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XII INTERNATIONAL RANGELAND CONGRESS AUSTRALIA 2025

Application of vegetation indices obtained from satellite images for the management of the Voisin rational grazing

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Key words: Cattle; mediterranean climate; NDVI; pastures.

Abstract

Cattle ranchers have problems making informed decisions for the management of natural pastures. The lack of information ends up forcing the animals to be supplemented with external feed and forage. The degradation of natural pastures, climate change, and agricultural policies aimed to make farms more sustainable. Sustainability requires improving natural resource management techniques. Voisin Rational Grazing manages grazing time based on the critical leaf area index; it has been proposed as a sustainable alternative for livestock. This method is based on optimizing the productivity of pasture and livestock but requires constant plots monitoring. The objective was to estimate through remote sensing the evolution of growth, biomass, and other pasture management parameters, which facilitate decision making in the Voisin. A real case study was chosen. The farm has 240 ha in 81 paddies in 5 counties, and 1,703 ha of communal pastures in joint use for summer use. It is in the northern of Madrid, in Central Spain under Mediterranean climate. Sentinel-2 images were used between 2017 and 2020, the processing and calculation of the vegetation indices was carried out with Sen2Cor and QGIS. In the field, biomass was sampled, and images were taken and processed with QGIS and SW Maps. A wide variety of factors affect the farmer decision, making the dynamics of the pastures between the plots heterogeneous in phenology and production. The evolution of the vegetation indices follows the dynamics of the grass logistic curve. Vegetation indices seem appropriate to detect the point of maximum grass biomass gain, necessary to apply the Voisin. Plots that are being grazed at high instantaneous stocking density, characteristic of the Voisin, can be detected using vegetation indices. Also, it was appreciated how this grazing method allows rapid regrowth. We considered that remote sensing can facilitate the application of Voisin Rational Grazing.

Introduction

Rangelands ecosystems cover more than a third of the world land surface, supporting key ecosystem services and livelihoods. The main drive variables for sustainability of rangeland are climate change, temperature and precipitation, and social-economic trends (Herrara and Davies 2014; Gartzia et al. 2016; Sanz et al. 2021). Identifying critical factors and main sources of risk into the rangelands provide useful tools for the design of mitigation measures and other measures (Iglesias et al. 2016).

Rational grazing (Worstell and Voisin 2015), specifically the methodology developed during the 1950s by researcher and farmer André Voisin (whose surname is used to commonly refer to this methodology as Rational Voisin Grazing, or RVG), is proposed as a grazing system to be implemented. While there are numerous grazing methodologies that could be considered rational—or at least account for both the development of the animal and the pasture—they all share the same foundation.

The main target of this grazing system is to optimize the production of the grazing animal and the productivity of the grazed pasture, which entails finding an optimal balance between meeting the needs of both the livestock and the pasture simultaneously. For the grazing animal, the aim is to maintain an adequate diet for the livestock in the pasture. This requires meeting the animals' needs in sufficient quantity and quality to achieve appropriate production parameters, which can only be reached if the animals' health and welfare are ensured (Pinheiro Machado et al. 2021). Our objective was to estimate through remote sensing the evolution of growth, biomass, and other pasture management parameters, focus on apply vegetation indices to facilitate decision making in the Voisin Rational Grazing systems.

Methods

We selected a rangeland from central Spain. The livestock operation under study is located at the northern mountain of the Community of Madrid. The lower parts of this area feature gentle topography, situated around 1,000 meters above sea level, while the highest peaks reach up to 2,000 masl. The operation runs a surface area of 240 hectares divided into 81 plots, of which 25 hectares equipped with irrigation. Also, it runs communal pastures covering 1,703 hectares grazing between March and October (as summer pastures). The operation includes 126 nursing cows of the native "Berrenda en Negro" Spanish breed (average 550 kg LW/cow), which are crossbred with Charolais bulls for industrial purposes.

The annual average temperature recorded is 11.3 °C, with the minimum average temperature of 4 °C in January and the maximum of 20.7 °C in July. The annual average rainfall is 637 mm, with November being the wettest month (90.7 mm) and August the driest (18.1 mm). This rainfall and temperature regime results in a dry period lasting four months: June, July, August, and September. Regarding the frost period, estimates using the Papadakis method indicate a medium frost-free season from April 21st to November 4th. The soils in the area are classified under the USDA Soil Taxonomy as Inceptisols in higher areas and Entisols in the valley floor. The soil pH is moderately acidic, ranging between 5.78 and 6.3, and the soil organic matter content varies from 0.66% to 4.3%.

In the field, biomass was sampled, data was gotten from the farmer land book and from field samples. Up to seven different types of pastures have been identified, also the agroforestry of ash (*Fraxinus angustifolia* Vahl.) and oak (*Quercus pyrenaica* Willd.), because they constitute a considerable source of food at the end of summer and beginning of autumn, when sometimes there is no grass regrowth and therefore, they represent an alternative source of great importance. The habitats present according to European Union Habitats Directive (Council Directive 92/43/EEC) are 6220 (*Festuco amplae-Poetum bulbosae*); 6310 (*Juniper oxycedri-Quercetum rotundifoliae pastures*); 91B0 (*Querco pyrenaicae-Fraxinetum angustifoliae*) and 92A0 (*Rubo-Salicetum atrocinereae*). During 2020, two types of management were studied: continuous grazing (in which areas that were being grazed during sampling were determined) and rotational grazing (areas that were excluded from grazing).

Following a literature review, seven vegetation indices have been chosen that have already been used to relate them mainly with grass biomass (Table 1).

Table 1. Vegetation indices obtained according with the literature for vegetation quantity or quality that can be calculated using pairs of Sentinel-2 bands.

Vegetation indices	Acronyms	Equations
Normalized Difference Vegetation Index	NDVI	(B08 - B04) / (B08 + B04)
Enhanced Vegetation Index	EVI	2.5 × (B08 - B04) / [(B08 + 6×B04 - 7.5×B02) + 1]
Renormalized Difference Vegetation Index	RDVI	(B08 - B04) / √(B08 + B04)
Green Normalized Vegetation Index	GNDVI	(B08 - B03) / (B08 + B03)
Sentinel 2 Red Edge Position	S2REP	705 + 35 × ([(B07 + B04)/2) - B05] / (B06 - B05)
Red-Edge Normalized Difference Vegetation Index I	RENDVI I	(B06 - B04) / (B06 + B04)
Red-Edge Normalized Difference Vegetation Index II	RENDVI II	(B07 - B04) / (B07 + B04)

*Sentinel-2 layers bands (ESA 2021): B02 (490 nm), B03 (560 nm), B04 (665 nm), B05 (705 nm), B06 (740 nm), B07 (783 nm), and B08 (842 nm).

Sentinel-2 images were used between 2017 and 2020 from Copernicus Open Access Hub to calculate vegetation indices and to monitor rangeland pastures. The processing and calculation of the vegetation indices was carried out with Sen2Cor 02.08.00 and QGIS 3.16.1. All data was processed with QGIS and SW Maps. A wide variety of factors affect the farmer decision, making the dynamics of the pastures between the plots heterogeneous in phenology and production.

Results

Pastures biomass

The farmland displays a wide variety of factors leading to heterogeneity in the phenology and production of pasture across plots. Pasture productivity ranged from 1,563 kg DM/ha in non-irrigated plots (2017) to a maximum of 4,108 kg DM/ha in irrigated plots (2020), with an average of 2,686 kg DM/ha in rain-fed plots and 3,174 kg DM/ha in irrigated plots.

The evolution of the vegetation indices

The evolution curves of the vegetation indices (VIs) showed that all indices detected changes in pasture senescence. Figure 1 illustrates how the senescence of irrigated pastures is delayed compared to non-irrigated pastures.

a) b)

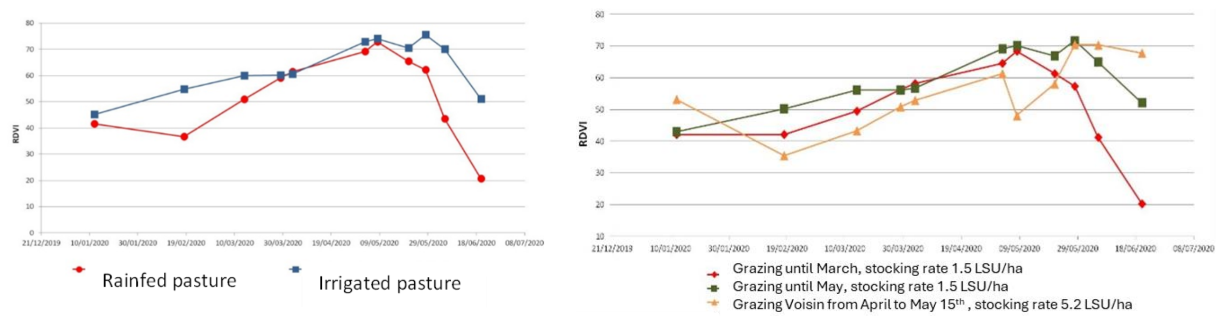

Figure 1. a) Evolution of Renormalized Difference Vegetation Index RDVI in rainfed areas and under irrigation during pasture growth periods in from winter 2019 to summer 2020; b) Evolution of Renormalized Difference Vegetation Index RDVI with different pastures management from winter 2019 to summer 2020.

When examining the effects of grazing, clear changes were only observed in plots with high instantaneous stocking rates (5.2 LSU/ha) according to Voisin. In contrast, plots with low stocking rates (1.5 LSU/ha) showed no significant differences between grazed and reserved plots (Figure 1b). From Figure 1b, it can be seen what effects are expected from PRV through the plot grazed for a short time at a high loading: the estimated production was 3,060 kg DM/ha compared to 4,060 kg DM/ha despite having been thoroughly grazed and reserved for a period at least two weeks less than the plot reserved in May. The application of rational Voisin grazing improved grass production by 24% to 76% depending on the type of grass and management (Table 2).

The evolution of VIs follows the same logistic curve dynamic as pasture growth, indicating their suitability for detecting the point of maximum biomass gain. Specifically, the RDVI index was selected for its higher sensitivity to phenological and management changes.

Table 2. Pasture productivity (kg DM/ha year) in the current and Voisin. Current management continuous grazing (in which areas that were being grazed during sampling were determined) and rotational grazing (areas that were excluded from grazing)

Management	**Current grazing** kg DM/ha year	**Rational Voisin Grazing** kg DM/ha year	**Pasture gain** kg DM/ha year, (%)
Continuous grazing (rainfed)	2,750	4,825	2,075 (76%)
Rotational grazing (rainfed)	3,625	4,825	1,200 (33%)
Rotational grazing (irrigated)	4,934	6,134	1,200 (24%)

Regarding the correlation of the evolution of vegetation indices with biomass in summer, it has been found that this is more adjusted in the grazing paddocks that have not been grazed since March for the set of years 2017-2019-2020. Therefore, considering the period within each season between March and the date with available satellite image following that with which the highest value of May is obtained and a linear adjustment; the cumulative or integral of the IV that has the best correlation with the estimated biomass of the pasture is the EVI ($r^2 = 0.52$).

Discussion and conclusions

It has been demonstrated that vegetation indices can identify plots grazed with high instantaneous stocking rates, a key feature of the RVG system. Additionally, this type of grazing allows for rapid pasture regrowth, achieving satisfactory productivity compared to other management approaches. The RDVI appears to be the most sensitive index for detecting changes in pasture management and phenology, making it a valuable indicator for Voisin grazing management.

Following Sanz et al. (2022) vegetation indices time series could allow us to understand better the rangelands´ evolution and the effect of management in these trends. The biomass estimation results suggest that the relationship between biomass and the accumulated VI value throughout the growth season depends on the availability of satellite imagery, particularly during critical growth periods in spring when cloud cover can limit data availability.

The best vegetation index for estimating pasture biomass in this study was the EVI. While the results could be improved with more data and biomass sampling, the index can still be used for pasture management, considering its limitations. These limitations primarily relate to the reliance on final biomass data from long growth periods without grazing. Therefore, it is proposed to use RDVI for detecting changes in pasture (management, phenology, or rest periods) and EVI for estimating available biomass after reserving pastures for cutting.

Acknowledgements

The data provided by the farmer is greatly appreciated. This work was partially funded by CEIGRAM, ENESA, and Community of Madrid by grant no. AGRISOST-CM S2018/BAA-4330, and RP220220C024: classification of grasslands by supervised methods from Universidad Politécnica de Madrid. Also, thanks our colleagues for their helpful comments during the review process.

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