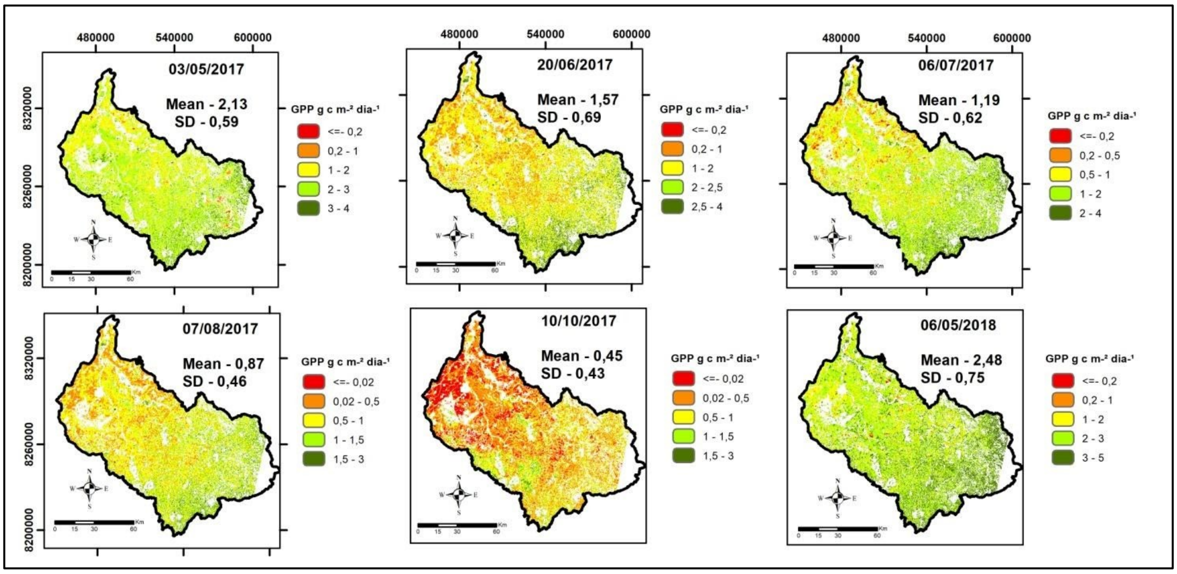

Figure 05 - Gross Primary Productivity for BHRV in g C m^{-2} day^{-1}, using the SEBAL/CASA model.

For this period (rainy), this productivity pattern of pasture areas is directly related to environmental factors, such as precipitation, humidity and high temperatures. These variables are pinpointed as those that most influence the forage production in the Cerrado (TUCKER *et al.*, 1991; NEMANI *et al.*, 2003; MA *et al.*, 2013; BORGES and SANO, 2014; GAO *et al.*, 2016). Churkina and Running (1998) argue that in type C4 plants, such as *Brachiaria brizanta*, water availability largely controls productivity in all regions of the planet.

Studies carried out in pasture areas in African savannas (EKLUNDH and OLSSON, 2003; HERRMANN *et al.*, 2005) observed an increase in NDVI values with an increase in water availability in pasture areas, corroborating this hypothesis of the relationship between water availability and the increase in forage production.

Another important factor for the productivity of pasture areas is the temperature, which for this period presents average values of approximately 27 ºC (INMET, 2015), within the ideal temperature range for the development of the plant (MCWILLIAM, 1978). Studies developed by Costa *et al.* (2007) found an increase in the production of dry matter of *Brachiaria brizantha* in the Cerrado biome linked to the increase in temperature.

On April 12, 2015, the lowest GPP values for this year were recorded, predominance in the 1.5 to 2.0 g C m^{-2} day^{-1} classes in the CASA-SEBAL methodology and 1.3 at 1.8 g C m^{-1} day^{-1} in the MOD17 (L8) methodology. This result is associated with the low PAR value registered on this day (7.75 MJ m^{-1} day^{-1}), showing a reduction of approximately 48% since February 23. For this date, the images present high cloud cover, and this event may

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have influenced the PAR values, impacting low GPP values since the assimilation of carbon by pasture depends directly on the PAR intensity.

For the drought period, the CASA-SEBAL methodology showed a reduction in the values of GPP, which was explained by the low availability of water in the soil. At the beginning of the drought period, the soil still has water availability. However, with the prolongation of the drought and the reduction of water in the soil, the values tend to decrease, reaching the lowest average values for July, August and September, when little precipitation incidence was registered. Another relevant factor is the decrease in absorbed photosynthetically active radiation (PAR), with a reduction of approximately 20% during the rainy season.

Thus, the dynamics that the dry season causes in the pasture areas is an important factor because, with water stress, this environment tends to absorb less solar radiation, increasing its reflectance in the visible range while absorbing more radiation in the infrared range, with less biomass accumulation. This pattern of reduction in GPP values coincides with the studies developed by Qin *et al.* (2013), Chen *et al.* (2014), and Eckert *et al.* (2015), who demonstrated a reduction in precipitation patterns in periods of drought, reducing plant productivity. In addition, Ponzoni *et al.* (2012) argued that plants such as pastures are sensitive to water stress since the root systems are shallow, presenting greater vulnerability to variations in soil moisture. Therefore, the plant under water stress decreases the photosynthetic process, where the hydrogen in the chemical composition of the water is used to convert carbon dioxide into carbohydrates.

Similar results were found by MA *et al.* (2016), who observed a reduction in the productivity indexes when they verified a decrease in the pluviometric indexes from 2000 to 2012 in areas with different phytophysiognomies in Australia. Rosa and Sano (2013), in a study, carried out in pasture areas in the Paranaíba river basin, found the lowest values of primary productivity (NPP) in the dry season, which was related to low rainfall and high temperatures. These authors argue that the combination of high temperatures with low soil moisture levels induces plants to close stomata, reducing the flow of water into the atmosphere (evapotranspiration) and the assimilation of CO_2, causing the decline in the photosynthetic rate.

Still, based on the analysis of Figures 3, 4 and 5, for September 2015 and 2016, an increase in the GPP values is observed, a result due to the increase in precipitation in the period in which, between those months, precipitation volumes were recorded in the

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weather station (A014 Goiás). It demonstrates the sensitivity of the CASA-SEBAL model to detect climatic variations in the region and their impacts on pasture areas.

In the MOD17 (L8) methodology, there is also a trend towards a reduction in the GPP values with the prolongation of the drought; however, with greater differences in the values observed between the CASA-SEBAL methodology for the months when the pasture presents greater water stress (July and August). Even so, the CASA-SEBAL method demonstrated greater sensitivity to the climatic seasonality of the region than the MOD17 (L8) method, considering the water factor expressed in the evaporative fraction (obtained with SEBAL).

To better explain the GPP seasonality in pasture areas, a polynomial regression model was generated to simulate its variation on all days of 2015, correlating this result with the rainfall data recorded each month. This analysis was carried out for 2015, which this year presents greater availability of images in both the dry and rainy periods. Figure 06 shows the results of the GPP simulation in pasture areas using the CASA-SEBAL and MOD17 (L8) methods. Note that in the hydrographic basin of the Rio Vermelho, according to the rainfall data, there are two well-defined seasons, one dry, from April to September, and the other rainy, from October to May. However, when analyzing the GPP, it is observed that with the end of the rainy season, the process of water deficiency in the soil begins, hindering the pasture from developing its full growth potential.

However, the decrease in pasture productivity in the dry season is more evident in July and August due to the prolongation of the drought, and in the first months of this dry period, the pasture still maintains good average production levels, given the availability of moisture in the soil. Therefore, the CASA-SEBAL methodology was more sensitive in detecting this seasonal variation of GPP in BHRV pasture areas; in addition, the reduction in the values of GPP accompanied the reduction in rainfall, demonstrating the sensitivity of the method to climatic variations in the region, and it is possible to state that variations in the local climate directly affect the values of GPP. On the other hand, as demonstrated by the simulation curve, the MOD17 method (L8) showed a little reduction in the values of GPP in the transition from the rainy to the dry season, maintaining certain stability in the year and being less sensitive in monitoring climatic seasonality.

For an analysis of the performance of the methods, a comparison of the GPP values estimated by the satellite images and those observed by the regression model was performed. The methodology used to compare the results was based on the estimate of the Pearson correlation index, the mean absolute error, the root of the mean square error

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and the Willmott agreement index. Table 02 shows a high correlation between the data estimated by the CASA-SEBAL method and those observed by the regression model, with Pearson's correlation index approaching the perfect positive correlation (1) for the analyzed period. The mean absolute error (MAE) and the root mean square error (RMSE) are measures of model accuracy; as it is a quadratic error, the greatest weight is associated with the largest deviations, the ideal for this index being that it is as small as possible; however, given the magnitude of the estimates, the errors presented by the CASA-SEBAL model can be considered low.

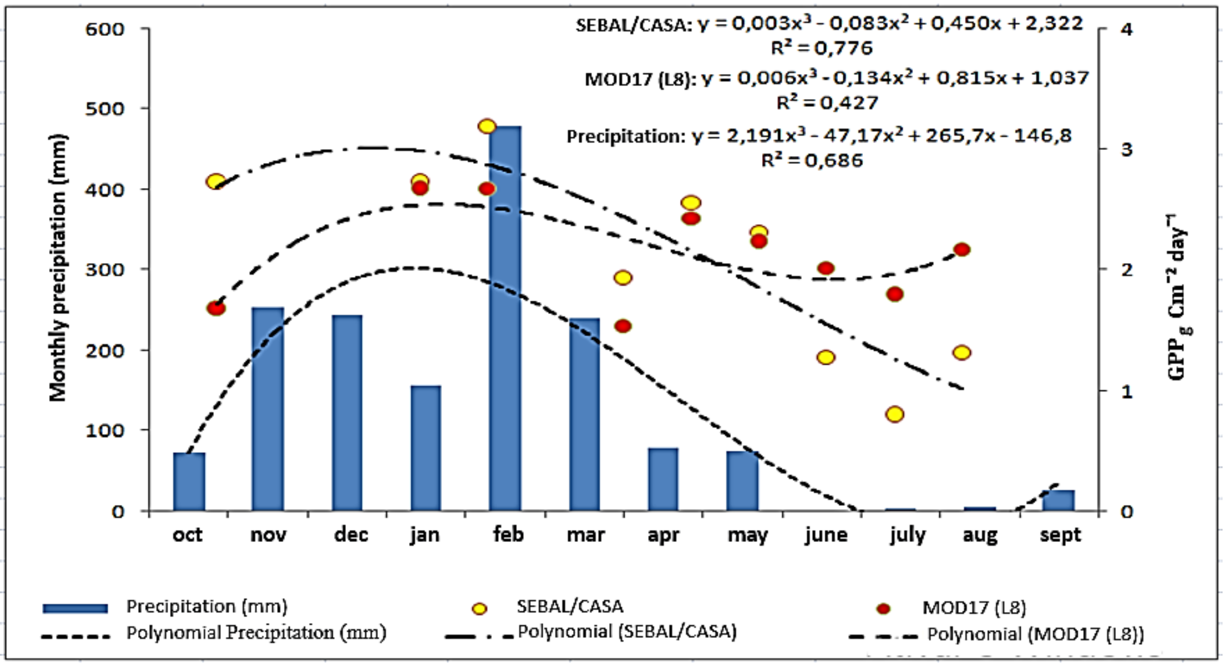

Figure 06 – Regression Models for Simulating the Variability of the GPP throughout the year in pasture areas in the BHRV, using the MOD17 (L8) and CASA-SEBAL models.

Analyzing the Willmott agreement or adjustment index is one of the ways to measure the accuracy related to the approximation of the estimated values concerning those observed. Its values vary from zero, where there is no agreement, to 1, for perfect agreement. In this sense, the CASA-SEBAL method showed high agreement with the polynomial regression model, closely following the effects of climatic seasonality in the BHRV's pastures.

Table 02 shows that the MOD17 (L8) method performed less well than CASA-SEBAL in comparing the data estimated by satellite images and that observed by the polynomial regression model. This result may be associated with the low variation of this method in the period of soil water stress, especially in July and August, in which the LUE values

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remained high even during prolonged drought (July and August). Due to low water availability, pasture areas undergo significant changes during the dry season.

Table 02: Pearson's correlation indices, mean absolute error (MAE), the root of the mean square error (RMSE), and Willmott's agreement index (d), applied to the data of gross primary productivity in the CASA-SEBAL and MOD17 methods (L8).

METHOD	Correlation of Pearson	MAE (g C m^{-1} day^{-1})	RMSE (g C m^{-1} day^{-1})	d
CASA-SEBAL	0.898	0.3267	0.556	0.833
MOD17 (L8)	0.681	1.48	1.621	0.228

Comparing the methods applied in this research with the product of MOD17A2H (collection 6), it was observed that the GPP values were significantly lower than this on most of the dates analyzed. For example, the MOD17 (L8) method presented median values that varied between 1.19 g C m^{-2} day^{-1} (August 4, 2016) and 4.41 g C m^{-2} day^{-1} (May 29, 2016); the CASA-SEBAL method presented median values that varied between 0.50 g C m^{-2} day^{-1} (August 4, 2014) and 3.10 g C m^{-2} day^{-1} (February 23, 2015). The MOD17A2H product showed values higher than those this research estimated on most of the days analyzed, with a variation between 0.27 g C m^{-2} day^{-1} and 5.5 g C m^{-2} day^{-1}.

For the dates of the rainy season, the median values of the GPP were around 5 g C m^{-2} day^{-1}, showing an average difference of 2.5 g C m^{-2} day^{-1} between the methods applied in this research. For the dry season, the product MOD17A2H showed a reduction in the values of GPP, reaching the lowest value in July and August; however, for the dates in September, when an increase in NDVI values was observed due to the increase in precipitation recorded in this period, this product showed little sensitivity to the resumption of the photosynthetic process of pasture. This result is attributed to the low spatial resolution of this product (500 meters) concerning the Landsat 8 OLI / TIRS images (30 meters).

These differences in results are probably associated with several factors related to the MOD17A2H methodology, which may have influenced the higher values of GPP in pasture areas. Emax is one of the factors that interfere in the values of GPP, where the value attributed to the pasture areas in this product is 0.86 g C MJ m^{-2} day^{-1}; however, the value attributed in this research was 0.50 g C MJ m^{-2} day^{-1}, estimated for the pasture of the species *Brachiaria brizanta* in the climatic conditions of the Cerrado. In the MO17A2H methodology, an Emax value is assigned to each of the biomes mapped on the globe (MCD12Q1), which is a source of possible errors, as there is a wide variety of systems in

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terrestrial environments, in which an Emax value of a given biome may behave differently in other climatic conditions, even if they are similar biomes. An example is the Emax value assigned to pasture areas in Brazil as being the same for pasture areas in Mongolia. Even though both involve grasses, this Emax value can behave differently due to the great diversity of environmental factors.

Another source of possible errors is the meteorological data involved in this methodology, such as PAR and the temperature and atmospheric pressure variability values, the latter serving as attenuating environmental factors of Emax. The possible errors related to this input data are associated with the low spatial resolution of the Global Modeling and Assimilation Office (GMAO) input products (spatial resolution from 0.5º to 0.625º), which is significantly lower than the resolution of the final product MOD17A2H at 500 meters.

Although the MOD17A2H methodology (collection 6) has improved concerning the scale of the input meteorological data, which in the previous version (Collection 5) was 1 x 1.25º, this may be one of the main sources of error. Even with meteorological data undergoing a rigorous interpolation process, errors caused by the original low spatial resolution are difficult to eliminate.

In addition, the MOD17A2H algorithm uses land cover and use data (product MCD12Q1), where the classification accuracy directly determines the Emax value to be attributed to the given surface; that is, errors in this classification of land use and cover can influence the GPP estimates. Almeida *et al.* (2017) evaluated the uncertainties introduced by the cover and land use product of MCD12Q1H in the GPP estimate in the Amazon and Cerrado areas. They concluded that this product presents significant classification errors, especially in heterogeneous areas, such as anthropized land and savanna. Furthermore, considering that the Cerrado biome presents an intense and dynamic use of the soil, in addition to a complex vegetation mosaic (a mixture of physiognomies in different strata), with significant variation in time and space, the GPP estimates of this product can express significant errors.

Another product that serves as input to the MOD17A2H algorithm for estimating GPP is MOD15A2H, referring to the fraction of photosynthetically absorbed radiation (FPAR), which uses a complex radioactive transfer process to estimate it. However, the reference values used for each biome (based on the product MCD12Q1) in the land use and cover classification cannot be overlooked. Wang *et al.* (2017) found overestimated FPAR values in several biomes around the world, and these results were related to errors in

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meteorological data and classification of land use and cover. Therefore, the use of local meteorological data, as well as a good land use classification product, can significantly improve the estimated GPP data. In addition, the use of medium-resolution images, such as those of Landsat 8 OLI / TIRS (30 meters), can provide the analysis of these biophysical variables at rural property levels, helping to identify possible areas of degradation, making it possible to take more precise and dynamic decisions.

4. CONCLUSIONS

The results of this research show the potential of using remote sensing images to estimate GPP in pasture areas, where the analysis of this parameter, with the respective techniques, allowed continuous and more detailed monitoring in pasture areas in the BHRV, differently from the specific analyses. The CASA-SEBAL method was the one that demonstrated the greatest efficiency in this calculation by detecting in greater detail the influence of climatic seasonality in the spatial and temporal variation of this parameter. For this method, the GPP varied between 0.02 and 5.0 g C m^{-2} day^{-1}, where the highest values were recorded in the rainy months and showed a reduction with the prolongation of the drought (with the lowest values in August). It is noted that water availability is a determining factor in GPP in pasture areas in the Cerrado biome.

The estimation of GPP by the MOD17 method (L8) proved less sensitive to the climatic seasonality of the BHRV. Despite presenting a reduction in GPP in the dry season, these values were higher than those of the previous method (CASA-SEBAL), and this result was associated with the estimate of the efficiency of the use of light (LUE). This is because, in the CASA-SEBAL method, the water factor expressed in the SEBAL model is considered the evaporative fraction. Bearing that pasture area are strongly influenced by water availability, this is an important factor in GPP analyses. Thus, it appears in this research that water availability is the main climatic factor that influences the seasonality of carbon sequestration in pasture areas, especially in Cerrado areas; the availability of PAR and ideal temperatures, however, did not prove to be limiting factors for the development of forage. Thus, the importance of calibrating these models for the most coherent GPP estimates was noted, and the use of light efficiency - specifically LUE for Brachiaria brizanta. The use of detailed mapping of pasture areas for the BHRV, as well as the use of local climatic data, reinforce the thesis of better precision in these estimates. Furthermore, the methodology used in this research for estimating the GPP with images with a better spatial resolution (Landsat 8 OLI / TIRS) proved to be more efficient than the MODIS sensor images used until now in this type of analysis. In this way, the results may assist in managing and decision-making for these pasture areas (usually degraded), as they bring more detail about the spatial and temporal variation of the physical-climatic components.

Finally, further experiments are recommended to investigate the maximum light efficiency for different types of pastures, such as Brachiaria, Panicum, Andropogon etc., as well as more detailed studies of the interaction of solar radiation to produce biomass, mainly parameters like FPAR.

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REFERENCES

BASTIAANSSEN, W. G. M.; ALI, S. A new crop yield forecasting model based on satellite measurements applied across the Indus Basin, Pakistan. **Agriculture, Ecosystems and Environment,** v. 94, p. 321-340, 2003.

BORGES, E. F.; SANO, E. E.; MEDRADO, E. Radiometric quality, and performance of TIMES AT for smoothing moderate resolution imaging spectroradiometer enhanced vegetation index time series from western Bahia State, Brazil. **Journal of Applied Remote Sensing,** v. 8, p. 1-21, 2014.

CHEN, B.; ZANG, X.; TAO, J.; WU, J.; WANG, J.; SHI, P.; ZHANG, Y.; YU, C. The impact of climate change and anthropogenic activities on alpine grassland over the Qinghai-Tibet Plateau. **Agricultural and Forest Meteorology,** v. 189-190, p 11-18, 2014.

CHAPIN, F. S.; MATSON, P. A.; MOONEY, H. A. **Principles of Terrestrial Ecosystem Ecology. 2**. ed. Springer: New York, 2011. 549p.

CHEN, B.; ZANG, X.; TAO, J.; WU, J.; WANG, J.; SHI, P.; ZHANG, Y.; YU, C. The impact of climate change and anthropogenic activities on alpine grassland over the Qinghai-Tibet Plateau. **Agricultural and Forest Meteorology,** v. 189-190, p 11-18, 2014.

CHURKINA, G.; RUNNING, S. W. Contrasting climatic controls on the estimated productivity of global terrestrial biomes. **Ecosystems,** v. 1, p. 206-215, 1998.

CONFEDERAÇÃO NACIONAL DA AGRICULTURA 2014. **Balanço da Pecuária Bovídea de Corte.** Fórum Nacional Permanente da Pecuária de Corte. Disponível em http://www.canaldoprodutor.com.br/. Acesso em: 29 set. 2022.

COSTA, K. A. D. P.; OLIVEIRA, I. P.; FAQUIN, V.; NEVES, C.; SAMPAIO, F. M. T. Intervalo de corte na produção de massa seca e composição químico-bromatológica da

ISSN 2318-2962
DOI 10.5752/p.2318-2962.2022v32n.71p.1149

Brachiaria brizantha cv. MG-5. **Ciência e Agrotecnologia,** v. 31, n. 4, p. 1197–1202, 2007.

DANELICHEN, V. H. M.; BIUDES, M. S.; VELASQUE, M. C. S.; MACHADO, N. G. GOMES, R. S. R.; VOURLITIS, G. L.; NOGUEIRA, J. S. Estimating of gross primary production in an Amazon-Cerrado transitional forest using MODIS and Landsat imagery. **Anais da Academia Brasileira de Ciências,** v. 87, p. 1545-1564, 2015.

DEFRIES, R. S.; TOWNSHEND, J. R.; LOS, SO Scaling land cover heterogeneity for global atmosphere-biosphere models. In: QUATTROCHI, D. A.; GOODCHILD, M. F. (Eds.). **Scale in Remote Sensing and GIS.** Boca Raton: Lewis Publishers, 1997. cap. 6, p. 231-246.

DEFRIES, R. S.; LOS, SO Implications of land-cover misclassification for parameter estimates in global land-surface models: an example from the Simple Biosphere Model (SiB2). **Photogrammetric Engineering & Remote Sensing,** v. 65, n. 9, p. 1083-1088, 1999.

DEL'ARCO, J. O.; RIOS, A.; DAMBRÓS, L.; TARAPANOFF, I.; ASS, N. **Diagnóstico ambiental da bacia do rio Araguaia-Trecho Barra do Garças (MT) - Luís Alves (GO).** AHITAR/IBGE. Goiânia, Brasil, 1999.

DIAS-FILHO, M. B. **Degradação de pastagens:** processos, causas e estratégias de recuperação. 4. ed. Ed. do Autor: Belém, 2011.

ECKERT, S.; HÜSLER, F.; LINIGER, H.; HODEL, E. Trend analysis of MODIS NDVI time series for detecting land degradation and regeneration in Mongolia. **Journal of Arid Environments**, v. 113, p. 16-28, 2015.

EKLUNDH, L.; OLSSON, L. Vegetation index trends for the African Sahel 1982–1999. **Geophysical Research Letters**, v. 30, n. 8, p. 1-13, 2003.

FAO. **The State of food and agriculture:** Livestock in balance. 2009.

FIELD, C. B.; RANDERSON, J. T.; MALMSTROM, C. M. Global net primary production: combining ecology and remote sensing. **Remote Sensing of Environment,** v. 51, p. 74-88, 1995.

FRIEDL, M. A. Examining the effects of sensor resolution and sub-pixel heterogeneity on spectral vegetation index: implications for biophysical modeling. In: QUATTROCHI, D. A.; GOODCHILD, M. F. (Eds.). **Scale in Remote Sensing and GIS.** Boca Raton: Lewis Publishers, 1997. cap. 6, p.113-136.

FONSECA, E. L.; SILVEIRA, V. C. P.; SALOMONI, E. Eficiência de conversão da radiação fotossinteticamente ativa incidente em biomassa aérea da vegetação campestre natural no bioma Campos Sulinos do Brasil. **Ciência Rural,** Santa Maria, v. 36, n. 2, p. 656-659, 2006.

GAO, Q.; SCHWARTZ, M. K.; ZHU, W.; WAN, Y.; QIN, X.; MA, X.; LIU, S.; WILLIAMSON, M. A.; PETERS, C. B.; LI, Y. Changes in global grassland productivity during 1982 to 2011 attributable to climatic factors. **Remote Sensing,** v. 8, n. 384, p. 1-12, 2016.

GALVANI, E. Avaliação da radiação solar fotossinteticamente ativa (PAR) em São Paulo, SP. **GEOUSP:** Espaço e tempo, São Paulo, n. 25, p. 155-164, 2009.

GOETZ, S. J.; PRINCE, S.; GOWARD, S. N.; THAWLEY, M. M.; SMALL, J. Satellite remote sensing of primary production: an improved production efficiency modeling approach. **Ecological Modelling,** v. 122, n. 3, p. 239–255, 1999.

GUIMARÃES, L. D. A. **Natureza viva:** Cerrado: caracterização e conservação. Goiania: UCG, 2006. p. 21–42.

HERRMANN, S. M.; ANYAMBA, A.; TUCKER, J. C. Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. **Global Environmental Change,** v. 15, p. 394-404, 2005.

LAPIG – LABORATÓRIO DE PROCESSAMENTO DE IMAGENS E GEOPROCESSAMENTO. **Mapa Síntese da Área de Pastagem para o território brasileiro.** Disponível em: <https://atlasdaspastagens.ufg.br/>. Acesso em: 29 set. 2022.

LIU, S.; WANG, T.; GUO, J.; QU, J.; AN, P. Vegetation change based on SPOT-VGT data from 1998-2007, northern China. **Environment Earth Science,** v. 60, p. 1459-1466, 2010.

INMET - Instituto Nacional de Meteorologia. **Banco de Dados Meteorológicos para Ensino e Pesquisa.** 2018. Disponível em: <http://www.inmet.gov.br/portal/index.php?r=bdmep/bdmep>. Acesso em: 22 out. 2017.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE. **Sistema IBGE de recuperação automática - SIDRA.** 2010. Disponível em: <http://www. ibge.br/sidra/>. Acesso em: 25 jul. 2010.

MA, X.; HUETE, A.; YU, Q.; COUPE, N. R.; DAVIES, K.; BROICH, M.; RATANA, P.; BERINGER, J.; HUTLEY, L. B.; CLEVERLY, J.; BOULAIN, N.; EAMUS, D. Spatial patterns and temporal dynamics in savanna vegetation phenology across the North Australian Tropical Transect. **Remote Sensing of Environment,** v. 139, p. 97-115, 2013.

MA, X.; HUETE, A.; CLEVERLY, J.; EAMUS, D.; CHEVALLIER, F.; JOINER, J.; POULTER, B.; ZHANG, Y.; GUANTER, L.; MEYER, W.; XIE, Z.; CAMPOS, G. P. Drought rapidly diminishes the large net CO2 uptake in 2011 over semi-arid Australia. **Scientific Reports,** v. 6, n. 37747, p. 1-9, 2016.

MACHADO, P. M. **Séries Temporais do Modis em Pastagens Cultivadas do Cerrado:** Comparação com Dados Espectorradiométricos de Campo. 2014. 98 f. Dissertação (Mestrado em Geociências Aplicadas) – Universidade de Brasília, Brasília, 2014.

MCWILLIAM, J. R. Response of pasture plants to temperature. In: WILSON, J. R. (Ed.). **Plant Relation in Pasture.** Melbourne: CSIRO, 1978. p. 17-34.

MEIRELLES, M. L.; FARIAS, S. E. M.; FRANCO, A. C. Balanço de energia de uma pastagem cultivada no cerrado, 2003. **Boletim de Pesquisa e Desenvolvimento,** Embrapa Cerrados. Planaltina, DF. 14p.

MONTEITH, J. L. Solar radiation, and productivity in tropical ecosystems. **Journal of Applied Ecology,** v. 9, p. 747-766, 1972.

MOYSÉS, A.; SILVA, E. R. Ocupação e urbanização dos cerrados: desafios para a sustentabilidade. **Cadernos Metrópole,** v. 20, p. 197-220, 2008.

NEMANI, R. R. Climate-Driven Increases in Global Terrestrial Net Primary Production from 1982 to 1999. **Science,** v. 300, n. 5625, p. 1560–1563, 2003.

POTTER, C. S.; RANDERSON, J. T.; FIELD, C. B.; MATSON, P. A.; VITOUSEK, P. M.; MOONEY, H. A.; KLOOSTER, S. A. Terrestrial ecosystem production: a process model based on global satellite and surface data. **Global Biogeochemical Cycles,** v. 7, n. 4, p. 811-841, 1993.

PONZONI, F. J.; SHIMABUKURO, Y. E.; KUPLICH, T. M. **Sensoriamento Remoto da Vegetação:** edição atualizada e ampliada. 2. ed. São Paulo: Oficina de Textos, 2012. 160p.

QIN, Y.; YI, S.; REN, S.; LI, N.; CHEN, J. Responses of typical grasslands in a semi- arid basin on the Qinghai–Tibetan plateau to climate change and disturbances. **Environmental Earth Sciences**, v. 71, n. 3, p. 1421-1431, 2013.

ROSA, R.; SANO, E. Determinação da produtividade primária líquida (NPP) de pastagens da bacia do Rio Paranaíba, usando imagens MODIS. **Geofocus,** Madrid, v. 13, p. 367-395, 2013.

SANTOS, P. S. **Caracterização e mapeamento biofísico ambiental da bacia hidrográfica do rio Vermelho a partir de dados remotamente sensoriados.** 2014. 157 f. Tese (Doutorado) – Instituto de Estudos Socioambientais, Universidade Federal de Goiás, Goiânia, 2014.

SELLERS, P. J.; BERRY, J. A.; COLLATZ, G. J.; FIELD, C.; HALL, F. G. CANOPY reflectance, photosynthesis, and transpiration. III. Reanalysis using improved leaf models and a new canopy integration scheme. **Remote Sensing Environment,** v. 42, n. 3, p. 187-216, 1992.

SELLERS, P. J.; DICKINSON, R. E.; RANDALL, D. A.; BETTS, A. K.; HALL, F. G.; BERRY, J. A.; COLLATZ, G. J.; DENNING, A. S.; MOONEY, H. A.; NOBRE, C. A.; SATO, N.; FIELD, C. B.; HENDERSON-SELLERS, A. Modeling the exchanges of energy, water, and carbon between continents and the atmosphere. **Science,** v. 275, n. 24, p. 502- 509, 1997.

SILVA, B. B.; GALVÍNCIO, J. D; MONTENEGRO, S. M. G; MACHADO, C. C. C; OLIVEIRA, L. M. M; MOURA, M. S. B. Determinação por Sensoriamento Remoto da Produtividade Primária Bruta do Perímetro Irrigado São Gonçalo – PB**. Revista Brasileira de Meteorologia,** v. 28, n. 1, p. 57-67, 2013.

TUCKER, C. J.; DREGNE, H. E.; NEWCOMB, W. W. Expansion and contraction of the Sahara desert from 1980 to 1990. **Science,** v. 253, p. 299-300, 1991.

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DOI 10.5752/p.2318-2962.2022v32n.71p.1149

VIEIRA, P. A.; FERREIRA, M. E.; FERREIRA Jr., L. G. Modelagem Dinâmica da Paisagem Aplicada na Análise de Uso do Solo na Bacia Hidrográfica do Rio Vermelho, Goiás, Brasil. **Revista Brasileira de Cartografia,** v. 1, p. 6, 2015.

VIEIRA, P. A. **Dinâmica de ocupação, vulnerabilidades e cenários para bacia hidrográfica do Rio Vermelho, Goiás.** 2013. 94 f. Tese (Doutorado) – Instituto de Ciências Biológicas, Universidade Federal de Goiás, Goiânia, 2013.

WANG, S.; ZHANGA, B.; YANG, Q.; CHENC, G.; YANGA, B.; LUA, L.; SHENA, M.; PENGA, Y. Responses of net primary productivity to phenological dynamics in the Tibetan Plateau, China. **Agricultural and Forest Meteorology,** v. 232, p. 235-246, 2017.

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