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USE OF REMOTE SENSING TO EVALUATE PERFORMANCE OF IRRIGATION DISTRICTS AND SMALL IRRIGATED AREAS

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Summary

It is considered of importance to evaluate small irrigated areas, using the images of Sentinel 2A satellites, which have a spatial resolution of 10 meters, equivalent to 100 pixels per hectare, in contrast to Landsat 8 images, which only have a little more of 11 pixels per hectare, so in this work the condition of a couple of small plots in the Irrigation District 03, Tula, in the state of Hidalgo is analyzed and the area irrigated in the spring summer cycle of this year is estimated in the district through the use of a mask and the Qgis program. For the analysis of the plots, the development of the crop is adjusted according to the variation of the NDVI and SAVI indices for corn cultivation to a logistic function, through which the growth of the crop is estimated, evaluating the growth rate of both indices, to estimate its effect on the yield in each one, which is compared with that obtained by its producers. Additionally, an estimation of the leaf area index is made based on the NDVI and the SAVI.

Keywords: Remote sensing, NDVI, SAVI, Logistics, Sentinel 2A



Introduction

The use of remote sensing using satellites began in the 1960s; however, it was until 1972 when the first Landsat satellite was launched into space especially to monitor agricultural production. In Mexico, the use of satellite images began in 1975, when the Ministry of Agriculture and Livestock established a program to study land use using satellite images, subsequently published in 1980 (SARH, 1980) and since then many studies have been conducted using different satellites, among which the use of SPOT satellites stands out, when an antenna was installed at the Secretary of the Navy to receive these images and the Ermex program (2007) was created; The Graduate College joined the program that same year and used many images of these satellites to conduct studies in different regions of the country. He has also done many research papers using Landsat satellites and other satellites such as Rapid Eye and Deimos; more recently, images of Sentinel satellites have been used, both A and B, with a spatial resolution of 10 meters and the advantage of their free availability every 5 days, which allows adequate coverage to study agricultural areas, Freeing days with cloudiness.

The study of small plots under irrigation requires an adequate spatial resolution which is achieved with the resolution of 10 meters, equivalent to 100 pixels per hectare, so for that matter two plots of the irrigation district 03 have been evaluated, in the Hidalgo state, where one of its main crops is corn. According to the user registry, this district has an area of 45,284 hectares under irrigation, with 41,509 registered users, which gives an average area of 1.09 ha / user. According to the latest information available from CONAGUA, the area irrigated in the 2015-2016 agricultural cycle was 52,597 ha, so an estimated 16% of second crops are estimated. On the other hand, as the area under irrigation estimated for this year in the spring summer cycle plus perennial crops will be reported later, it was 53,692 ha.

According to what has been reported, this work aims to show a methodology that allows estimating the behavior of a small area under irrigation, cultivated with corn whose behavior can be characterized by two indices that are the NDVI and SAVI calculated in 11 images of the Sentinel satellite, to cover the development of corn cultivation, using the logistic function to simulate the development of this crop.

On the other hand, considering of interest to estimate the surface that has in a district or unit of irrigation in production, a methodology is shown that can be used to evaluate this area, which would also be a test that allows to verify it, since in several irrigation districts It has been observed that those responsible for the operation of the irrigation modules usually report a smaller area than the irrigated area.

Materials and methods

For this work the Qgis software was used in its most recent version, as well as the latest version of IDRISI called TerrSet, in addition to 10 images of the Sentinel Satellite that covers the area where the Irrigation District 03, Tula, Hidalgo, considering everything



the time of the spring-summer cycle of crops established in this district for 2019. The district vector data dr003_parcelas_14N was also used.

To estimate the development of corn cultivation, two indices will be used to assess said development, since they are correlated with the generation of biomass and the evapotranspiration processes of crops, the oldest is the vegetation index of standardized differences, called NDVI (Rouse *et. al.* 1974) whose value is based on radiation measurements in the red and near infrared bands:

$$NDVI = (NIR-R)/(NIR+R) \quad (1)$$

Where NIR is near infrared radiation and R is red radiation

The other index used is the SAVI, Soil Adjusted Vegetation Index developed by Alfredo Huete, then a professor at the University of Arizona (Huete, A. R. 1988) who makes a correction based on the effect of the soil.

$$SAVI = (1+L)*(NIR-R)/(NIR+R+L) \quad (2)$$

Where NIR and R have already been defined and L is a correction for the soil effect that is usually considered as 0.5, although it may vary according to the soil conditions.

On the other hand, it is considered that there is a relationship between this index and the leaf area index (LAI, by its initials in the English language, IAF in Spanish) according to the following relationship (W. G. M. Bastiaanssen, 1998)

$$SAVI = C_1 - C_2 \exp (-C_3 LAI) \quad (3)$$

It also follows that LAI can be obtained as a function of SAVI by clearing of (3) LAI

$$LAI = 1/-C_3 * \ln ((C_1-SAVI)/C_2) \quad (4)$$

The indices that Bastiaanssen reports in his book, for corn obtained in the US, are C1 = 0.68, C2 = 0.5 and C3 = 0.55

To estimate the behavior of corn cultivation in two plots of the irrigation district, a sigmoidal function will be used, which usually represents crop development as suggested by J. H. Thornley (1976); Among these types of functions, Logistics and the Gompertz function (Winsor C.P. 1932) stand out, although Logistics was better shown in the adjustment tests (Martínez Rodríguez E, 2008).

The differential equations on which biomass development is based, in the case of the logistics model is:

$$\frac{dy}{dt} = k(Y_m - y)y \quad (5)$$

For the Gompertz model it is:

$$\frac{dy}{dt} = -k[\text{Ln}Y_m - \text{Lny}]y \quad (6)$$

Where y is the dependent variable that for the case could be the amount of biomass, t at development time, k a constant of proportionality, Y_m is the maximum value reached by the variable y .

By integrating the following functions are obtained, which is usually presented as:

$$y = \frac{Y_m}{1 + \frac{Y_m - y_0}{y_0} \exp(-ct)}, \text{ la cual suele presentarse como:}$$

$$y = \frac{a}{1 + b \exp(-ct)} \quad (7)$$

y_0 is the initial value of the variable, which of (7) for $t = 0$ is worth: $y_0 = \frac{a}{1+b}$

The Gompertz function is: $y = Y_m \exp[-\exp(b - kt)]$,

which is usually presented as $y = a \exp[-\exp(b - ct)]$

The growth rate based on the functions (8) and (9) is also often used in both cases, these rates that are presented as a campanular function, have a maximum value at the inflection point and is a good indicator of when it starts maturation and senescence of the crop. In the case of the logistics function, the maximum value is reached at a time:

$$t_m = \frac{1}{-c} \text{Ln} \left[\frac{1}{b} \right] \quad (8)$$

In the case of the Gompertz function, this value is reached when

$$t_m = \frac{b}{c} \quad (9)$$

On the other hand, taking the derivative of the logistic function of obtaining the growth function of the NDVI and the accumulated SAVI that simulates the development of the crop, this bell-shaped function indicates the way in which the crop is developed;

The function is shown below:

$$\frac{dy}{dt} = cy - ky^2 \quad (10)$$

Where $k = c/a$ (11)

Results

To calculate the area established in the irrigation district, the TerrSet software is used, with the RECLASS function, the numbering of the plots in the vector is changed:

dr003_parcelas_14N, so that only a few remain and with this modified vector makes a mask that will cover the image of the Sentinel satellite dated March 3, 2019, with the NDVI values, maximums in the series of 11 images that will be used for this study and that corresponds to the image of March 3, so that only what is inside the irrigation district is visualized; then with the “Recode” algorithm of Qgis the irrigated areas are classified according to the value of the NDVI in 3 levels, from -1 to 0.25, without crops, after 0.25 to 0.5 which is the stage of growth or decline of the crops and from 0.5 to 1 which is when the crop tends to reach its maximum development. Subsequently, the “Report” algorithm is used and the surfaces are obtained according to each of the three levels considered

When carrying out this work, it was obtained as a result for the area without cultivation class1: 1,151,912 ha, for class 2, no hectare and for class 3: 53,692 ha, which implies that the entire area with crops is in full development, which coincides quite well with what was reported in the last available report of the irrigation districts of CONAGUA for the 2015-2016 agricultural year that were for this district 52,597 ha the surface established in this season.

In the analysis of two small plots that planted corn, plot number 20120 and 20102, the adjustment to a Logistics function was used to simulate the development of the crop, by using the 11 images of the Sentinel satellite, using the NDVI and SAVI.

In plot 20120, the adjustment of the accumulated values of the NDVI index to a logistic function, $Y = 6.84/(1+24.4*\exp(-0.0487*X))$ has a value of the coefficient of determination R2 of 0.997, with a standard error of 0.1194, equivalent to 4.23%. This setting is show in Figure 1 below

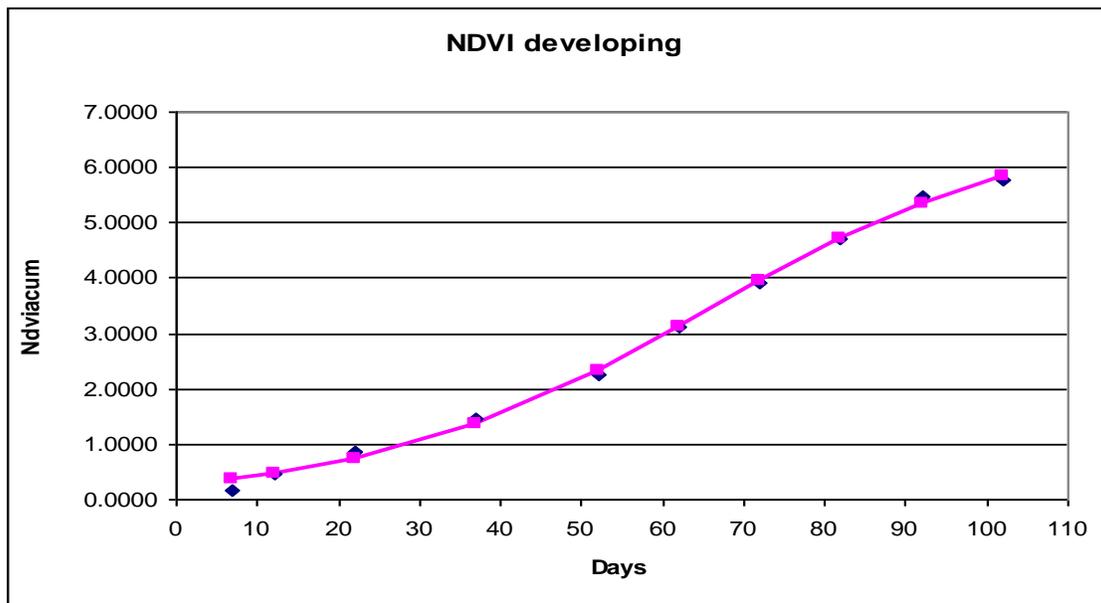


Figure 1. Adjustment of the accumulated values of NDVI to Logistics curve

On the other hand, the growth rate is adjusted to a reciprocal quadratic curve: $Y=1/(82.4-1.98X+0.0139X^2)$ as seen in Figure 2.

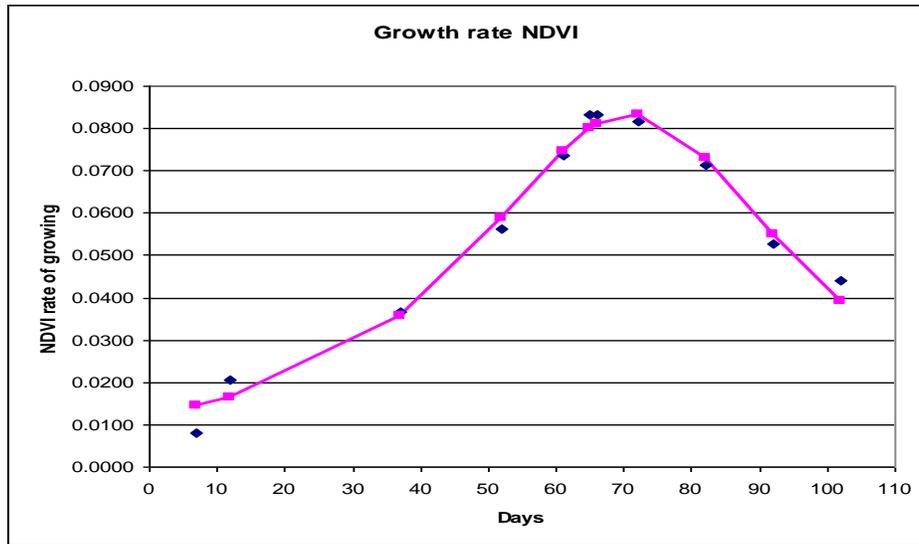


Figure 2. Cumulative NDVI growth rate

The turning point when it reaches the maximum development which is calculated with function 8 is at 65.6 days.

A similar process is carried out with the SAVI index values, which, as will be observed, also has an acceptable adjustment to the same functions as the NDVI index, observing a more regular adjustment in the growth rate. The adjustment to the logistics function of the SAVI index is shown in Figure 3 with the function:

$Y = 4.03 / (1 + 39.06 * \exp (-0.06 * X))$ with R2 of 0.997, error of 0.0896 equivalent to 4.84%.

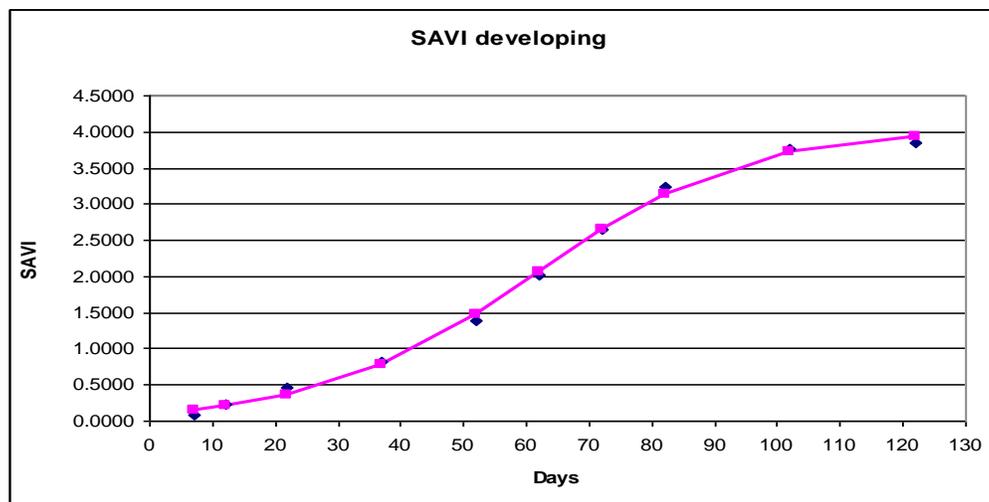


Figure 3. The SAVI developing curve adjustment

The growth rate of SAVI also adjusts to a more regular inverse quadratic curve than that of NDVI as shown in Figure 4.

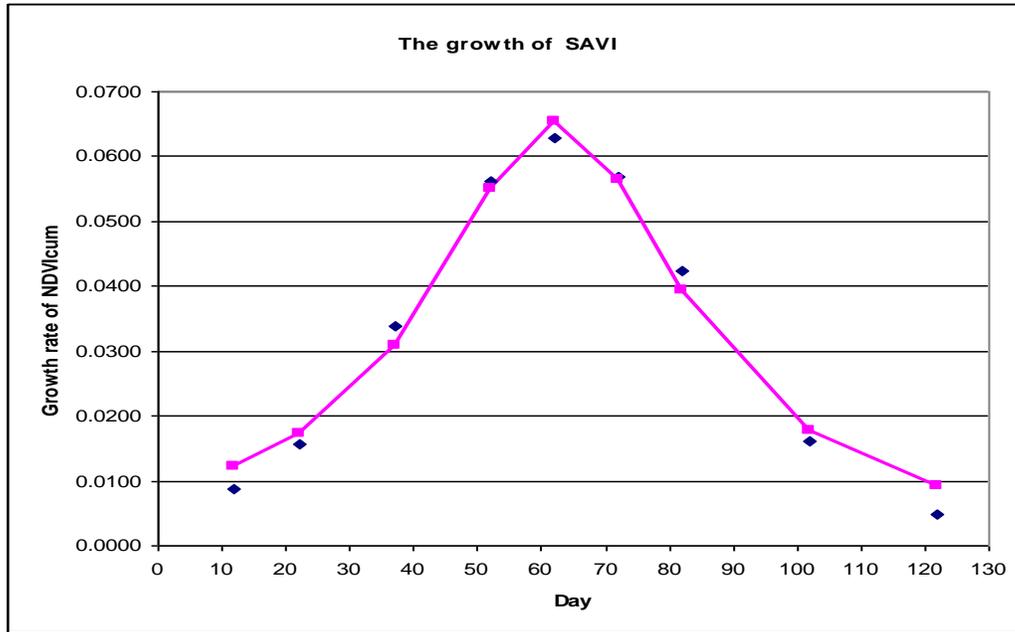


Figure 4. Cumulative growth rate of SAVI.

The growth rate of SAVI adjusted to a reciprocal quadratic curve of the next form:
 $Y=1 / (117.7-3.28 X+ 0.0263 X^2)$

In the case of the SAVI index, the maximum growth and inflection point occurs at approximately 61 days, very similar to NDVI.

The value of a in the logistic function as in that of Gompertz, is the value at which the function is made asymptotic and in the case of wheat cultivation it was found that there is a relationship between this value in the logistics and the yield obtained, although the function is not linear, so it can be inferred that there is a similar relationship between this value and the yield of corn, for which it is required to have sufficient function values, in order to find that relationship. Under this consideration, if the rule is applied to 20120, the value of a is 6.84 and for plot 20102, the value is 4.03 so that higher performance could be assumed for the first; what is confirmed in the case of SAVI where the value of a for plot 20120 is 4.03 for 20102 is 3.84.

For plot 20102 the variation graphs are presented below, with the values observed for both cases.

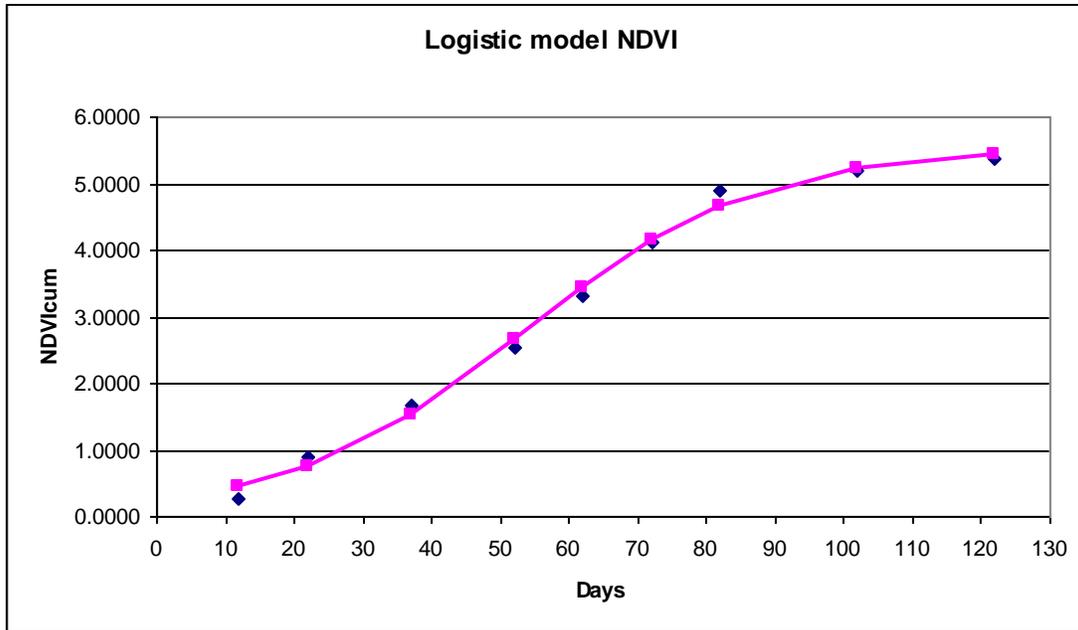


Figure 5. Variation of NDVI values

For this case the function is $Y=5.526/(1+23.38*\exp(-0.059*t))$, and for the NDVI growing rate the graphic is showing in figure 6.

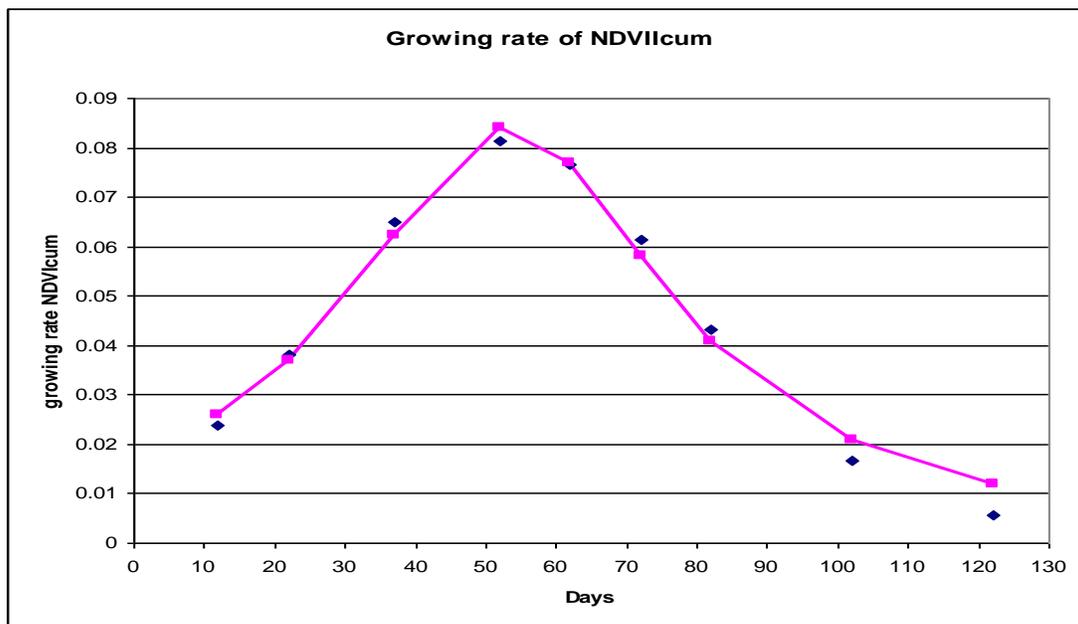


Figure 6. Growing rate of NDVIcum

The growth rate of NDVI adjusted to a reciprocal quadratic curve of the next form: $Y = 1/(55.966-1.649 X+ 0.0154 X^2)$

On the other hand, when analyzing the spatial variability in the two plots, greater variability was observed in the 20102 plot, than in 20120; the area sown and irrigated in



plot 20120 was 2.36 ha and in 20102 the area sown and irrigated net was 3.40 ha. Although the plot has a total area of 4.74 ha

According to the information provided by the Chief of Operations of the district, in the previous cycle the yields obtained were very similar in the order of 11 tons in plot 20120 and 11.5 in plot 20102. We hope that the yields obtained in this one will be communicated to us agricultural cycle

Conclusions

The information that can be obtained from Sentinel2A and 2B satellites, available every 5 days, in relation to the development of agricultural crops through the use of indices such as NDVI and SAVI, can be very useful for irrigating producers in district and irrigation units know how their crops are developed, although their plots are small in size as shown in the examples presented in this work; since the spatial resolution of 10 meters, representing 100 pixels per hectare is sufficient to obtain a knowledge of the spatial variability within the plots. As can be seen in the graphs, the growth rate of the accumulated SAVI is more regular in its form than that of the accumulated NDVI, which is surely due to the ground effect and allows us to know when maximum development is reached.

Also as shown in this work, it is relatively easy to estimate the area that is cultivated and irrigated in an irrigation district or unit, if the vector is available where the shape and size of its plots are available; This is useful to know the area cultivated in the district or unit, especially taking into account that in the irrigation districts it has been proven that those responsible for the operation of the irrigation modules usually report smaller areas to the irrigated areas.

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