ORIGINAL ARTICLE

Relationship between Biophysical Variables and Spectral Vegetative Indices in Cultivation of Potato (*Solanum tuberosum*)

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Relación entre variables biofísicas e índices vegetativos espectrales en el cultivo de la papa (*Solanum tuberosum*)

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ABSTRACT: The objective of the present work is to identify the relationship between the spectral vegetative indices (VI) and biophysical variables in potato crop. The study was carried out in Valle del Yabú Agricultural Enterprise in Villa Clara Province, located at coordinates 22. 54491º North Latitude and 79. 99791º West Longitude, in an area of 10 ha irrigated by central pivot system. The monitoring of the morphological indicators of growth was carried out through field measurements, for which 15 experimental points georeferenced with GPS were taken. To monitor the VIs, the land cover images and spatial distribution maps available in the Earth Observed System were used. The study showed that indexes as NDVI, EVI and SAVI vary in correspondence with the development of the biophysical properties, showing correlations greater than 0,9. The strong correlation of 0,98 was obtained between NDVI index and leaf area (AF). On the other hand, by monitoring NDVI it was possible to identify the changes that occurred in AF and soil moisture during vegetative period. The spatial distribution of NDVI values also made it possible to identify the variability in the plant cover of the crop.

Keywords: Coverage, Satellite, Agriculture, Maps, Yield.

RESUMEN: El presente trabajo tiene como objetivo identificar la relación entre los índices vegetativos espectrales (IV) y las variables biofísicas en el cultivo de la papa. El mismo se realizó en la empresa agropecuaria Valle del Yabú de la provincia Villa Clara, ubicada en las coordenadas 22,54491º Latitud Norte y 79,99791º Longitud Oeste, en un área de 10 ha con riego por pivote central. El seguimiento a los indicadores morfológicos de crecimiento se realizó a través de mediciones de campo para lo cual se tomaron 15 puntos experimentales georreferenciados con GPS. Para el monitoreo de los IV se emplearon las imágenes de cobertura terrestre y mapas de distribución espacial disponibles en el sistema *Earth Observed System*. El estudio mostró que los IV: NDVI, EVI y SAVI varían en correspondencia con el desarrollo de las variables biofísicas, mostrando correlaciones mayores a 0,9. La mayor correlación se obtuvo entre el índice NDVI y el área foliar (AF) y fue de 0,98. Por su parte, mediante el monitoreo del NDVI se logró identificar los cambios ocurridos en el AF y la humedad del suelo durante el período vegetativo. La distribución espacial de los valores NDVI posibilitaron identificar la variabilidad en la cobertura vegetal del cultivo.

Palabras clave: cobertura, satelital, agricultura, mapas, rendimiento, índice de vegetación, variables biofísicas.

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INTRODUCTION

The use of remote sensing technology has shown substantial advances in the biophysical characterization of vegetation. Research shows a correct correlation between data from satellite sensors and biophysical variables such as the leaf area index, plant cover and the presence of pests (Lago *et al.*, 2011; Sishodia *et al.*, 2020; Safi *et al.*, 2022; Wagner *et al.*, 2022; Lizarazo *et al.*, 2023). The vegetative indices (VI) are obtained from relating the red band of the electromagnetic spectrum and the near infrared, reflecting general patterns of the optical properties of the crops. The purpose is to extract the information related to the vegetation and minimize the influence of soil among other factors (Perry & Lautenschlager, 1984; Fang *et al.*, 2015; Zakeri y Mariethoz, 2021). The use of VIs to monitor the evolution of the crop according to its state of development and yield forecasts, has been extended to crops such as corn, soybeans, bananas, potatoes and sugarcane among others (Sinha *et al.*, 2020; Souza *et al.*, 2020; Shao *et al.*, 2021; Soltanikazemi *et al.*, 2022). In potato crop, studies have been carried out aimed at identifying the severity of late blight in the winter season *(Kundu et al., 2021)*. The leaf area in different seasons has been determined by using the VIs data (Wu *et al.*, 2007) and the use of interferometric coherence data from the Sentinel-1 satellite has been evaluated as a monitoring tool (Villarroya-Carpio *et al.*, 2022). Methods have also been introduced to improve the identification of wilt symptoms caused by verticillium wilt (Lizarazo *et al.*, 2023), as well as research on different indexes to determine water stress and irrigation management (Ekinzog *et al.*, 2022).

The use of remote sensing to monitor the development of potato crop in Cuba by monitoring the VIs can play an important role in identifying the presence of pests, water needs and yield forecasts. The objective of this work is to determine the evolution of biophysical indicators of potato crop through monitoring with spectral images.

MATERIALS AND METHODS

The research was carried out in Valle del Yabú Agricultural Enterprise, Villa Clara Province in a field of potato (*Solanum tuberosum*), Loane cultivar, located at coordinates 22.54491º North Latitude and 79.99791º West Longitude (Figure 1a). The sowing was carried out in the period from January 4th to 11th in an area of 10 ha with central pivot irrigation, at 0.90 x 0.30 m in a loose, moderately washed brown soil. The harvest was carried out from April 11th to 26th, 2022.

The follow-up to morphological indicators of growth was carried out through field measurements. For this, 15 experimental points georeferenced by GPS system were taken, with precision of 0.2 m. The area of the experimental points was taken as the square of the distance between ridges, resulting in 2.25 m^2. For each point, measurements of soil moisture (Figure 1b), number of leaves and diameter and height of the stems (Figure 1c) were made. The foliar area (AF) was determined by processing the RGB images of each experimental point in the ImajeJ v1.54 software to obtain the area of the crop (Figure 1d). Moisture based on dry soil (hbss) percentage, was determined by gravimetric method. The measurements were made in the area of the ridge near the plant, the samples were dried in the oven at a constant temperature of 105 °C, for 24 h, they were cooled for 20 min, after which they were weighed every two hours until reaching a constant mass. The samples were weighed before and after drying with a balance of ± 0.01 g precision.

For the monitoring of the VIs, land cover images were used and spatial distribution maps were obtained through the Earth Observed System, available on the website https://eos.com. The platform facilitates the calculation and interpolation Vis values from the spectral images, taken from the sensors of the LandSat and Sentinel surface reconnaissance satellites. The spectral indices used to monitoring were the following: normalized difference vegetation index (NDVI), improved vegetation index (EVI), soil-adjusted vegetation index (SAVI) and normalized differential water index (NDWI).

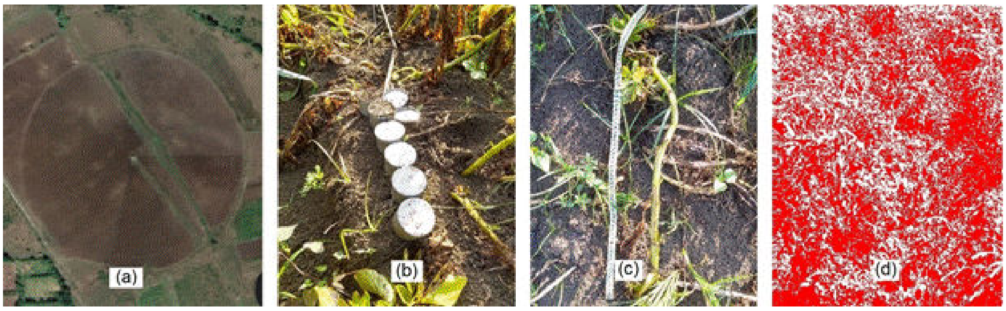

FIGURE 1. Field measurements, (a) circular cultivated area, (b) soil sampling, (c) plants measurement and (d) leaf area determination.

RESULTS AND DISCUSSION

The results of the measurement of the biophysical indicators and the spectral vegetative indices of the crop during the vegetative period are shown in Table 1. In all cases, soil moisture was above 30%, because of the periodic irrigation task. The values of leaf area increased until reaching maximum value close to the harvest stage. In the same way, the number of leaves and the diameter of the stem increase, until the maturation period when leaves fall and the stem caliber is reduced due to the low nutrient transfer activity and prior to the harvest stage. The length of the stem shows growth up to the tuber-formation stage and maintains a constant value. The results obtained are in correspondence with the observations made in different crops by Wu *et al.* (2007) and Villarroya-Carpio *et al.* (2022).

In general, the average of spectral vegetative show values that increase as the crop develops and do not exceed the value of 0,8 in any case, which indicates no saturation of the vegetation. The spatial distribution that takes place in vegetative indices is shown in Figure 2. It refers to sampling 4, where crop showed the maximum foliage state. In all indicators, the uncultivated area is identified, which is represented diagonally at the center of the field. The NDVI and EVI indices show values that correspond to the predominant vegetation, while SAVI index show values between 0,1 and 0,2, which underestimates the presence of vegetation. By EVI index is possible to identify areas of greater foliage. NDVI index shows a uniform humidity value that is closely related to the use of central pivot irrigation. The spatial distribution of the NDVI also allows visualizing the variability in crop yields and the preparation of fertilization maps already used by Lago *et al.* (2011).

The temporal analysis of the data series taken after sprouting, growth and maturation periods showed different levels of correlation with vegetative indices. Table 2 shows the result of multiple correlation analysis of variable combinations that showed at least one significant relationship with the other variables. Therefore, stem diameter and length, as well as the NDWI biomass moisture index, are excluded from the analysis because no linear relationship was found. The

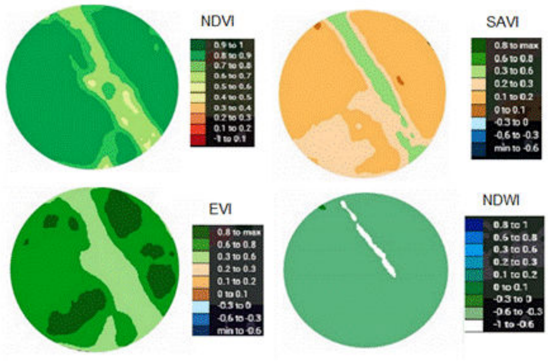

FIGURE 2. Spatial distribution of vegetative indices.

table shows the combinations that obtained high values of the correlation coefficient (r) with statistical significance at confidence levels of more than 95%, denoted by p-value less than 0,05, and the combinations that showed $r \geq 0{,}9$ are highlighted, which demonstrate a strong linear relationship between the variables.

Regarding the temporal distribution, SAVI and EVI indices shows a high correlation with soil moisture, which also shows a strong correlation with the number of leaves and leaf area. The data obtained show the dependence between soil moisture and the morphological development of the crop. On the other hand, the highest correlation coefficient is obtained between the NDVI index and the leaf area, reaching a value of 0.985, which demonstrates the effectiveness of this indicator in monitoring the state of the crop. The values of NDVI index during vegetative period of the crop is shown in Figure 3, where it is possible to identify the different changes that take place both, in the leaf area and in soil moisture accordingly with sampling result in field.

Figure 4 shows the field special distribution of NDVI index during sprouting (I), at greatest vegetation state (II) and wilting stage (III), which also allows a temporal analysis of the behavior in the period. The initial state is characterized by the absence of plant cover, values between 0,2 and 0,4 being in correspondence with the incipient development of the crop in sprouting time. In stage II, the crop has the maximum value of leaf area increasing NDVI at 0,9 to decrease later in stage III with a predominant value of 0,4.

TABLE 1. Results of the biophysical variables and vegetative indices

Samples	Stem long, cm	Stem diam, cm	N° of leaf	Leaf area, %	Soil Moisture %	Vegetation index average			
						NDVI	EVI	SAVI	NDWI
1	10,32	0,54	12,7	10,12	38,3	0,12	0,11	0,12	-0,61
2	20,21	1,18	69,5	22,24	34,7	0,21	0,24	0,26	-0,52
3	32,6	1,21	110,9	40,15	41,4	0,65	0,67	0,61	-0,32
4	43,52	1,26	101,8	41,63	42,6	0,72	0,65	0,55	-0,67
5	44,37	1,24	69,2	37,54	38,7	0,53	0,47	0,32	-0,52
6	44,51	1,22	33,5	32,13	32,4	0,46	0,33	0,29	-0,61

TABLE 2. Multiple correlation between temporal variables

	Soil Moisture, %	Leaf area, %	NDVI	EVI	SAVI
N° of leaf	0,9602	0,7974	0,7730	0,8908	0,9267
	0,0023	0,0574	0,0715	0,0172	0,0079
Soil Moisture, %		0,9013	0,8963	0,9356	0,9187
		0,0141	0,0156	0,0061	0,0096
Leaf area, %			0,9852	0,9048	0,8270
			0,0003	0,0132	0,0423
NDVI				0,9337	0,8500
				0,0065	0,0320
EVI					0,9781
					0,0007

First number: correlation coefficient (r)
Second number: p-value

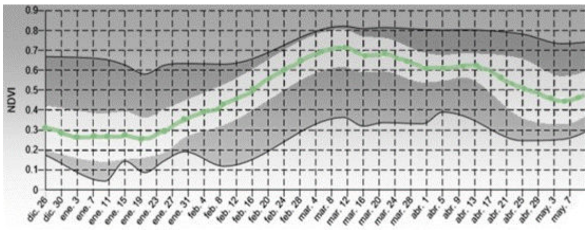

Figure 3. Monitoring NDVI index during cultivation.

CONCLUSIONS

The monitoring of vegetative indexes as: NDVI, EVI and SAVI shows an adequate correspondence with biophysical variables development in potatoes crop at the different stages of growth. In all the cases, correlations greater than 0,9 are achieved, highlighting the SAVI index which shows a strong correlation with the number of leaves and soil moisture.

The highest correlation of 0,98 was found between NDVI index and the leaf area. The NDVI monitoring allows identifying the changes take places in leaf area and soil moisture during the vegetative period of the crop. Similarly, the spatial distribution of NDVI, makes possible to identify the plant cover variability of the crop.

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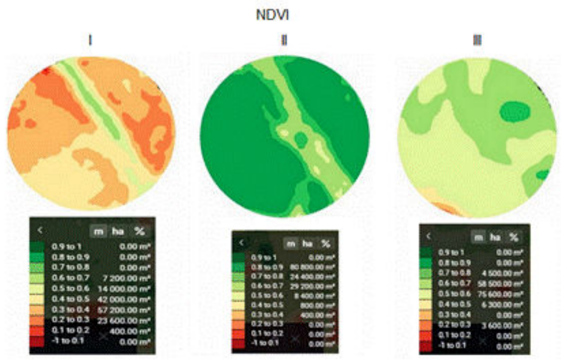

Figure 4. Special distribution of the NDVI index during the vegetative period.

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