TEMPORAL COMPARISON OF MULTIPLE SENSORS FOR MONITORING PADDOCK MANAGEMENT IN AN INTEGRATED CROP-LIVESTOCK SYSTEM

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ABSTRACT

Analysing remote sensors' response for monitoring intensively managed areas, such as integrated crop-livestock systems (ICLS) is still necessary. Each sensor offers a level of detail for land use monitoring. Thus, the objective of this study was to assess and compare the temporal profile of the Normalised Difference Vegetation Index (NDVI) time series from different sensors for paddock monitoring in intensively managed pasture fields. We used the NDVI time series from three remote sensors (PlanetScope/CCD, Sentinel-2/MSI and Terra and Aqua/MODIS). The results showed that the NDVI temporal profiles of all sensors were able to capture variations in the phenological stages of pasture development, as well as the paddock management operations in our study area.

Key words — *managed pasture, temporal profile, MODIS, Sentinel-2, PlanetScope.*

1. INTRODUCTION

Integrated crop-livestock systems (ICLS) are characterised by the annual rotation of crops and pastures to generate positive economic and environmental outcomes [1]. These systems usually occur in climatically favourable regions and show high spatial and temporal variability due to farm management practices [2]. Some procedures can provide timely-spatial information to assist land use management, such as guiding farmers in decisions related to the condition of pastures [3] and monitoring agricultural practices [4].

Time series of high temporal resolution images have proved to be an outstanding alternative to monitor highly dynamic areas over phenological cycles, such as agriculture [5], [6] and pasture [7]. However, satellite images often have limitations and one of them is the difficulty of obtaining data with adequate spatial resolution in regions based on small farm fields. In this context, it is necessary to analyse the available remote sensors' response for monitoring intensively managed areas, since different sensors have specific characteristics and offer different levels of details for land use management.

While Landsat missions' medium spatial resolution data (30 m) have been operationally used to monitor land-use changes on a global scale, their temporal resolution is limited (16 days), which can be a problem under adverse atmospheric conditions [8]. On the other hand, sensors with a coarser spatial resolution (250 m), such as the Moderate Resolution Imaging Spectroradiometer - MODIS [9], offer a high frequency of images, but with a limited application on the effective monitoring of agricultural systems at sub-field scales [8]. An important advance for solving the trade-off between opting for spatial or temporal gain images was the deployment of the Sentinel-2 mission [10]. Additionally, the emergence of nano-satellite constellations increased the availability of high temporal and spatial resolution data. The standardised CubeSat concept generated a new operational paradigm, such as the Planet CubeSat satellites, which now provides global high spatial resolution (~ 3 m) data with high temporal resolution (daily) [11].

Many studies have used vegetation index data, such as the Normalized Difference Vegetation Index (NDVI) [12], for monitoring agricultural fields and pasturelands, since such index shows a high correlation with in-situ green biomass and growth vigour [13], [2]. Therefore, the main objective of this study was to assess and compare the NDVI temporal profile from three different sensors (PlanetScope/CCD, Sentinel-2/MSI and Terra and Aqua/MODIS) for paddock monitoring in intensively managed pasture fields. In other words, this paper aims to verify the responses obtained from these profiles according to the phenological development stages and management operations performed on pastures within an ICLS area.

2. MATERIAL AND METHODS

The study area is located in the municipality of Caiuá, in the western region of the São Paulo State, the southeast region of Brazil (Figure 1). It comprises four fields of approximately

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50 ha each, totalising 200 ha. These fields have been managed as an ICLS based on the rotation of pasture during the winter season, and soybean cultivation in the summer season, since 2018. The pasture is composed of a mixture of ruzi grass (*Urochloa ruziziensis*) and millet (*Pennisetum glaucum*). Pasture planting started on March 28th, after soybean harvest, and lasted until April 6th 2019. For this study, we focused only on the pasture period and selected two different paddocks with known and distinct management practices with approximately 15 ha and 17 ha, respectively. These paddocks are covered by two MODIS pixels, which were used as a reference for the multitemporal evaluation of the different sensors.

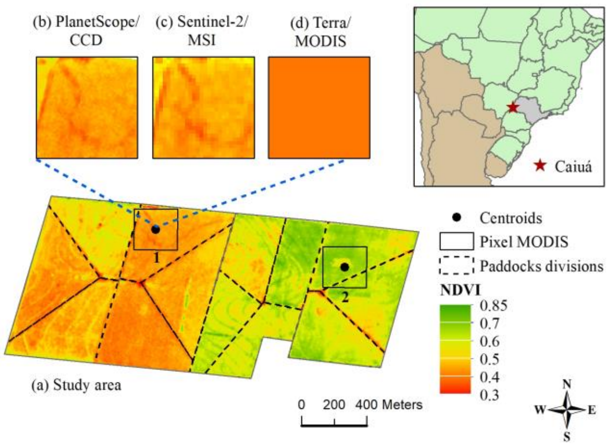

Figure 1. (a) Study area and the two selected MODIS pixels showed in a PlanetScope/CCD NDVI image of June 2019. NDVI variation in the selected MODIS pixels for the different images: (b) PlanetScope/CCD, (c) Sentinel-2/MSI, and (d) MODIS.

Initially, we acquired surface reflectance images from PlanetScope/CCD and Sentinel-2/MSI sensors. We set the maximum cloud coverage at 50%, and the analysis period from March 22th to September 30th, 2019, which matches the growth cycle of pasture in the paddocks. Subsequently, we calculated the NDVI from the red and near-infrared bands for all available cloud-free images from PlanetScope/CCD and Sentinel-2/MSI for the analysis period. In the case of MODIS images, we used the 16-day composites of the MOD13Q1 [14] and MYD13Q1 [15] products, that correspond to the best available pixel value from all the acquisitions from the 16-day period, based on the criteria of low clouds, low view angle and the highest NDVI value.

To generate the NDVI temporal profiles for both paddocks, we used the two selected MODIS pixels (Figure 1) to extract the NDVI mean values from the total time series imagery of the three sensors. Then, we compared the NDVI profile patterns obtained by the different sensors and evaluated each sensor's potential to monitor the paddocks operations using the information of pasture management (Table 1).

Management	Paddock 1	Paddock 2
Pasture sowing	2019/03/28 - 2019/03/31	2019/04/04 - 2019/04/06
1st Cattle entry	2019/05/17	2019/06/02
1st Cattle exit	2019/06/09	2019/06/18
2nd Cattle entry	2019/08/04	2019/08/06
2nd Cattle exit	2019/09/13	2019/09/13

Table 1. Period information about the pasture management performed on the two selected paddocks.

A total of 69 PlanetScope/CCD images, 35 Sentinel-2/MSI images, and 24 MODIS images were used in this analysis. The difference in the number of images from each sensor was due to each one's specific temporal resolution. To improve the temporal profiles' visualisation, we applied the Savitzky-Golay filter to smooth the NDVI time series. This filter is based on a moving window (size 4), which uses linear least-squares adjustment through successive polynomial equations [16].

3. RESULTS AND DISCUSSIONS

The NDVI temporal profiles for the pasture growing period obtained from the different sensors are shown in Figure 2. Image dates are represented by markers while the smoothed time series of NDVI are illustrated as lines. The number of images used to build the NDVI profiles can be seen from the marker density in the time series, whose frequency could change the representation of the management operations. In general, all sensors were able to detect the paddocks' management operations.

The NDVI temporal profile patterns were highly related to the grazing activities in the paddocks. We highlighted the date disparity in which each paddock was managed (Table 1), resulting in expected differences in their NDVI temporal patterns. At the beginning of the NDVI profile, we could visualize the end of the soybean cycle, which occurred before the pasture sowing. Considering the dates of the management operations for both paddocks between the pasture sowing and the first cattle entry, there was significant growth in NDVI values. This initial signal is mainly due to the millet growth, whose cycle is shorter than ruzi grass, as also discussed in [17]. Only after the first exit of cattle that ruzi grass could become predominant. Immediately after the first and second exit of the cattle, we verified an increase in the NDVI values for all satellites/sensors, which can be explained by the regrowth of pasture, demonstrating the ability of sensors to follow variations in green biomass availability in the paddocks.

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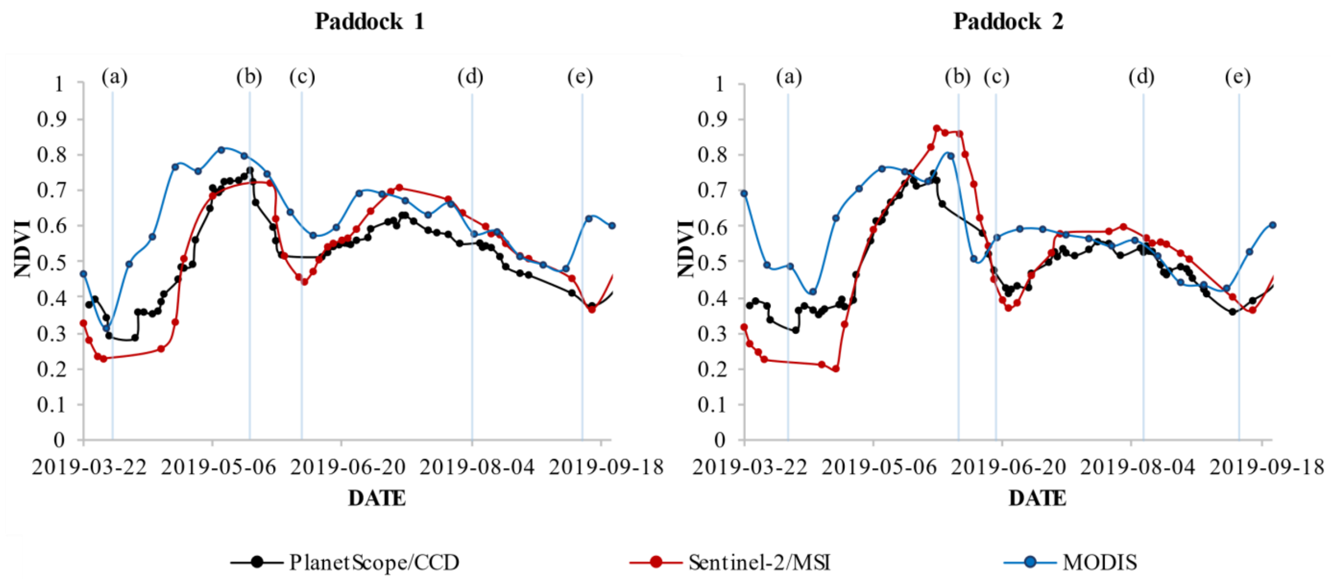

Figure 2. NDVI temporal profile obtained from PlanetScope/CCD, Sentinel-2/MSI and MODIS time series in the paddocks. Pasture management: (a) pasture sowing, (b) 1st cattle entry, (c) 1st cattle exit, (d) 2nd cattle entry and (e) 2nd cattle exit.

We observed that the selected pixels showed different NDVI values for the same image date depending on the sensors. This may be associated with the spectral specifications of each sensor, such as the bandwidth and central wavelength (i. e., red and near-infrared bands). In this context, we found that the reflectance of our targets covered by one MODIS pixel differs from the mean's average of several pixels covered by Sentinel-2/MSI and PlanetScope/CCD for the same geographical location.

Another factor that should be taken into consideration is the size of the paddocks in our study area. Both paddocks are larger than 15 ha and could be monitored by MODIS images. However, in smaller paddocks or when more detailed land information is required, MODIS data may not be suitable. In these cases, images provided by PlanetScope/CCD or Sentinel-2/MSI are more suitable due to their spatial characteristics, Figure 1.

From the analysis of each sensor NDVI profile, we observed that Sentinel-2/MSI data showed the lowest value in sparse green biomass cover sites (Figure 2) and the highest value in greenest biomass cover sites. The Sentinel-2/MSI and PlanetScope/CCD curves showed a similar pattern, with similar NDVI values for several dates. This result may address new studies involving data fusion or gap-filling when images from these satellites are unavailable.

Our results allowed us to evaluate the performance of each sensor in the paddock monitoring. Thus, the PlanetScope/CCD, Sentinel-2/MSI and MODIS imagery time series showed the greatest potential for monitoring the biomass condition in the ICLS paddocks. However, depending on the level of spatial detail required, Sentinel-2/MSI may be a better alternative, since this platform offers free of charge imagery and the data follows a rigorous calibration process. PlanetScope/CCD offers an unprecedented combination of high temporal (daily) and high spatial (~ 3 meters) resolution data. However, these images are high-cost, which may be a limitation of their widespread utilisation. Some studies have also reported cross-sensor variations that may affect the NDVI values derived from PlanetScope/CCD imagery even in images from the same day [18], [8].

4. CONCLUSIONS

This study evaluated NDVI temporal profiles derived from three different sensors (PlanetScope/CCD, Sentinel-2/MSI and Terra and Aqua/MODIS) during the pasture growing season in an area of ICLS. All the sensors were able to capture the variations in the phenological stages of pasture development and paddock management operations in the study area. Considering the typical-sized paddocks, free-data availability, and the spatial resolution of the images, Sentinel-2/MSI showed great potential to support pasture monitoring and biomass spatial variability assessment in ICLS grazed areas.

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REFERENCES

[1] G. Lemaire, A. Franzluebbers, P. C. de F. Carvalho, and B. Dedieu, Integrated crop–livestock systems: Strategies to achieve synergy between agricultural production and environmental quality. *Agric. Ecosyst. Environ.*, vol. 190, p. 4–8, Jun. 2014, doi: 10.1016/j.agee.2013.08.009.

[2] S. Green, F. Cawkwell, and E. Dwyer. Cattle stocking rates estimated in temperate intensive grasslands with a spring growth model derived from MODIS NDVI time-series. *Int. J. Appl. Earth Obs. Geoinformation*, vol. 52, p. 166–174, Oct. 2016, doi: 10.1016/j.jag.2016.06.012.

[3] S. M. Punalekar *et al.* Application of Sentinel-2A data for pasture biomass monitoring using a physically based radiative transfer model. *Remote Sens. Environ.*, vol. 218, p. 207–220, Dec. 2018, doi: 10.1016/j.rse.2018.09.028.

[4] C. L. M. de O. Santos *et al.* Classification of Crops, Pastures, and Tree Plantations along the Season with Multi-Sensor Image Time Series in a Subtropical Agricultural Region. *Remote Sens.*, vol. 11, nº 3, p. 334, Jan. 2019, doi: 10.3390/rs11030334.

[5] M. C. A. Picoli *et al.* Big earth observation time series analysis for monitoring Brazilian agriculture, *ISPRS J. Photogramm. Remote Sens.*, vol. 145, p. 328–339, Nov. 2018, doi: 10.1016/j.isprsjprs.2018.08.007.

[6] P. Griffiths, C. Nendel, and P. Hostert. Intra-annual reflectance composites from Sentinel-2 and Landsat for national-scale crop and land cover mapping., *Remote Sens. Environ.*, vol. 220, p. 135–151, Jan. 2019, doi: 10.1016/j.rse.2018.10.031.

[7] L. Parente *et al*. Monitoring the Brazilian pasturelands: A new mapping approach based on the Landsat 8 spectral and temporal domains. *Int. J. Appl. Earth Obs. Geoinformation*, vol. 62, p. 135–143, Oct. 2017, doi: 10.1016/j.jag.2017.06.003.

[8] R. Houborg and M. F. McCabe. A Cubesat Enabled Spatio-Temporal Enhancement Method (CESTEM) utilising Planet, Landsat and MODIS data. *Remote Sens. Environ.*, vol. 209, p. 211–226, May 2018, doi: 10.1016/j.rse.2018.02.067.

[9] C. O. Justice *et al.* The Moderate Resolution Imaging Spectroradiometer (MODIS): land remote sensing for global change research. *IEEE Trans. Geosci. Remote Sens.*, vol. 36, nº 4, p. 1228–1249, Jul. 1998, doi: 10.1109/36.701075.

[10] M. Drusch *et al.* Sentinel-2: ESA's Optical High-Resolution Mission for GMES Operational Services. *Remote Sens. Environ.*, vol. 120, p. 25–36, May 2012, doi: 10.1016/j.rse.2011.11.026.

[11] H. Riihimäki, M. Luoto, and J. Heiskanen. Estimating fractional cover of tundra vegetation at multiple scales using unmanned aerial systems and optical satellite data. *Remote Sens. Environ.*, vol. 224, p. 119–132, Apr. 2019, doi: 10.1016/j.rse.2019.01.030.

[12] W. Rouse *et al.* Monitoring Vegetation Systems in the Great Plains With Er. *Earth Resources Technology Satellite Symposium*, vol. 1, p. 9, 1973.

[13] W. Ouyang *et al.* Integration of multi-sensor data to assess grassland dynamics in a Yellow River sub-watershed. *Ecol. Indic.*, vol. 18, p. 163–170, Jul. 2012, doi: 10.1016/j.ecolind.2011.11.013.

[14] Didan, Kamel. MOD13Q1 MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V006. NASA EOSDIS Land Processes DAAC, 2015, doi: 10.5067/MODIS/MOD13Q1.006.

[15] Didan, Kamel MYD13Q1 MODIS/Aqua Vegetation Indices 16-Day L3 Global 250m SIN Grid V006. NASA EOSDIS Land Processes DAAC, 2015, doi: 10.5067/MODIS/MYD13Q1.006.

[16] Abraham. Savitzky and M. J. E. Golay. Smoothing and Differentiation of Data by Simplified Least Squares Procedure. *Anal. Chem.*, vol. 36, nº 8, p. 1627–1639, Jul. 1964, doi: 10.1021/ac60214a047.

[17] A. A. Dos Reis *et al.* Monitoring Pasture Aboveground Biomass and Canopy Height in an Integrated Crop-Livestock System Using Textural Information from PlanetScope Imagery, *Remote Sens.*, vol. 12, nº 16, Aug. 2020, doi: 10.3390/rs12162534.

[18] R. Houborg and M. McCabe. High-Resolution NDVI from Planet's Constellation of Earth Observing Nano-Satellites: A New Data Source for Precision Agriculture., *Remote Sens.*, vol. 8, nº 9, p. 768, Sep. 2016, doi: 10.3390/rs8090768.