ORIGINAL ARTICLE

Monitoring of Sugarcane Cultivation Using Satellite Images

Monitoreo del cultivo de la caña de azúcar mediante imágenes satelitales

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ABSTRACT: In the present work, the vegetation indices obtained from satellite images are used to monitoring sugarcane crop. The study was carried out in 5,5 ha of sugarcane field, planted with CP 52-43 variety located in Camajuaní Municipality, Cuba. Vegetative evolution of the plantation was monitored by field measurements of leaf width, stem diameter, stem height, soil moisture and vegetal cover, using the diagonal distribution method for samples collection. The services available in Earth Observed System (EOS) were used to obtain images of vegetative index of: NDVI, SAVI, EVI and NDWI. The initial stage of crop was characterized by low values of soil moisture and foliar development of sugarcane plants, EVI and NDVI indices showed results according to the low vegetative development with values between 0,2 and 0,4, while NDWI agreed with dry soil. In the rainy season, after the fourth month of the plantation, an increase in soil moisture to 42,9% took place, the plants´ biophysics parameters: stem height, stem diameter and leaf width also increased, EVI index reached between 0,6 and 0,8 in 74,4% crop area and in the same way NDVI index showed values between 0,7 to 0,8. However, NDWI index showed values between -1 and -0.6 belonging to dry soil, no matching with the actual moisture conditions. Through monitoring with Sentinel-2 satellite, a more stable representation of the increase in vegetation was achieved, as well as more adequate values of the initial and final state of the crop were obtained.

Keywords: Vegetative Index, Harvest, Spectral, Agriculture.

RESUMEN: En el presente trabajo se utilizan los índices de vegetación, obtenidos a partir de imágenes satelitales, en el seguimiento del cultivo de la caña de azúcar. El estudio se realizó en una plantación cañera del municipio de Camajuaní, Cuba, en un área de 5,5 ha plantada de la variedad CP 52-43. Durante el período vegetativo del cultivo, se realizó el seguimiento del crecimiento mediante mediciones en el campo del ancho de la hoja, el diámetro y la altura del tallo, la humedad del suelo y el espesor de la cobertura vegetal, empleando el método de distribución diagonal doble. Para el monitoreo con imágenes satelitales, se emplearon los servicios disponibles en el sistema *Eart Observed System* (EOS). Los índices evaluados fueron: NDVI, SAVI, EVI y NDWI. La etapa inicial del cultivo se caracterizó por bajos valores de humedad del suelo y desarrollo foliar de las plantas, los índices EVI y NDVI mostraron resultados acordes al bajo desarrollo vegetativo del área, con valores entre 0,2 y 0,4, en tanto el NDWI se identificó con un suelo seco. En la etapa lluviosa, después del cuarto mes del cultivo, la humedad alcanzó valores de 42,9% y tuvo lugar un incremento de la altura, el diámetro del tallo y el ancho de las hojas, el índice EVI alcanza valores de 0,6 a 0,8 en el 74,4% del cultivo, de igual modo el índice NDVI mostró valores de 0,7 a 0,8. Por su parte el índice NDWI mostró valores entre -1 y -0,6 lo que no se ajusta a las condiciones de humedad imperantes. Mediante el monitoreo con el satélite Sentinel-*2,* se logró una representación más estable del aumento de la vegetación, así como valores más adecuados del estado inicial y final del mismo.

Palabras clave: índice vegetativo, cosecha, espectral, agricultura.

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INTRODUCTION

The use of remote sensing is increasingly widespread in the analysis and management of natural resources. Its use is related to the availability of time series satellites images in visible, infrared and ultraviolet spectra. In the same way, the number of satellites placed in orbit with thermal imaging, multispectral and hyperspectral sensors have contributed in the uses of spectral images (Triantafyllou *et al.*, 2019; Segarra *et al.*, 2020). Through monitoring with remote sensors, it has been possible to carry out biophysical a characterization of the surface vegetation, the state of the soil and humidity. Due to the optical properties of leaves, their absorption in the red spectral band of the electromagnetic spectrum is very high, while they reflect in the near infrared band. (Xie *et al.*, 2019).

Numerous investigations in this field have shown the existence of empirical relationships between sensor information and biophysical properties such as biomass, leaf cover and surface moisture content. (Gutierrez *et al.*, 2018; Hatfield *et al.*, 2019; De Grave *et al.*, 2020; Sishodia *et al.*, 2020).

The vegetation indices (VI) are calculated through the combination of the red and near infrared bands of the electromagnetic spectrum. Thus, the empirical relationships calculated between biophysical variables of crops and VI, reflect general patterns or trends between crops optical properties and their architecture with respect to the spatial and angular distribution of the foliage phytoelements for a given sensor-illumination geometry. (Kharuf-Gutierrez *et al.*, 2018).

In Cuba, the cultivation of sugarcane is carried out extensively and it has a high economical value with the production of raw and refined sugar. The by-products of the industrial process are used as raw material in food, chemical, and energy industries, among others. As part of the modernization of sugarcane cultivation, improvements have been made in varieties, irrigation technologies and harvesting and transportation. (Alvarez, 2014). Precision agriculture techniques have also been applied in fertilization, irrigation and sanitary control systems. (Hernández *et al.*, 2003; Quevedo *et al.*, 2006; Gutierrez *et al.*, 2018).

In this framework, the present work aims to evaluate the effectiveness of monitoring sugarcane cultivation through spectral indices, obtained from satellite images and based on the correlation with the crop development in the field.

MATERIALS AND METHODS

Location of Area of Study

The study was carried out in the Basic Unit of Cooperative Production (UBPC) ¨Juan Verdecia¨, Camajuaní Municipality, Cuba. For crop monitoring, field number 3 was selected, located at 22°26'55" North and 79°41'48" West coordinates, with an area of 5,5 ha planted with sugarcane variety of CP 52-43 (Figure 1) and average yield of 35 t/ha. The previous harvest took place on 09-01-2021 and a combined KTP-2M and the ZIL-130 truck were used for it.

Methodology for Field Measurements

Crop growth control was performed to determine the effectiveness of satellite measurements. For this, the double diagonal or X distribution method was used (Flores, 2006), nine experimental points were taken, which GPS georeferenced for precision of 0,2 m. The controlled variables in the plants were leaf width, stem diameter and stem height. In addition, the measurement of soil moisture and thickness of the vegetation cover was carried out. For plants dimensions and ground cover, eight samples were taken at each experimental point and four repetitions were carried out. Tape measure, graduated rule and Vernier caliper with an appreciation of 1 mm and 0,05 mm, respectively, were used in measuring (Figures 2a and 2b).

Moisture based on dry soil (hbss)%, was determined by gravimetric method. Measurements were made in the ridge next to the cane stump (Figure 2c). Four measurements were made at each experimental point at 0 to 10 cm depth. The humidity of the samples was determined in the laboratory according to NC 3437:2003 standard.

FIGURE 1. Field selected for monitoring.

Methodology for Satellite Monitoring

For satellite image monitoring of the area, a georeferenced study plot was configured using the services available in the Earth Observed System (EOS) on the site https://eos.com. The indices monitored during the vegetative period of the sugarcane plantation were: Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Enhanced Vegetation Index (EVI) and the Normalized Differential Water Index (NDWI). The spatial distribution images for indices were obtained from LandViewer Repository, calculated from spectral images taken by terrestrial reconnaissance satellites LandSat and Sentinel-2. With data of field measurements and the spectral indices of crop, the descripted statistics of variables were determined, multiple correlation and regression analyses were carried out for a confidence interval of 95% using Centurions Plus software.

RESULTS AND DISCUSSION

Result of Measurements in the Field

When monitoring the evolution of the crop physiological indicators through the field measurements, reduced increases were seen until April, as shown in Figure 3. In this sense, a gradual increase in the width of the leaf, diameter and height of the stem took place. This increase become more evident in measurements made to the stem height. The three indicators showed a similar pattern for the nine months of cultivation, after which a gradual decrease happens.

The soil cover has a maximum value after the harvesting the field, as a result of the cleaning process by the harvester during the cutting (Aguilar-Pardo *et al.*, 2016). The leaf fragments and shoot reach an average height of 5,6 cm, forming a regular residues layer distributed on the ground. In the second month, a reduction in coverage happens, as a result of the first mechanized cultivation, later a gradual reduction of it takes place gradually as part of the decomposition process, with increase in soil moisture. A further decrease in soil cover takes place in the month seven of cultivation, caused by the second mechanized cultivation operation which reduces the superficial layer of the soil to 0,2 cm.

The measurements made in soil moisture throughout the crop growth (Figure 4), show the transition from dry to rainy period, imposing two fundamental moisture conditions. As a result, the average value of humidity in the first four months was 18,9%, because the absence of rainfall, which reduced

FIGURE 2. Measurements of crop parameters and humidity.

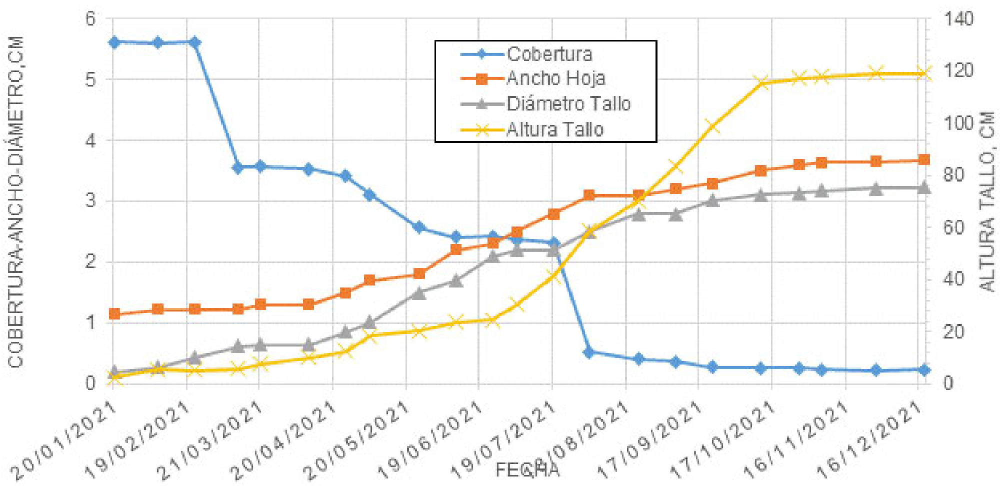

FIGURE 3. Evolution of crop growth indicators and cover.

the availability of micronutrients and minerals for new shoots (Taiz y Zeiger, 2006). In the fifth month of the crop, the first rainfall in the area took place, soil moisture increases an average of 42.9% for the rest of the season and remained stable due to new rains contribution and water retention by plantation foliage.

Result of the Spectral Indices

Figure 5 shows the spectral images of the indices evaluated at the beginning of the study. The EVI index reaches values between 0,3 and 0,6, located fundamentally in the central zone of the field and values between 0,2 and 0,3 in periphery. In both cases, these values are related to the presence of low density vegetation, without damage from pests or other cause (Wang *et al.*, 2010). With a similar distribution pattern to the EVI, the NDVI index shows values between 0,4 and 0,5 in the central area of the crop and values between 0,3 and 0,4 in the periphery, which characterizes a vegetation of limited development for both cases (Gilabert *et al.*, 2002). The SAVI vegetation index shows a regular distribution in the range of 0,2 to 0,3 over the entire surface of the field. The NDWI index shows values in the range of -0,6 and 0,3, which corresponds to dry soil and a low moisture content in the biomass (Senay *et al.*, 2014).

The spectral images of the crop final stage (Figure 6), show EVI index reaches values between 0,6 and 0,8 up to 74,4% of the crop, in the same way, NDVI index shows values between 0,7 and 0,8 which represents abundant vegetation, corresponding with the foliar development of plantation according to the field. SAVI index shows values between 0,3 and 0,6 which underestimates the real density of the existing biomass over surface. Regarding the water content of biomass and soil, NDWI index shows values between -1 and -0.6. Although the soil at this stage has moisture content greater than 40%, and the water content in the grass during the maturation stage is greater than 70% (Rosell Pardo y Ramírez Rubio, 2021).

Analysis of Spectral Indices Variability

As shown in NDVI index from LanSat and Sentinel satellites (Figure 7), between the frames under study, the values obtained in both cases represent an increases in vegetation with respect to initial values. Two stages are identified, divided by the fifth month of the crop, where NDVI goes from 0,33 to 0,65. This increase coincides with the beginning of the rainfall, where biomass increase is reflected by plants biophysical variables in according to data from field.

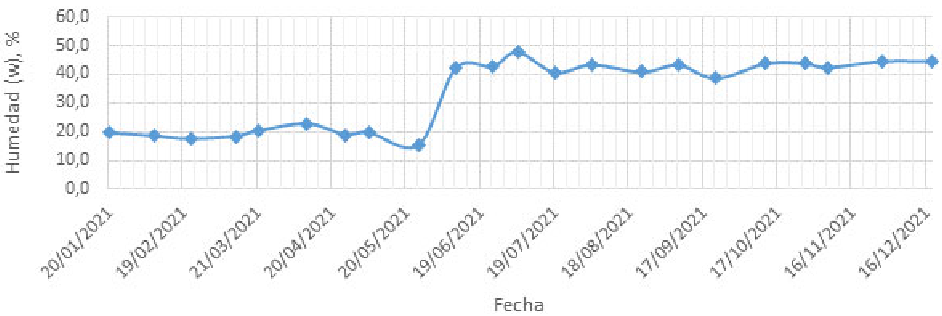

FIGURE 4. Soil moisture behavior.

FIGURE 5. Initial stage of spectral indices in sugarcane crop.

However, by Sentinel monitoring, a more stable representation of the increases in vegetation is achieved, as well as more adequate values of initial and final states of the crop. The fluctuation of LandSat data in the fifth and tenth month does not correspond to changes in vegetation, being attributable to the dispersion of electromagnetic waves due to the effect of radiation from the atmosphere (Wang *et al.*, 2010).

In moisture monitoring by NDWI index (Figure 8), in both satellites, initial values between -0,35 and -0,4, are obtained identifying a dry soil which coincide with values from field soil moisture. From the fifth month, NDWI decreases to -0.5 in both cases, and remains so until the tenth month where it shows a brief increase, to end again at low values of -0,47. With the foliar growth, the acquisition of soil reflectance is difficult, until the fifth month NDWI represent a dry soil due to the little foliar cover of soil. With the beginning of spring season, the increase in biomass happens and NDWI begins to reflect the moisture contained on it, which interferes with soil moisture readings. Despite the impossibility of monitoring soil moisture directly,

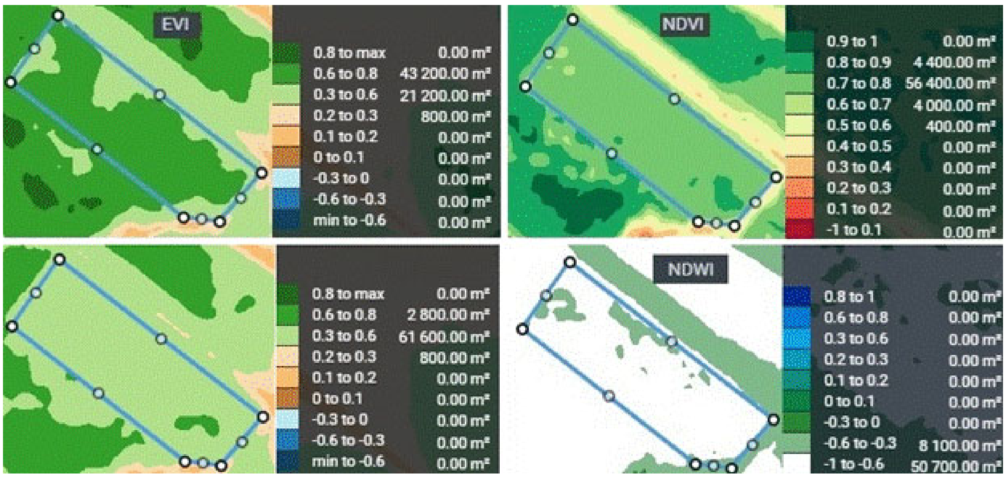

FIGURE 6. Final stage spectral indices in sugarcane crop.

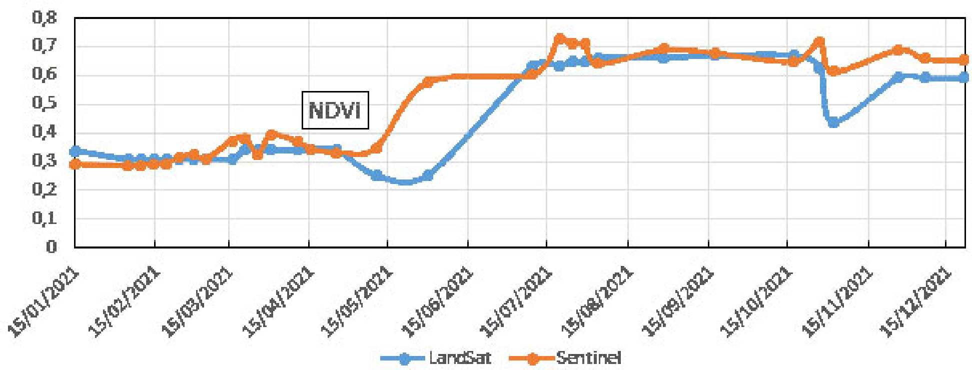

FIGURE 7. NDVI index obtained from LanSat and Sentinel sensors.

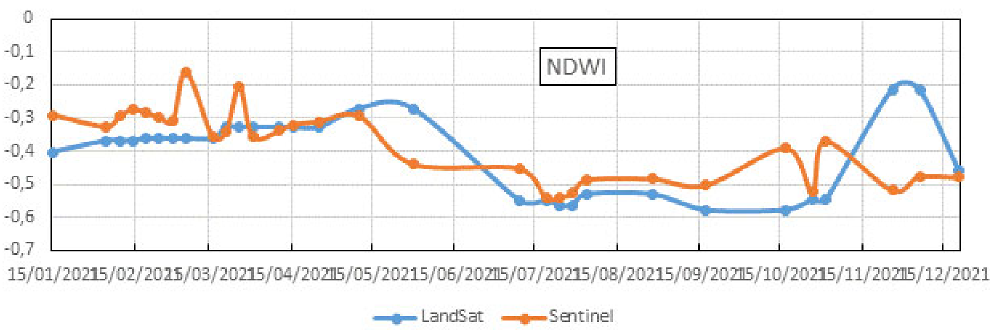

FIGURE 8. NDWI index obtained from LanSat and Sentinel sensors.

through the NDWI is possible to identify the moisture values for uncovered soil as well as the stage where changes take place.

Correlation between Indices and Field Measurements

Table 1 shows the correlation between the spectral indices and growth variables through the Pearson correlation coefficient. In this sense, the strongest correlation with NDVI is obtained with respect to the stem diameter, reaching a value of 0,93 followed by leaf width, soil moisture and stem height, all the coefficient have positive values except coverage. Soil moisture and soil cover do not have a direct link with the spectral response of plants vegetative state and correlation with NDVI is established more clearly than the other variables. Similarly, in the correlation between NDVI and NDWI, a value close to -1 is obtained, which shows the low interdependence between indices. NDWI, only has a positive correlation with land cover of 0,67; negative values are obtained for the other parameters. Although soil moisture is the parameter most closely related to NDWI, the correlation obtained is -0,817, the development of plant foliage is one of the factors that prevent establishing the adequate prediction of moisture.

The linear regression adjusted model between stem diameter and NDVI index is shown in Figure 9. There, it is possible to make an adequate forecast of the stage of development of the crop from NDVI with a determination coefficient R^2 of 87,6%. Likewise, Table 1 shows a high correlation of stem diameter with height and width of the leaf, whichmakes possible to predict the general state of development of the crop at different times.

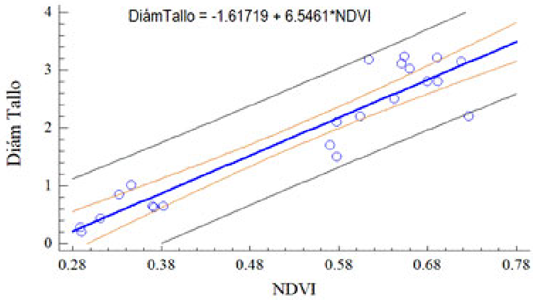

FIGURE 9. Plant stem diameter prediction model with respect to NDVI.

CONCLUSIONS

- In the evolution of the physiological indicators of the crop, a first stage of four months is distinguished, characterized by a limited development, and soil moisture average of 18,9 %.
- The EVI, NDVI and NDWI indices shows results according to the prevailing conditions in the first four months of the crop.
- After starting the rainfall, an increase in biophysical variables in sugarcane plants takes place, high values of EVI and NDVI indices are obtained by mean of satellite image monitoring, while NDWI index does not agree with the field moisture conditions.
- A high correlation is obtained between the stem diameter and NDVI index described by a linear regression model at 97% adjustment.
- Through monitoring with Sentinel-2 satellite, a more stable representation of the increase in vegetation is achieved, as well as more adequate values of its initial and final state are obtained.

REFERENCES

AGUILAR, P. A.; PÉREZ, J. A.; AGUILAR, D.: "Nuevos paradigmas en la cosecha de la caña para el uso sustentable de toda la biomasa en las bioeléctricas. Parte I", *ICIDCA. Sobre los Derivados de la Caña de Azúcar*, vol. 50 (3): 3-8, 2016. ISSN:0138-6204.

ALVAREZ, A.: Consideraciones económicas sobre algunas de las principales prácticas agronomicas en caña de azúcar. En: 50 aniversario del INICA, pp. 148, La Habana, Cuba. 2014.

DE GRAVE, C.; VERRELST, J.; MORCILLO, P.; PIPIA, L.; RIVERA, J. P.; AMIN, E.; MORENO, J.: "Quantifying vegetation biophysical variables from the Sentinel-3/FLEX tandem mission: Evaluation of the synergy of OLCI and FLORIS

TABLE 1. Correlation between variables

Index		Stem height	Cover	Stem diameter	Leaf width	Soil moisture	NDVI	NDWI
NDVI	Coef.Pearson	0.782	-0.896	0.936	0.911	0.873		-0.873
	P-Value	0.000	0.000	0.000	0.000	0.000		0.000
NDWI	Coef.Pearson	-0.491	0.675	-0.734	-0.686	-0.817	-0.873	
	P-Value	0.020	0.001	0.000	0.000	0.000	0.000	
Stem diameter	Coef.Pearson	0.9273	-0.9585		0.9900	0.8883	0.9363	-0.733
	P-Value	0.0000	0.0000		0.0000	0.0000	0.0000	0.0001

data sources", *Remote Sensing of Environment*, vol. 25 (1): 112-101, 2020. ISSN:1879-0704.

FLORES, J. R. N.: *Diseño experimental: Aplicaciones en agricultura,* 316pp., Costa Rica, Editorial UCR, 2006, ISBN: 9789-9776-78900.

GILABERT, M. A.; GONZÁLEZ, J.; GARCIA, F. J.; MELIÁ, J: "A generalized soil-adjusted vegetation index.", *Remote Sensing of Environment*, vol. 82 (1): 303-310, 2002. ISSN:1879-0704.

GUTIERREZ, S. K.; SANTANA, L. H.;. MORALES, R. O; O. DÍAZ, A. MORA, I. D.: "Análisis de imágenes multiespectrales adquiridas con vehículos aéreos no tripulados en agricultura de precisión", *Revista Ingeniería Electrónica, Automática y Comunicaciones*, vol. 39 (2): 2018. ISSN:1815-5928.

HATFIELD, J. L. PRUEGER, ; J. H.; SAUER, T. J.; DOLD, C.; O'BRIEN, P; WACHA, K.: "Applications of Vegetative Indices from Remote Sensing to Agriculture: Past and Future", *Inventions*, vol. 4 (4): 71, 2019. ISSN:2411-5134.

KHARUF, G. S.; HERNÁNDEZ, L.; OROZCO, R.; ADAY, O. D. L. C.; DELGADO, M. I.: "Análisis de imágenes multiespectrales adquiridas con vehículos aéreos no tripulados", *Ingeniería Electrónica, Automática y Comunicaciones*, vol. 39 (1): 79-91, 2018. ISSN:1815-5928.

NC 3437:2003: *Máquinas Agrícolas y Forestales. Metodología para la determinación de las condiciones de ensayo.,* Vig. Septiembre 2003.

ROSELL, P. R.; RAMÍREZ, A: "Evaluación de la frescura de la caña de azúcar para minimizar pérdidas industriales (Original)", *Redel. Revista Granmense de Desarrollo Local*, vol. 5 (2): 107-119, 2021. ISSN:2664-3065.

SEGARRA, J.; BUCHAILLOT, M. L.; JARAUS, . L. KEFAUVER, S. C.: "Remote Sensing for Precision Agriculture: Sentinel-2 Improved Features and Applications", *Agronomy*, vol. 10 (5): 641, 2020. ISSN:2073-4395.

SENAY, G.; WARD, A.; LYON, J.; FAUSEY, N. NOKES, S.: "Manipulation of high spatial resolution aicraft remote sensing data for use in site-specific farming", *Transation of ASAE*, vol. 41 (1): 489-495, 2014. ISSN:0001-2351., S. K.

SISHODIA, R. P.; RAY, R. L. SINGH: "Applications of Remote Sensing in Precision Agriculture: A Review", *Remote Sensing*, vol. 12 (19): 31-36, 2020. ISSN:1879-0704.

TAIZ, L.; ZEIGER, E.: *Fisiología vegetal,* Universitat Jaume I, 2006, ISBN: 9788480216012.

TRIANTAFYLLOU, A.; SARIGIANNIDIS, P.; BIBI, S.: "Precision Agriculture: A Remote Sensing Monitoring System Architecture", *Information*, vol. 10 (11): 348-354, 2019. ISSN:2078-2489.

WANG, F.; HUANG, J.; CHEN, L.: "Development of a vegetation index for estimation of leaf area index based on simulation modeling", *Journal of Plant Nutrition*, vol. 33(3):328-338 2010. ISSN:0190-4167.

XIE, Q.; DASH, J.; HUETE, A.; JIANG, A.; YIN, G.; DING, Y., HUANG, W.: "Retrieval of crop biophysical parameters from Sentinel-2 remote sensing imagery", *International Journal of Applied Earth Observation and Geoinformation*, vol. 80 (1): 187-195, 2019. ISSN:0303-2434.

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