ORIGINAL ARTICLE

Estimation of Infection Severity in Sugarcane Using Satellite Images

Estimación de la severidad de la infección en la caña de azúcar mediante imágenes satelitales

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ABSTRACT: Brown rust (*Puccinia melanocephala*) contamination in sugarcane (*Saccharum spp.*) is a major problem because of the costs it imposes on growers. Based on a recent study using hyperspectral analysis at the laboratory level as well as multispectral analysis by unmanned aerial vehicle (UAV), this work undertook the task of estimating brown rust infection using multispectral images (MSI) from the Sentinel-2 satellite constellation. The results show a high agreement between the estimation by UAV, the one obtained by satellite images and the one observed in the field by a specialist. These results make it possible to extend the estimation of the infection of this disease to large areas, reducing the costs involved in moving the UAV to the regions to be studied, where it can only cover a limited space in each flight.

Keywords: Remote sensing, rust, satellite imagery, unmanned aerial vehicles, sugarcane.

RESUMEN: La contaminación con roya parda (*Puccinia melanocephala*) en la caña de azúcar (*Saccharum* spp.) es un importante problema por los costos que impone a los productores. Basándonos en un estudio reciente, en el que se utilizó análisis hiperespectral a nivel de laboratorio, así como multiespectral mediante vehículo aéreo no tripulado (UAV), este trabajo acometió la tarea de estimar la infección con roya parda mediante las imágenes multiespectrales (MSI) de la constelación satelital Sentinel-2. Los resultados arrojan gran coincidencia entre la estimación mediante UAV, la obtenida mediante imágenes satelitales y la observada en el terreno por un especialista. Estos resultados posibilitan extender la estimación de la infección de esta enfermedad a grandes áreas reduciendo los costos que implica trasladar el UAV hasta las regiones a estudiar, en las que solo puede cubrir un espacio limitado en cada vuelo.

Palabras clave: Sensado remoto, roya, imágenes satelitales, vehículos aéreos no tripulados, caña de azúcar.

INTRODUCTION

Brown rust (*Puccinia melanocephala*) of sugarcane (*Saccharum spp.*) is a foliar disease of economic importance because of the costs it causes to both producers and society due to the losses it causes. It is reported in 57 countries (Aday-Díaz *et al.*, 2020; Grisham *et al.*, 2020). All this is exacerbated at a time when many countries are facing a complex economic situation, aggravated by various factors due to the COVID-19 epidemic and armed conflicts in various regions. Spectrometry, either by means of geospatial technologies (satellites), aerial (UAV) or at the laboratory level under controlled conditions, provides an approach for dealing with brown rust infection in sugarcane plantations.

Spectrometry, whether multispectral (MSI) or hyperspectral (HSI), is considered an alternative to traditional field sampling methods and is becoming increasingly popular thanks to the development of new instruments and software. An example of this has been the application of spectrometry in the study of brown rust and orange rust infection in sugarcane Soca-Muñoz *et al.* (2020), in which, in addition, a vegetation index (VI) sensitive to brown rust (*Puccinia melanocephala*) and orange rust (*Puccinia kuehnii*) was determined among those commonly used, being this the basis of this work. The study on

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multispectral aerial image processing in precision agriculture Kharuf-Gutierrez *et al.* (2018a), as well as the analysis of MSI acquired with UAVs also constitute bases of this work (Kharuf-Gutierrez *et al.*, 2018b). All these works have been developed by the *Grupo de Automatización, Robótica y Percepción* (GARP), from the *Universidad Central "Marta Abreu" de Las Vilas* (UCLV) and the *Instituto de Investigaciones de la Caña de Azúcar* (INICA Villa Clara).

The use of UAVs for MSI analysis of sugarcane crops is widely reported, since they can be used to obtain low altitude images with high spatial resolution (Som-Ard *et al.*, 2021). According to a paper recently published in Remote Sensing Applications: Society and Environment Amarasingam *et al.* (2022), it is recognized that, in Cuba, specifically in the province of Villa Clara, has been one of the places in the world where UAVs have been used in sugarcane agriculture. The use of UAVs has been critical for crop management and improvement given their flexibility and adaptability to local requirements, flying below the clouds, which frees them from the shadows they produce, as well as not being restricted to a specific flight schedule. However, the use of cameras for HSI in UAVs is expensive, being common to equip them with cameras for MSI. On the other hand, it is costly to transport UAVs to crop sites, considering that UAV flights only cover relatively small areas, acquiring tens or thousands of images that must then be processed by specialized software. In addition, government regulations limit the intensive and extensive use of UAVs in many places.

Given the tropical nature of sugarcane (*Saccharum spp*.), some of its varieties are very susceptible to brown rust infection, mainly in countries with little development due to the limitations they suffer to acquire the resources and technologies suitable for its early detection. Traditionally, estimating the severity of brown rust infection has been done by visual inspection and the application of graded symptom severity scales. The traditional method requires specialized personnel to cover large areas performing sporadic or scattered samplings whose results are conditioned by the subjectivity characteristic of human estimation and lack reproducibility. Thus, the result depends on the expertise and sharpness of the estimation made by the personnel available at each site, which may vary between large distant areas. In addition, surveying large areas is a process that consumes a great deal of time and effort. Coincidentally, the introduction of new technologies by local farmers, such as UAVs, is hampered by limitations of resources and adequate knowledge for their use, ranging from flight planning to image processing, the high initial investment cost, including the usual reluctance to use new technologies.

In contrast to UAVs, satellites provide images that can cover large areas on a regular basis with a stable temporal resolution and with a spectral resolution that allows imaging in multiple bands. Some satellite image databases are freely available from the internet. However, due to the altitude at which satellites fly, their spatial resolution can be much lower than that obtained by a UAV flying at low altitude. In addition, satellite images are affected by the scattering of electromagnetic radiation caused by refraction through the atmosphere, as well as its absorption by particles such as dust or smoke. All this makes satellite analysis to be recognized as one of the remaining challenges in plague detection, making it difficult to extrapolate the methods used at laboratory scale or at very low altitude, to the processing of images taken at high altitude (Müllerová *et al.*, 2017; Caasi *et al.*, 2020; Lu *et al.*, 2020). That is why the purpose of this work is to show the feasibility of using MSI from the Sentinel-2 satellite constellation in the estimation of sugarcane plantations infected with brown rust, about which we are not aware of another previous publication. Likewise, to discuss its benefits and limitations and to propose a solution implemented by processing satellite MSI of 10 m spatial resolution, which offers comparable results to those obtained by UAV and which has been validated by field work in the crop area analyzed. The result of this work is already introduced in the SDI (Spatial Data Infrastructure) of the AZCUBA sugar group.

MATERIALS AND METHODS

Location of Area of Study and UAV images

The images for this work were acquired on July 23, 2020 in sugarcane fields of the "Héctor Rodríguez" sugar mill, located northeast of Sagua la Grande, Villa Clara Province, Cuba (Figure 1). This date corresponds to the season of high temperature and humidity in the sugarcane fields. According to Aday-Díaz *et al.* (2020), brown rust infestation is most severe in Cuba between April and September, mainly in August and September.

The rotary-wing UAV used was equipped with the *MicaSense RedEdge-MX* multispectral camera (https://micasense.com/rededge-mx/home), weighing only 150 g and specially designed for professional work in agriculture. This camera simultaneously images in five discrete spectral bands B: blue (475 nm, 32 nm BW), G: green (560 nm, 27 nm BW), R: red (668 nm, 16 nm BW), RE: red edge (717 nm, 12 nm BW), and NIR: near infrared (842 nm57 nm BW). It has its own global positioning system (GPS) and WiFi. In addition, it includes state-of-the-art technology to measure the sun's irradiance and angular position, as well as a reliable radiometric correction. The images are saved in GeoTiff format with 12 bits per pixel, which produces 4'096 grayscale intensity levels for each pixel, each having 1280 x 960 pixels.

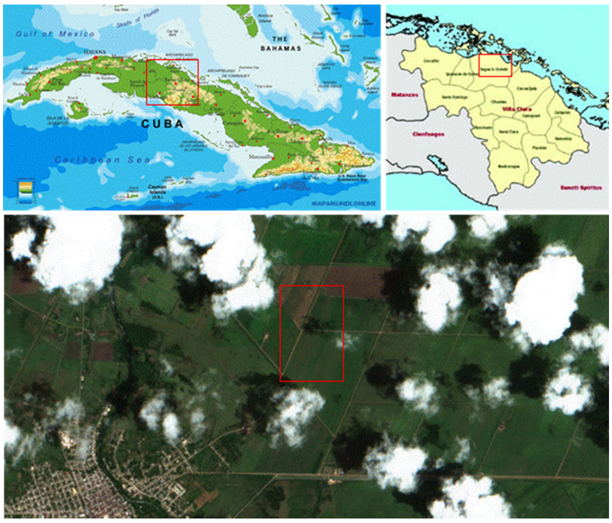

FIGURE 1. Sugarcane fields of the "Héctor Rodríguez" sugar mill in Villa Clara, Cuba, used for this work. In red box the area studied according to the scale of the map.

The flights were performed at 90 m altitude, obtaining a spatial resolution of 6 cm/pixel (GSD). The duration of the flights was about 10 minutes, limited by battery capacity. The flights were scheduled in the middle of the morning, which minimizes the uncertainty in the radiometric correction, as well as the thermal irradiation due to ground heating. The images obtained during the flight were processed using the free software *Agisoft PhotoScan Professional* (http://www.agisoft.com/) for the construction of the georeferenced orthomosaics of each of the spectral bands. The phases of image alignment, geometry construction and orthomosaic generation were followed. The geographic information of the orthomosaic corners is: latitude 22.822° ~ 22.834° and longitude -80.041° ~ -80.047°.

Satellite Data Acquisition

The Copernicus program (https://copernicus.eu/) of the European Space Agency (ESA) launched since 2015 the Sentinel-2A satellite and in 2017 the Sentinel-2B, designed for remote sensing, mainly in agriculture, so they can be considered relatively novel in this field according to the European Space Agency (ESA, 2015). These provide images in 13 spectral bands covering the visible, NIR and SWNIR electromagnetic frequencies with spatial resolutions (GSD) of 10, 20 and 60 m per pixel, being considered multispectral sensors (Lu *et al.*, 2020; Segarra *et al.*, 2020; Som-Ard *et al.*, 2021). In addition, the Copernicus program provides true color (RGB) images, as well as some vegetation indices, such as NDVI, or humidity (MI). Both satellites form a constellation flying in the same polar orbit at an average altitude of 786 km, but 180° out of phase to provide a temporal resolution of five days, with Mean Local Solar Time (MLST) at 10:30 AM; that is, synchronized with the sun. The radiometric resolution is 12 bits/pixel, so radiation is recorded with an accuracy of 4'096 intensity levels in each pixel (Lastovicka *et al.*, 2020). These features of Sentinel-2 MSIs have already been exploited for the detection of yellow rust (*Puccinia striiformis*) in wheat crops Zheng *et al.* (2018), as well as to monitor sugarcane crops (López-Bravo *et al.*, 2022). The stability in the periodicity of the images, with only 5 days of temporal resolution, has been widely used for the development of time series to detect, with great ease and efficiency, early signs of various dynamic factors of biotic and abiotic nature that stress crops (Wang *et al.*, 2019; 2020; Xu *et al.*, 2020; Ruan *et al.*, 2021; Vaudour *et al.*, 2021).

The satellite images were downloaded from the Sentinel-2 satellite constellation database, corresponding to August 23, 2020; that is, 30 days after the date of the UAV flights. The time difference is due both to the temporal resolution of Sentinel-2 and to the presence of clouds over the studied terrain on some of the intermediate days. The geographic information of the corners of the images is: latitude 22.806° ~ 22.844° and longitude -80.004° ~ -80.086°, which coincides with the lower part of Figure 1.

Processing software

Both the orthomosaics constructed from the images acquired by the UAV and those obtained by Sentinel-2 were processed using the computational tool Matlab 2017a with the Image Processing Toolbox and the Mapping Toolbox Swami (2009); The Math works (2009), installed, for which the necessary codes were programmed both for the manipulation of the images and for the computation of the operations performed with them, as well as for the visualization of the results. All this was based on the work published in Soca-Muñoz *et al.* (2020), where a highly sensitive vegetation index (VI) was found to estimate the degree of brown rust infestation in sugarcane. The code created in scripts with .m format runs on Windows 10 Pro platform for 64 bits, installed on a Lenovo-ThinkPad laptop with an Intel® Core i5 @ 2.5 GHz and 8 GB of RAM. It should be noted that no pre-processing (smoothing, noise reduction, contrast enhancement, etc.) was performed on the images, which were downloaded from the Sentinel-2 database with the corrections made by the Copernicus program.

RESULTS

In Soca-Muñoz *et al.* (2020) it is concluded that in order to better recognize the spectral signature of brown rust (*Puccinia melanocephala*) in its different stages of the percentage of affected leaf area (ALA), spectral bands with wavelengths in the range between 700 nm and 1500 nm should be used. However, the small number of spectral bands in the Sentinel-2 images, as well as the limitation of the MicaSense camera to only five spectral bands, means that in neither case are the ideal bands available for estimating the severity of brown rust infection. Therefore, based on the results of the aforementioned work, the VI is determined using the images of the RE (735 nm) and NIR (790 nm) bands of the MicaSense camera attached to the UAV. Based on this, the best correspondence between the results obtained with the UAV and the satellite images was obtained using Sentinel-2 bands 4 (665 nm) and 8 (842 nm), both with 10 m spatial resolution.

Figure 2 a) and b) shows an example of the orthomosaics constructed with the images of the NIR and RE bands of the *MicaSense* camera respectively in the study area shown in Figure 1. Figure 2 c) shows the result of the processing using the images of both bands. The orange color (*pseudo color*) highlights the areas identified as having the highest infection, while the green color highlights the uninfected areas. The red color is related to other types of vegetation.

Figure 3 shows the images obtained by Sentinel-2 in the same study area flown by the UAV. Compared to the RGB image shown in Figure 1, these have been cropped in order to show, with the highest possible resolution, the analyzed area. Part a) corresponds to the true color image (RGB), while parts b) and c) correspond to bands 4 and 8 respectively as explained in section 2.2. Figure 3 d) shows in *pseudo color* the result obtained after processing using both spectral bands, to which a red box has been superimposed indicating the approximate area flown by the UAV that was shown in Figure 2. The yellow-orange color indicates the areas with the highest brown rust infection, while green and blue indicate the non-infected areas. The intense

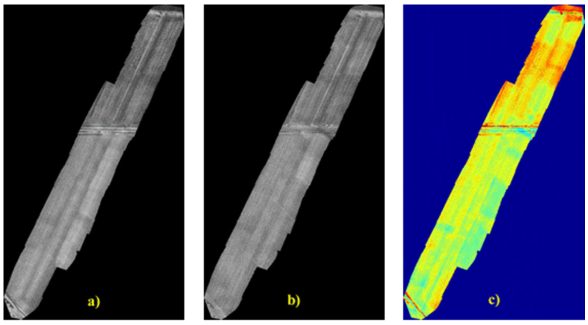

FIGURE 2. Orthomosaics constructed using the MSI of the a) NIR and b) RE bands of the *MicaSense* camera. c) Result of image processing, highlighting in orange the highest infection and in green the no brown rust infection.

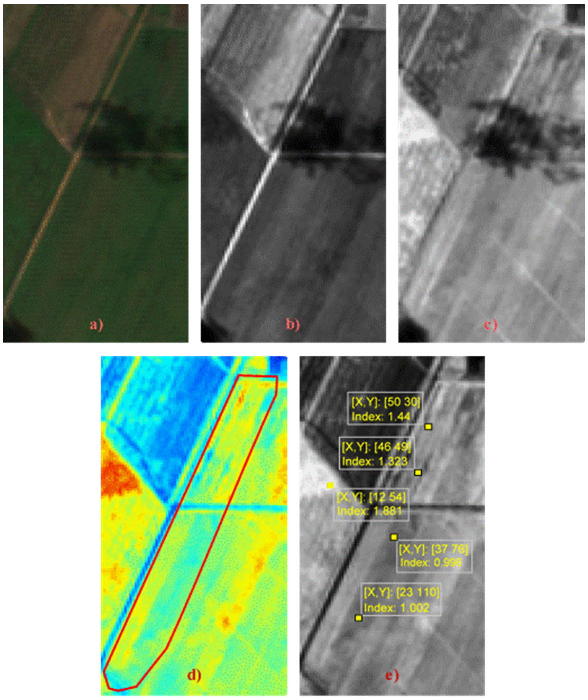

FIGURE 3. Images obtained by Sentinel-2. a) True color (RGB), b) and c) bands 4 and 8, d) calculated index in pseudo color and e) calculated index showing some values.

orange color is not associated with the presence of this infection.

Since Sentinel-2 MSIs are digitized with 4'096 levels of radiometric resolution (12 bits/pixel) between zero and one, the calculated index can take the same amount of values, but in the interval ±2.5, although for the area shown it does so between 0.271 and 1.898, which depends on the content of vegetation, soil and other elements within the image. However, the VI in the areas affected with brown rust takes values between 1.3 and 1.44, as can be seen in Figure 3 e), where the calculated VI is shown, but without using *pseudo color*.

From the calculated VI (Figure 3 e), the histogram of the values obtained for the region shown in this figure is plotted, which is shown in Figure 4. In part a) for the range of VI values between 0.27 and 1.898. Between red lines are the VI values corresponding to the pixels where brown rust is present. In part b) of Figure 4 the histogram area between 0.9 and 1.58 is enlarged. The multimodal character of the distribution of values shown by the calculated VI is due to the diversity of elements that make up the region shown, in which there is the presence of uninfected sugarcane with varying degrees of infestation, other vegetation, soils, etc. The histogram also shows a large dispersion of the distributions of each of the elements that compose the region shown. This is a consequence of the low spatial resolution of the Sentinel-2 images, in which each pixel covers an area of 10x10m.

The values of the index calculated within a region depend on the degree of leaf area affected, the susceptibility of the sugarcane variety to brown rust infection, the phenological stage of the crop, as well as other abiotic factors (humidity, temperature, etc.) Aday-Díaz *et al.* (2020); Soca-Muñoz *et al.* (2020), so the final decision on the presence of rust must take into account all these aspects.

It should be noted in Figures 3 d) and e) that the calculated VI is not affected by the presence of the cloud shadow, as observed in the original images of Figures 3 a), b) and c), corresponding to true color and bands 4 and 8 respectively.

The validation of the results obtained from remotely sensed images, such as UAV and satellite images, which are based on electromagnetic radiation, is a source of information about the effectiveness of the methods used to obtain and process such images. Several authors Gruber *et al.* (2020) recommend the need for locally measured reference data using traditional methods. The correlation between results from remote observations and reference data is an invaluable source of estimation errors. Obviously, the stochastic nature of all measurements, especially those obtained remotely, should not be ignored, with the consequent uncertainty in the results. To this end, coinciding with the date of the UAV flights, an INICA specialist sampled the fields overflown, which made it possible to estimate the severity of the brown rust infection in each of them. As a result, by comparing the images obtained after digital processing, both from the UAV and Sentinel-2, it was possible to verify that in both cases there is coincidence between the estimated areas and what was observed on the field. For this purpose, it is not possible to determine a numerical correlation value between the areas with and without the presence of brown rust due to the difference in resolution between the images obtained by the UAV and the satellite, as well as between these and the field observation, for which only the infested region of each field and the severity of the infection were determined. The coincidence between the observation and the infested areas of each type of image was determined from the georeferenced coordinates.

The processing time using the scripts created, either from the orthomosaics built from the images acquired by the UAV or from the images acquired by the Sentienel-2, was less than one minute on the platform mentioned above. Obviously, when processing large extensions of sugarcane crops, the analysis should concentrate only on those plantations with sugarcane varieties susceptible to brown rust, thus reducing the computational load.

The result of this work is already part of the Spatial Data Infrastructure (SDI) in the sugarcane growing areas of northern Villa Clara, Cuba, which can be accessed at https://azcuba.geocuba.cu/visor. An example can be seen in Figure 5.

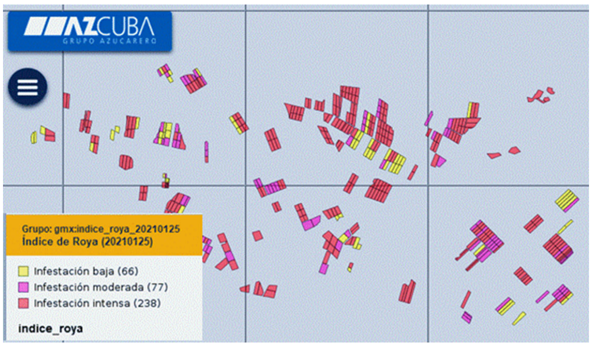

FIGURE 5. Example of the Spatial Data Infrastructure (SDI) of the AZCUBA sugar group showing the severity of brown rust infection in various sugarcane plantations.

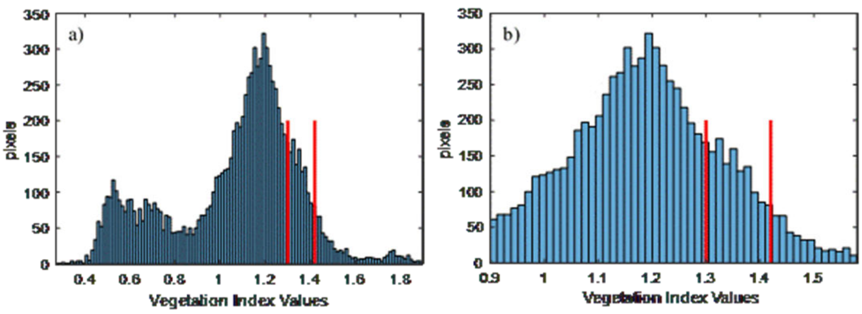

FIGURE 4. Histogram with VI values shown in Figure 3 e). In a) for VI values between 0.27 and 1.898, in b) for VI values between 0.9 and 1.58. Between red lines the values associated with the presence of brown rust.

CONCLUSIONS

- Since the traditional method of estimating brown rust infection, consisting of human observation, requires qualified personnel, great human effort and time, and is not free of subjectivities, this task can be carried out using spectral analysis.
- The use of UAVs with multispectral cameras reduces background time and subjectivity, however, their use is limited to relatively small areas per flight, which leads to multiple flights to cover large areas of sugarcane plantations, with the consequent expense in transportation. In addition, there is a need for specialized personnel to operate the UAVs and process the images locally.
- With the use of Sentinel-2 constellation images, which are freely available for download, large areas of crops can be analyzed in a few minutes, periodically and without the need to travel to the sugarcane fields. Moreover, taking advantage of the temporal stability of Sentinel-2 periodicity, it is possible to easily obtain time series showing the evolution of disease infection in crops, the direction of its spread, as well as its dependence on biotic and abiotic factors.
- The results achieved in the estimation of brown rust infection using MSIs acquired by Sentinel-2 correspond with those obtained by the UAV flying at low altitude, as well as with the field observations made by a specialist. This shows that the MSIs acquired by Sentinel-2 have the potential to detect the severity of brown rust infection in sugarcane plantations.

GRATEFULNESS

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REFERENCES

ADAY-DÍAZ, O. de la C.; MONTALVÁN DELGADO, J.; DELGADO PADRÓN, J.; PUCHADES IZAGUIRRE, Y.; RODRÍGUEZ LEMA, E.L.; ALFONSO-TERRY, I.: "Orange rust disease progress in different plantation cycles of sugarcane in Cuba", *Sugar Tech*, 22(6): 1057-1062, 2020, ISSN: 0972-1525, DOI: 10.1007/s12355-020-00843-w.

AMARASINGAM, N.; SALGADOE, A.A.; POWELL, K.; GONZALEZ, L.F.; NATARAJAN, S.: "A review of UAV platforms, sensors, and applications for monitoring of sugarcane crops", *Remote Sensing Applications: Society and Environment*, 26: 100712, 2022, ISSN: 2352-9385, DOI: 10.1016/j.rsase.2022.100712.

CAASI, O.; HONGO, C.; WIYONO, S.; GIAMERTI, Y.; SAITO, D.; HOMMA, K.; SHISHIDO, M.: "The potential of using Sentinel-2 satellite imagery in assessing bacterial leaf blight on rice in West Java, Indonesia", *Journal of International Society for Southeast Asian Agricultural Sciences*, 26(1): 1-16, 2020.

ESA: *Sentinel-2 user handbook*, Ed. European Space Agency, 64 p., 2015.

GRISHAM, M.P.; WARNKE, K.Z.; MAGGIO, J.R.; TODD, J.R.; DAVIDSON, W.; HAUDENSHIELD, J.S.; HARTMAN, G.L.; HERNANDEZ, E.; SCOTT, A.; COMSTOCK, J.K.: "First Report of Puccinia kuehnii Causing Orange Rust of Sugarcane in Texas, USA", *Plant disease*, 104(10): 2731, 2020, ISSN: 0191-2917, DOI: 10.1094/pdis-10-19-2117-pdn.

GRUBER, A.; DE LANNOY, G.; ALBERGEL, C.; AL-YAARI, A.; BROCCA, L.; CALVET, J.-C.; COLLIANDER, A.; COSH, M.; DAVIDSON, W.; DORIGO, W.: "Validation practices for satellite soil moisture retrievals: What are (the) errors?", *Remote sensing of environment*, 244: 111806, 2020, ISSN: 0034-4257, DOI: 10.1016/j.rse.2020.111806.

KHARUF-GUTIERREZ, S.; HERNÁNDEZ-SANTANA, L.; OROZCO-MORALES, R.; ADAY-DÍAZ, O. de la C.; DELGADO MORA, I.: "Análisis de imágenes multiespectrales adquiridas con vehículos aéreos no tripulados", *Ingeniería electrónica, automática y comunicaciones*, 39(2): 79-91, 2018a, ISSN: 1815-5928, DOI: 10.18046/syt.v16i47.3221.

KHARUF-GUTIERREZ, S.; OROZCO-MORALES, R.; ADAY-DÍAZ, O. de la C.; PINEDA-RUIZ, E.: "Multispectral aerial image processing system for precision agriculture", *Sistemas y Telemática*, 16(47), 2018b, ISSN: 1692-5238.

LASTOVICKA, J.; SVEC, P.; PALUBA, D.; KOBLIUK, N.; SVOBODA, J.; HLADKY, R.; STYCH, P.: "Sentinel-2 data in an evaluation of the impact of the disturbances on forest vegetation", *Remote Sensing*, 12(12): 1914, 2020, ISSN: 2072-4292, DOI: 10.3390/rs12121914.

LÓPEZ-BRAVO, E.; PLACERES-REMIOR, A.; GONZÁLEZ-CUETO, O.; HERRERA-SUÁREZ, M.: "Monitoring of Sugarcane Cultivation Using Satellite Images", *Revista Ciencias Técnicas Agropecuarias*, 31(3), 2022, ISSN: 2071-0054.

LU, B.; DAO, P.D.; LIU, J.; HE, Y.; SHANG, J.: "Recent advances of hyperspectral imaging technology and applications in agriculture", *Remote Sensing*, 12(16): 2659, 2020, ISSN: 2072-4292, DOI: 10.3390/rs12162659.

MÜLLEROVÁ, J.; BRŮNA, J.; BARTALOŠ, T.; DVOŘÁK, P.; VÍTKOVÁ, M.; PYŠEK, P.: "Timing is important: Unmanned aircraft vs. satellite imagery in plant invasion monitoring", *Frontiers in Plant Science*, 8: 887, 2017, ISSN: 1664-462X, DOI: 10.3389/fpls.2017.00887.

RUAN, C.; DONG, Y.; HUANG, W.; HUANG, L.; YE, H.; MA, H.; GUO, A.; REN, Y.: "Prediction of wheat stripe rust occurrence with time series sentinel-2 images", *Agriculture*, 11(11): 1079, 2021, ISSN: 2077-0472, DOI: 10.3390/agriculture11111079.

SEGARRA, J.; BUCHAILLOT, M.L.; ARAUS, J.L.; KEFAUVER, S.C.: "Remote sensing for precision agriculture: Sentinel-2 improved features and applications", *Agronomy*, 10(5): 641, 2020, ISSN: 2073-4395, DOI: 10.3390/agronomy10050641.

SOCA-MUÑOZ, J.L.; RODRÍGUEZ-MACHADO, E.; ADAY-DÍAZ, O. de la C.; HERNÁNDEZ-SANTANA, L.; OROZCO-MORALES, R.: "Spectral signature of brown rust and orange rust in sugarcane", *Revista Facultad de Ingeniería Universidad de Antioquia*, (96): 9-20, 2020, ISSN: 0120-6230, DOI: 10.17533/udea.redin.20191042.

SOM-ARD, J.; ATZBERGER, C.; IZQUIERDO-VERDIGUIER, E.; VUOLO, F.; AL-ZAHRANI, M.: "Remote sensing applications in sugarcane cultivation: A review", *Remote sensing*, 13(20): 4040, 2021, ISSN: 2072-4292, DOI: 10.3390/rs13204040.

SWAMI, M.: "A new toolbox for mapping regulatory sites", *Nature Reviews Genetics*, 10(5): 282-283, 2009, ISSN: 1471-0056. DOI: 10.1038/nrg2584.

THE MATH WORKS: *Mapping Toolbox™ User's Guide*, Mapping Toolbox™, 2009.

VAUDOUR, E.; GOMEZ, C.; LAGACHERIE, P.; LOISEAU, T.; BAGHDADI, N.; URBINA-SALAZAR, D.; LOUBET, B.; ARROUAYS, D.: "Temporal mosaicking approaches of Sentinel-2 images for extending topsoil organic carbon content mapping in croplands", *International Journal of Applied Earth Observation and Geoinformation*, 96: 102277, 2021, ISSN: 1569-8432, DOI: 10.1016/j.jag.2020.102277.

WANG, J.; XIAO, X.; LIU, L.; WU, X.; QIN, Y.; STEINER, J.L.; DONG, J.: "Mapping sugarcane plantation dynamics in Guangxi, China, by time series Sentinel-1, Sentinel-2 and Landsat images", *Remote sensing of environment*, 247: 111951, 2020, ISSN: 0034-4257, DOI: 10.1016/j.rse.2020.111951.

WANG, M.; LIU, Z.; BAIG, M.H.; WANG, Y.; LI, Y.; CHEN, Y.: "Mapping sugarcane in complex landscapes by integrating multi-temporal Sentinel-2 images and machine learning algorithms", *Land use policy*, 88: 104190, 2019, ISSN: 0264-8377, DOI: 10.1016/j.landusepol.2019.104.

XU, Z.; CAO, L.; ZHONG, S.; LIU, G.; YANG, Y.; ZHU, S.; LUO, X.; DI, L.: "Trends in global vegetative drought from long-term satellite remote sensing data", *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 13: 815-826, 2020, ISSN: 1939-1404. DOI: 10.1109/JSTARS.2020.2972574.

ZHENG, Q.; HUANG, W.; CUI, X.; SHI, Y.; LIU, L.: "New spectral index for detecting wheat yellow rust using Sentinel-2 multispectral imagery", *Sensors*, 18(3): 868, 2018, ISSN: 1424-8220, DOI: 10.3390/s18030868.

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