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REMOTE SENSING APPLIED TO PASTURE MONITORING: A REVIEW

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ABSTRACT

Objective: The goal of this study was to review the results obtained by various authors for large-scale pasture monitoring via remote sensing; to monitor the development and degradation conditions of pastures according to case studies; and to analyze data, images, and Geographic Information System (GIS) procedures in relevant works.

Theoretical Framework: In this topic, the principles that guided the literature review are presented, including a discussion of the search for remote sensing results related to pastures in large geographical areas, and case studies in works that denote the technological potential from field sampling and results worldwide are also presented.

Method: Research methods associated with different themes, keywords, and regions were adopted to identify results from research in the area of remote sensing applied to surveying the conditions of pastures in the different typologies in the studied regions.

Results and Discussion: The literature review in this study highlights the advances and methodologies developed for the evaluation of pasture conditions and mapping, from which it was possible to observe the stage of degradation of this vegetation, which is essential for agricultural production.

Research Implications: The potential of using remote sensing materials and mechanisms for pasture assessment, mapping areas in stages of degradation and identifying vegetation vigor is highly valuable in large-scale pasture management. The presented literature indicates that pasture vegetation varies greatly according to geographic region, indicating great complexity in deriving its phenological conditions and showing that field campaigns are essential for the description and establishment of a relationship between the foliar canopy and sensor response.

Originality/Value: This literature review addresses large-scale remote sensing surveys of pastures, contributing to research on the conditions of this vegetation. The bibliography presented in this review can support studies on mapping the pasture degradation process through remote sensing images and data.

Keywords: Pastures, Vegetation Indices, Satellites, Remote Sensing.

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SENSORIAMENTO REMOTO APLICADO AO MONITORAMENTO DA PASTAGEM: UMA REVISÃO

RESUMO

Objetivo: Esta pesquisa teve como objetivo realizar uma revisão de literatura sobre os resultados obtidos por diversos autores no monitoramento de pastagens em larga escala utilizando sensoriamento remoto, bem como sobre os avanços no manejo e monitoramento das condições de desenvolvimento e degradação das pastagens com base em estudos de caso, analisando dados, imagens e procedimentos no SIG, utilizados nos trabalhos científicos.

Referencial Teórico: Neste tópico, são apresentados princípios que nortearam a pesquisa bibliográfica, marcada pela pesquisa de resultados em sensoriamento remoto de pastagens em grandes extensões geográficas, mas também apresentando estudos de caso em trabalhos que denotam os potenciais tecnológicos a partir de amostragem de campo e resultados ao redor do mundo.

Método: Foram adotados métodos de pesquisa por tema, palavras-chave e regiões para que apresentem resultados em pesquisas na área de sensoriamento remoto aplicado ao levantamento das condições das pastagens nas diversas tipologias que ocorrem nestas regiões abordadas pelos estudos.

Resultados e Discussão: Os resultados alcançados na reunião dessa base bibliográfica denotaram os avanços e metodologias desenvolvidas para avaliação das condições das pastagens e mapeamento, a partir das quais foi possível observar o estágio de degradação dessa vegetação, fundamental para a produção agropecuária.

Implicações da Pesquisa: O potencial de utilização de materiais e mecanismos de sensoriamento remoto para avaliação das pastagens, mapeamento de áreas em estágios de degradação e identificação de vigor da vegetação se mostra de grande valia no manejo das pastagens em grande escala. A literatura apresentada mostra que a vegetação de pastagens denota grande variação de acordo com a região geográfica, indicando grande complexidade para derivação de suas condições fenológicas e mostra que o trabalho de campo é fundamental para a descrição e estabelecimento de relação entre as dossel foliar e resposta dos sensores.

Originalidade/Valor: Esta revisão de literatura aborda o levantamento das pastagens por meio de sensoriamento remoto em larga escala, contribuindo para a pesquisa referente às condições dessa vegetação. A bibliografia apresentada nesta revisão visa apoiar os estudos sobre o mapeamento do processo de degradação das pastagens por meio de imagens e dados de sensoriamento remoto.

Palavras-chave: Pastagem, Índice de Vegetação, Satélites, Sensoriamento Remoto.

SENSORES REMOTOS APLICADOS AL MONITOREO DE PASTURAS: UNA REVISIÓN

RESUMEN

Objetivo: El objetivo de este estudio fue realizar una revisión bibliográfica sobre los resultados obtenidos por diversos autores en el monitoreo de pastos a gran escala utilizando sensores remotos, así como los avances en el manejo y monitoreo de las condiciones de desarrollo y degradación de pasturas según estudios de caso, analizando los datos, imágenes y procedimientos SIG utilizados en los trabajos científicos.

Marco Teórico: En este tema, se presentan los principios que guiaron la revisión bibliográfica, marcada por la búsqueda de resultados en teledetección de pastos en grandes extensiones geográficas, pero también presentando estudios de caso en trabajos que denotan los potenciales tecnológicos del muestreo de campo y resultados de todo el mundo.

Método: Se adoptaron métodos de investigación por tema, palabras clave y regiones para presentar resultados en investigaciones en el área de la teledetección aplicada al estudio de las condiciones de los pastos en las diferentes tipologías que se presentan en estas regiones abordadas por los estudios.

Resultados y discusión: Los resultados logrados en la compilación de esta base bibliográfica denotaron los avances y metodologías desarrolladas para la evaluación y mapeo de las condiciones de los pastos, a partir de los cuales fue posible observar el estado de degradación de esta vegetación, esencial para la producción agrícola.

Implicaciones de la Investigación: El potencial de utilizar materiales y mecanismos de teledetección para la evaluación de pastos, el mapeo de áreas en etapas de degradación y la identificación del vigor de la vegetación es de gran valor en el manejo de pastos a gran escala. La literatura presentada indica que la vegetación de pastoreo muestra una gran variación según la región geográfica, lo que indica una gran complejidad para derivar sus condiciones fenológicas y muestra que la campaña de campo es esencial para la descripción y el establecimiento de una relación entre el dosel foliar y la respuesta del sensor.

Originalidad/Valor: Esta revisión bibliográfica aborda el estudio de teledetección a gran escala de los pastos, contribuyendo a la investigación sobre las condiciones de esta vegetación. La bibliografía presentada en esta revisión puede apoyar estudios sobre el mapeo del proceso de degradación de pastos a través de imágenes y datos de teledetección.

Palabras clave: Pastos, Índices de Vegetación, Satélites, Teledetección.

1 INTRODUCTION

Pastures, with their various typologies, whether planted pastures, grasslands, or rangelands, exist around the world and are of fundamental importance to the global economy, accounting for approximately 26% of the world's total land area and 70% of all land area linked to agriculture (LIU *et al*., 2019) (examples in the Figures 1 e 2). Some less conservative studies estimate that pastures cover up to 40% of the Earth's land surface (GHAJAR & TRACY, 2021; OGUNGBUYI *et al*., 2023). Owing to their vegetal stratification, which is largely herbaceous, pastures present striking phenology and seasonality features and thus require suitable studies of their responses to incident electromagnetic radiation. The layers of cells that form the phloem and tissues (e.g., parenchyma) and process water and sap flow are complex and result in the absorption, transmission, and emission of received energy, primarily at the leaf mesophyll level (PONZONI & SHIMABUKURO, 2010; PONZONI *et al*., 2012). Therefore, plant phenological features have a direct influence on the interactions between incident energy and reflectance levels in various bands or zones of the electromagnetic spectrum captured by passive satellite sensors, which depend on solar energy.

There are two methodologies for estimating pasture conditions: direct field sampling and remote sensing (LIU *et al*., 2019), with the latter being used extensively for monitoring purposes since the emergence of satellite images for environmental assessments in the 1970s (especially via the Landsat program and SPOT (Satellite Pour l'Observation de la Terre)). The objective of this study is to present results obtained by various authors in an effort to manage and monitor the development, advance, decline, and degradation conditions of pastures via remote sensing according to case studies and research projects for which a time series was employed. Owing to the dynamics of pastures, satellite sensors equipped with a medium-to-low spatial resolution show the highest temporal resolution levels, allowing for a better composition of spectral band sets and vegetation indices, with the aim of monitoring changes and degradation trends.

Figure 1

Examples of pastures in Brazil: (A) Pastures composed of mainly Brachiaria; and (B) pastures showing signs of degradation and weed species. (Source: the authors)

(A) (B)

Figure 2

Examples of pasture degradation in Brazil: (A) Degraded pasture; and (B) very degraded pasture, and exposed soil. (Source: the authors)

(A) (B)

2 THEORETICAL FRAMEWORK

To generate a comprehensive bibliography regarding pastures and remote sensing, a systematic review process is needed. This process involves predefining the research topic and platform. Well-defined parameters, including keywords, inclusion criteria, and exclusion criteria, are essential for a successful review. This meticulous planning stage establishes the foundation of the research protocol, which outlines the research question and the methodology used to address it. The development of a robust protocol involves four key steps: formulating the research questions, selecting relevant research databases, defining a comprehensive search strategy, and establishing clear inclusion and exclusion criteria. By adhering to these procedures, researchers can ensure a thorough and relevant survey of the literature on their chosen topic.

3 METHODOLOGY

This research aimed to identify articles that explore pasture management using remote sensing technologies to assess vegetation vigor and degradation. The CAPES Periodicals Portal, through its partnership with the Brazilian Agricultural Research Corporation (Empresa Brasileira de Pesquisa Agropecuária – EMBRAPA), provided access to a collection of relevant databases. We focused on platforms with strong academic recognition that publish research in remote sensing, agricultural sciences, and pastures. Consequently, Scopus, Web of Science, Scielo, and Science Direct were selected for the search. The data collection period spanned from February 2022 to June 2024, with no restrictions on publication dates.

The search strategy is exemplified by the following Scopus platform query: TITLE-ABS-KEY ((remote AND sensing) AND (pasture OR grassland OR rangeland OR grass OR meadow) AND (image OR satellite OR GIS OR mapping) AND (plantation OR degradation OR degraded)) AND (LIMIT-TO (DOCTYPE , "ar")).

This approach aims to capture all possible references to remote sensing applications in pastures that depict historical trends in condition mapping. The titles and abstracts of the retrieved articles were initially evaluated on the basis of their potential to address at least one of the guiding questions: Are there articles that discuss pasture management by remote sensing technologies and evaluate vegetation vigor and degradation? The articles selected for full-text reading were then required to answer all of the guiding questions definitively.

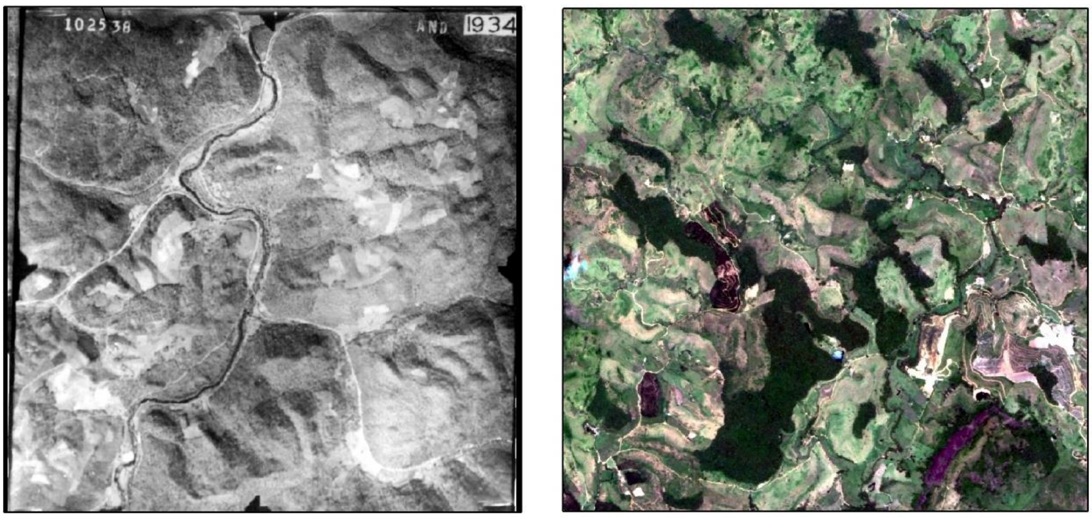
4 RESULTS AND DISCUSSIONS

In many areas of the world, pastures are extremely important for agriculture and livestock. Management approaches adopted for raising cattle and the species and cultivars used determine how herbaceous vegetation responds to remote sensing sensors used for monitoring. The Landsat series is part of a United States program of satellites designed for Earth surface monitoring via multispectral detection. It acquires images with a spatial resolution of 30 meters (plus a 15-meter panchromatic band) and a temporal resolution of 8 days. Landsat 1 was launched into space in 1972, and the most recent launch, Landsat 8, was in February 2013. Its longevity has resulted in an unparalleled image archive. The SPOT series was developed by the French National Centre for Space Studies, with its first launch, SPOT 1, in 1986, for Earth surface monitoring. The last launch, SPOT 7, took place in 2014 and, together with SPOT 6, is still operational (MARTÍN *et al*., 2020).

Thus, satellite images have been widely used for the study of pastures over the last three decades. The use of aerial photogrammetry was even mentioned in the 1930s (TUELLER, 1989). This approach is a mechanism and methodology that produces mosaics, which are costly compared with images currently developed (Figure 3).

Figure 3

Evolution of the mosaic process for complete image formation: (A) Mosaic of aerial photos from the 1930s in the United States (Source: West Virginia University); (B) RapidEye images of a Brazilian region from 2012 (Source: 2012 ® RapidEye AG All rights reserved).



(A) **(B)**

The use of satellite imagery in pasture studies has attracted increasing interest from the academic community. According to Ogungbuyi *et al*. (2023), from 1991 to 1992, 199 articles were published in 46 countries that studied the state of pastures using sensors – or a combination of sensors – in a defined area, validating the information through the use of – one or more – vegetation indices.

As highlighted by AKIYAMA & KAWAMURA (2007), remote sensing and geographic information systems (GIS) are promising tools for monitoring pastures, and these tools have recently become more viable because new sensor systems now allow the evaluation of degradation patterns.

Tropical pastures have seasonal vegetative characteristics, exhibiting relatively high levels of foliage density in the rainy season and relatively low-density levels in the dry season amid the consumption of available biomass by herds. The structuring of pastures can be defined as the spatial arrangement of aerial components of plants within a community (LACA & LEMAIRE, 2000). Pasture areas can be reserved for use in the dry season, leading to high flowering rates and the production of dead stems. According to SANTOS *et al*. (2009), for *Brachiaria decumbens*, this period cannot exceed 70 days, as palatability levels for animals would decrease otherwise. The perennialization of forage is a product of the continuous emission of leaves and tillers, which is a fundamental phenomenon for the restoration of leaf areas following periods of heavy grazing (GOMIDE, 1997; CHAPMAN & LEMAIRE, 1993). The tiller, the pasture production unit that ensures vegetative propagation, is positioned on leaf sheaths (HODGSON, 1990). The tiller growth process depends on energy reserves, which are critical during earlier stages of regrowth (SCHNYDER & VISSER, 1999). Foliage density levels can respond to sensor infrared channels. Through comparative studies, KAWAMURA *et al*. (2005) confirmed that the vegetation indices (VIs) of the Moderate Resolution Imaging Spectrometer (MODIS) sensor are efficient and reliable in the phenological quantification and qualification of steppe forage in China. According to FONTANA *et al*. (2008), the SPOT vegetation and MODIS Earth sensors are more efficient than the AVHRR (Advanced Very High Resolution Radiometer) sensor of the National Oceanic and Atmospheric Administration (NOAA) program when applied in phenological studies of alpine pastures in Switzerland, generating a high correlation between the normalized difference vegetation index (NDVI) and field data.

JONAS *et al*. (2008) analyzed Swiss meteorological data correlated with phenological trends of pastures in the Alps and concluded that shorter winters tend to increase biomass levels. By measuring the efficiency of radiation use through studies conducted in Argentina, CRISTIANO *et al*. (2015) reported that when the biomass of C3 (*Lolium perenne* and *Dactylis glomerata*) and C4 (*Cynodon dactylon*) grasses is concentrated in the subsoil and roots, remote sensing analyses are limited to pasture *phytophysiognomy*. Invasive and leguminous plants or tree and shrub species can obscure geospatial results despite being palatable and digestible to animals (especially in the early stages). THAIKUA *et al*. (2015) demonstrated that the anatomy, morphology, and hydrology of the phenology of *Brachiaria* may prove useful when determining selection criteria for digestibility in experimental areas in Japan. For the investigation of effective areas of pastures, numerous remote sensing and geoprocessing tools can be employed. Image visualization can be performed in different ways since the combination of bands is what generates the final product. The most common colors are natural color, pseudonatural color, and false infrared color (MARTÍN *et al*., 2020).

Various VIs obtained from transformations performed on satellite images have been developed, with each one being suited to specific research goals. These indices are cited and used in various technical-scientific publications (JENSEN, 2009; RUDORFF *et al*., 2007). Vegetation indices are essential components of any study involving remote sensing, as they allow, through various techniques, the analysis of the state, growth and health of vegetation (VIDICAN *et al*., 2023). Among them, the NDVI and enhanced vegetation index (EVI) are particularly noteworthy.

The NDVI index was first described by Rouse Jr. *et al*. (1973). It is an index that quantifies photosynthetically active biomass in plants. With respect to vegetation quality, the values of this VI can range from -1 to 1, with values closer to 1 indicating better vegetation quality (DAL COLLETTO *et al*., 2020).

The EVI is an index used to assess plant vitality and health. Its calculation represents a refinement of the NDVI because it considers atmospheric and soil conditions (VIDICAN *et al*., 2023).

The indices are essentially calculated from satellite bands in red (ρred) and near-infrared (ρnir) spectra, which are of low and high levels in the vegetation response, respectively. Specific factors are also used, subsequently creating an image that shows the degree of photosynthetic activity. The band operating in the blue spectrum ($\rho blue$) and fitting coefficients are also used to highlight vegetation features and noise suppression levels via the following formulas (JENSEN, 2009):

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}} \qquad (1)$$

$$EVI = G\frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + C_1\rho_{red} - C_2\rho_{blue} + L}(1 + L) \qquad (2)$$

where:

ρ_{nir} = near-infrared band

ρ_{red} = red band

ρ_{blue} = blue band

L = a factor for fitting the soil

G and C = coefficients of vegetation and atmospheric scattering

In the above formulas, L is a factor for fitting to the soil, and G and C are coefficients for empirically fitting to the vegetation and to atmospheric scattering; these values are determined to improve the expression of what photosynthetically active vegetation is. The EVI provides better results for denser vegetation conditions and for conditions presenting similar agricultural or forestry characteristics. Thus, the NDVI remains the most conservative and suitable method for the study of herbaceous, shrub and sparse tree vegetation. According to JENSEN (2009), time series of NDVI data have been studied to estimate the net primary production of various types of biomass and for the monitoring of phenological trends such as drying speeds after the achievement of physiological maturity. The MODIS output provides VIs, NDVI, EVI and VI quality (corrected VI – NDVI/EVI) products from calibrated sensors at a good spatial resolution. In fact, the MODIS provides NDVI data with an almost daily temporal resolution, with products processed from 16-day data, thus allowing for the elimination of noise and corrections in accordance with delays between the Terra and Aqua satellites, which are fitted with MODIS sensors. The NDVI data available in the MODIS sensor database can generate synoptic information to reveal the degree of photosynthetic activity in pastures. The basis for this is that while VIs and active photosynthetically absorbed radiation are nonlinearly related to the leaf area index (LAI), with saturation of LAI values at approximately 3.0, these indices have an almost linear relationship with the photosynthetic activity of canopies (SELLERS, 1985; SELLERS, 1987; SELLERS *et al*., 1992). Both the

NDVI and other indices associated with vegetation may allow the evaluation of growth and phenological conditions, thereby enabling the detection of young or dry foliage (PARK *et al*., 2008). Owing to the large amount of information available through satellite images, automated methods have been developed to map or classify terrestrial targets. Through unsupervised classification, LOVELAND & BELWARD (1997) released the DISCover database, which uses AVHRR/NOAA outputs to generate monthly NDVI compositions, detailing 17 NDVI classes. Countless methods for performing digital classification and data transformation to separate and extract the desired information are currently available.

JIAJU (1988) used PCA (Principal Component Analysis) to identify crops from multitemporal geospatial data and, in turn, obtained more precise classifications. Cao *et al*. (2003) sought to develop a methodology based on PCA from spectral and panchromatic images. The research yielded good visual and statistical results, preserving spectral information. Uddin *et al*. (2020) showed that PCA – and numerous variations of it – results in less space and time complexity, which can sometimes be a problem with the technique, with satisfactory classification results. CHEN *et al*. (2012) and HUSSAIN *et al*. (2013) discussed the results of various authors and the importance of existing tools for classification or object-based change detection (OBCD), which also allows alterations to be observed temporally in space. Bansal *et al*. (2022) performed an unsupervised OBCD to detect changes in high-resolution images on different dates. The study was conducted to observe the results of the method in each image before and after a change in the study area. The results, according to the authors, were superior to those of existing studies on the locality.

The NDVI is admittedly suitable for the mapping of pastures. TUCKER (1979) presented empirical analyses showing that the NDVI exhibits significant correlations with the biophysical variables of rural vegetation. HUETE *et al*. (2002) evaluated the performance of the MODIS VIs at a resolution of 500 m and reported a strong correlation between the field and aerial data and VIs (NDVI and EVI) for pasture, savanna, and forest locations, and they also demonstrated the applicability of these indices to biophysical measurements.

Several studies have shown that the results of monitoring pastures and plantations via VIs are highly satisfactory, achieving an accuracy of over 90%. In the evaluation of pastures, according to the literature review conducted by Vidican *et al*. (2023), among the VIs most commonly used in studies are the NDVI and EVI.

HOLM *et al*. (2003) used NDVI/AVHRR data accumulated during the growing season and related annual precipitation to phytomass as a degradation indicator of natural pastures in Australia. COPPIN *et al*. (2004) emphasized techniques based on the analysis of hypertemporal spatial profiles for change detection, and they addressed the phenological effects of growing seasons with limitations due to the low (AVHRR) to moderate (MODIS) resolution levels available. FERREIRA & HUETE (2004) analyzed converted areas of the Cerrado (savanna vegetation) on the basis of AVHRR indices transformed into the NDVI and EVI and achieved high levels of target discrimination. RATANA *et al*. (2005) reported that the accumulation or summing of spectral data improves the discrimination capacities of targets. GEERKEN *et al*. (2005) obtained good results for pasture classification in Syria on the basis of NDVI/MODIS data. FONSECA *et al*. (2007) used Landsat 7 images and an agro-meteorological model to predict the availability of forage in natural pastures in Brazil; however, their results were unsatisfactory due to the effects of soil. SANO *et al*. (2008) mapped the Cerrado biome through the segmentation of Landsat images and fieldwork; pastures were found to be predominant, accounting for 26.5% of the Earth's usage area.

XIE *et al*. (2008) reviewed the use of multitemporal remote sensing data for mapping vegetation in Europe on the basis of the AVHRR and MODIS sensors, cautioning against the use of such data owing to scale issues. Together with the evolution of time series, trend aspects started to emerge in some articles in which temporal statistics or metrics were applied to the technical-scientific themes associated with the series. AGUIAR *et al*. (2010) used MODIS time series and decomposition features as wavelets to distinguish between typical Cerrado vegetation and pasture areas. VERBESSELT *et al*. (2010) presented an algorithm as a way of detecting linear changes and trends in land use and discussed the detectable interannual phenology. VICTORIA *et al*. (2012) transformed the NDVI/MODIS time series for the state of Mato Grosso in Brazil into Fourier components. The cumulative profile methodology using MODIS data effectively discriminates among forests, savannas, agricultural crops, and pastures in Brazil (ANJOS *et al*., 2013).

KARNIELI *et al*. (2013) conducted a study using field variables and Landsat 7 ETM+ images transformed into the EVI and reported that higher VI values do not always signify better grazing conditions because of the presence of unpalatable invasive plants in Mongolia. RIGGE *et al*. (2013) established a relationship between the NDVI/MODIS accumulated by season (hot or cold) and rainfall for natural pastures in the United States. The phenological metrics applied to the series support distinctions between crop vigor and vegetation vigor. SILVA *et al*. (2010) obtained good results in characterizing types of pasture, forest, and agricultural crops in Brazil for the short series of MODIS bands (MOD13) by applying a linear spectral mixture model (LSMM) based on soil fractions, shade levels, and vegetation.

XU *et al*. (2013) estimated a growth index for pastures on the basis of an NDVI/MODIS time series for mapping degradation in China. XU *et al*. (2014) reported a strong relationship for the estimated Landsat-derived NDVI values of pastures in Canada. JIN *et al*. (2014) compared the biomass survey results for temperate pastures with various MODIS-based VIs; the NDVI generated a higher correlation coefficient (although not for steppes). According to ROUMENINA *et al*. (2015), new satellites and sensors such as those of the European Space Agency (ESA) have visible and infrared bands, such as Sentinel-1, Sentinel-2, and PROBA, which generate high temporal resolution data over 5 and 3 days, representing strong prospects for advances in database acquisition. However, traditionally, MODIS and Landsat time series have been used to evaluate management aspects of grazing, such as climate interactions, degradation, growth, and net primary productivity, allowing efficient estimates (HUANG *et al*., 2016; XU *et al*., 2018).

Bezerra *et al*. (2018) compared the NDVI values derived from data from Landsat-8 and Sentinel-2 satellites for a region in the Brazilian semiarid region. Despite the small difference, the researchers observed a greater delineation of the targets from the MSI-Sentinel sensor data, which allowed for greater confidence in the aspects of environmental monitoring. Liu *et al*. (2019) calculated the NDVI to quantify the conditions of pastures in China and Mongolia using 15 years of data. Although pasture degradation is a global problem, this study revealed that the alarm is greater for Asian countries, as it was concluded that approximately 90% of pastures are degraded. Segarra *et al*. (2020) studied the detection of abiotic and biotic stress and agricultural management.

The importance of freely accessible data and support software for the evolution of agricultural studies has been highlighted. Examples of discussions specifically about pasture degradation at localized levels (a fundamental theme in the agricultural environment), socioenvironmental issues and land use conversion in protected areas include Chadaeva *et al*. (2021), who studied degradation in the central region of Russia; Lang *et al*. (2021), who observed the impacts of pasture degradation on local production in inland Mongolia; Jiang *et al*. (2021), who sought to understand the climatic and anthropogenic influences on degradation in China; Feltran-Barbieri & Féres (2021), who concluded that restoring degraded pastures would increase agricultural production while protecting forest areas in Brazil; and Roque *et al*. (2022), who discussed land use conflicts in degraded pasture areas.

Some studies seek to work with this theme in a more macroscopic manner, that is, starting from a review of other works or from databases specific to their countries. As examples of this type of structuring, Ali *et al*. (2016) presented degraded pastures, from initial observations to management, through SR; Inácio *et al*. (2020) reviewed remote sensing monitoring for land use and cover; Reinermann *et al*. (2020), using remote sensing, researched the possible management and production of degraded pastures; Zhao *et al*. (2022) presented a review of the impact of pasture degradation on ecosystem services; and Zheng *et al*. (2022) presented an overview of pasture degradation based on the use of remote sensing.

5 CONCLUSION

Pasture vegetation, which covers large regions of the world and includes herbaceous plants, presents important dynamics that require a high degree of monitoring sensitivity. Thus, the science of remote sensing, GIS, and spatiotemporal metrics serve as alternative and less costly ways of collecting detailed or expeditious data. Specifically, for the analysis of pastures, the NDVI is outstanding in its remote perception of the vegetative conditions of pastures, and its time series can provide information on the variation in the phenological range and persistence of growing conditions. Owing to the large spatial extents of pasturelands, medium-to-low spatial resolution sensors with high temporal resolution produce results with appropriate sensitivity levels that are suited to seasonal or intraseasonal changes. In terms of remote sensing, there are currently several methodologies that can be applied to the monitoring of pastures, and the most appropriate one must conform to management conditions, territorial extent, and forage varieties.

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