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Determination of biomass production of cotton using satellite images and spectral indexes

Marcos A. V. Silva*, Éder S. Moscon**, Charles C. Santana***

* Adjunct Professor in Department of Human Sciences; University of the State of Bahia – UNEB, BR 242, km 04, Lot. Flamengo, s/n. Barreiras – BA - Brasil. Email: maavsilva@uneb.br (Corresponding author)
**Doctoral candidate in University of Brasília - UNB.
***Undergraduate in Department of Human Sciences; University of the State of Bahia – UNEB

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Abstract

The present study aimed to evaluate the mutual dependence between the spectral behavior in the cotton canopy, the leaf area index and biomass production. The study took place, in field conditions, under irrigation, in the Busato I Farm in the city of São Desidério-BA. The 10 samples for biomass determination were taken at intervals of approximately 15 days, collecting five consecutive plants contained in 0,45m^2. The designated goods MOD09GQ and MOD13Q1 were used, where you got the vegetation indices NDVI and SAVI. To calculate the Leaf Area Index three methods were tested. The accumulation of biomass was estimated by two models and these were evaluated by correlation coefficients (r), accuracy (d) and also the index (c). The maximum values for NDVI, SAVI, and total dry matter production were 0.903, 0.717 and 1200g.m^{-2}, respectively, at 90 days after emergence. The maximum leaf area index was found at 60 days after emergence. The highest growth rate of the culture was found at 80 days after emergence and 55% of the final dry matter were flower buds. The VIs were shown to be effective for obtaining the LAI, as well as the models that bring the radiation photosynthetically active if showed consistent, because they achieved reliability values considered excellent, and correlation coefficients and higher than 90% accuracy..

Keywords: LAI, MODIS, NDVI, remote sensing.

1. Introduction

In the Northeastern Region of Brazil, herbaceous cotton (*Gossypium hirsutum*) is considered higher socioeconomic importance culture. In Western Bahia its growth was one of the agricultural activities that grow the most in the last years. During the 1990's, when the culture was introduced, the plantation area was below 2.4 thousand ha, reaching in the last harvest season (2016/2017) an area above 190 thousand ha and a production above 769.5 thousand tons (AIBA, 2017). Such results place Bahia State as the second national producer for such culture, only behind Mato Grosso State (CONAB, 2017).

With the development and expansion of agriculture in the last decades, remote sensing techniques have been used to monitor field conditions, being applied to terrestrial surface studies, mapping and identification of the different ground coverage. The development of functional relations between the data collected by orbital platforms and vegetation characteristics have been the objective of many professionals of the agricultural and forestry sectors (Coura et al., 2010).

The absence of relations between radiometric responses of a canopy and the parameters that categorize the plant's growth stages is the principle used for the study of vegetation by remote sensing. The combination of the electromagnetic radiation measurements reflected by vegetation in some spectral bands results in vegetation index (VI). By means of vegetation indexes it is possible to reduce the dimensionality of data and highlight the spectral response of vegetation when related to the ground. The vegetation indexes were idealized from the characteristics of green vegetation's spectral response. The most used vegetation index is the Normalized Difference Vegetation Index (NDVI).

The leaf area index (LAI) is a non-dimensional value given by the reason between the sum of the area of one side of each of the leaves of a plant by the projected surface area that they occupy. The LAI estimates by image may be done in scale, at low cost, and high time frequency (Breunig et al., 2013). Many are the works that display the use of variables LAI, IV's and biomass production estimates from orbital images (Brandão et al., 2011; Breunig, 2011; Risso et al., 2012). Thus, the present paper had as goal to estimate Leaf Area Index and Vegetation Indexes for cotton by satellite images; analyze the relations between leaf area indexes and vegetation indexes from orbital platforms, with the production of biomass and test a model that considers PAR intercepted in the production of cotton biomass.

2. Materials and methods

The study took place, in field conditions, under central pivot irrigation, in the Busato I Farm in the city of São Desidério-BA, geographically located on 12°53'S and longitude 45°30'O, altitude 770 m. The experimental soil of the area is characterized as Oxisoil (EMBRAPA, 1999). The research was developed between January and July 2011.

The cotton genotype used was the hybrid SICALA 90 MDM of normal cycle. The seeds were planted on January 5th 2011, rising five days later. The planting density was 9 plants/linear meter, with spacing between lines of 0.76m.

The samples for determining total air part biomass were performed in intervals of approximately fifteen days, such as plant collection within 0.55m^2 ground. Five consecutive plants were collected, in five different lines within a 8100m^2 perimeter. Total air biomass was separated in stem, leaves, buds, apples and bolls and, later, the parts placed in forced air circulation greenhouse, under temperature of 65°C, until reaching constant mass and, then, the dry biomass was determined through the Equation 1:

$$DMa = ax + bx^2 + cx^3 + xo \quad (1)$$

where "a" is the estimate of maximum growth of DMa, gm^{-2} (provided a > 0); "x", the days of growth; b, c and xo (provided b > 0), constant adjustment.

For NDVI and SAVI generation were used images from the sensor MODIS (*Moderate Resolution Imaging Spectroradiometer*). Such sensor has high radiometric and geometric quality, different spatial resolutions and temporal frequency, important requirements for the precise monitoring of terrestrial coverage in order to observe the changes in use and soil coverage (Justice et al., 2002). The MODIS products, that have free distribution via Internet, may be found in the NASA website (www.reverb.echo.nasa.gov/reverb). Ten images MOD09 were used during the entire studied period. To visualize and process MODIS images after downloading, the app used was MR Tools (MODIS Reprojection Tool). Then, were calculated the NDVI and SAVI values for each image. To perform such calculation the tool Model Maker of the software ERDAS IMAGINE was used.

NDVI was obtained by Equation 3 and its values vary from -1 to 1, described by the relationship involving the reflectance of spectral bands of close infrared (IVP) and red (V):

$$NDVI = \frac{IVP - V}{IVP + V} \quad (2)$$

The SAVI was developed from the equation below:

$$SAVI = \frac{(IVP - V)}{(IVP + V + L)} (1 + L) \quad (3)$$

where was assigned (L = 0.5) as a considerable amount of noise reduction of soil to a wide range of densities canopies.

For LAI calculation, three methods were tested. In the first method (LAI_1), the estimate was performed in two stages. The first stage was determining the Fc value (Choudhury et al., 1994):

$$Fc = 1 - \left(\frac{NDVImax - NVI}{NDVImax - NDVImin}\right)^{1,1} \quad (4)$$

where Fc is the fraction of soil covered, NDVImax is the maximum value of NDVI, NDVImin is the minimum value of NDVI and NDVI is the value of NDVI sampled.

Then, LAI (LAI_1) was estimated as follows (Rizzi E Rudorff, 2007):

$$LAI = -2 * \ln(1 - Fc) \quad (5)$$

where, LAI is leaf area index and Fc is the fraction of soil covered, calculated by the above equation.

The second method (LAI_2) was the equation adjusted by Xavier and Vetorazzi (2004), as follows:

$$LAI = 1{,}4560 * NDVI^{5{,}5249} \quad (6)$$

The LAI_3 was obtained based on SAVI, which empiric equation is given by Allen et al. (2002).

$$LAI = -\ln\left(\frac{0.69 - SAVI)}{0.59}\right)/0.91 \quad (7)$$

The air biomass accruing was estimated according to the Montheith model proportional to the accrued active photosynthetically absorbed radiation (f x PAR) (Daughtry et al., 1992 stated by Bastiaanssen and Ali, 2003):

$$MSa1 = \alpha * \sum(f * PAR(t)t) \quad (8)$$

$$f = 0.161 + 1{,}257 * NDVI \quad (9)$$

For the air biomass estimate production (DMa_2) was also used the equation proposed by Monteith (1977):

$$MSa2 = \alpha * \sum RFAI \quad (10)$$

where (α) is the conversion efficiency of radiation RFAI dry biomass produced.

The photosynthetically active radiation intercepted was calculated using the methodology proposed by Varlet-Grancher et al. (1989):

$$RFAI = 0.95 * (RFAinc) * \mathcal{E}inc \quad (11)$$

where RFAI = photosynthetic active radiation intercepted (MJ.m-2); (Ɛinc) = efficiency of interception of photosynthetically active radiation.

For the estimate of (Ɛinc) was used in the following equation:

$$\mathcal{E}inc = 1 - e^{-K*IAF} \quad (13)$$

where (K) is the extinction coefficient of light, dimensionless, value of 1.1.

The adjusted values, both for IV's as for biomass determination, were performed using the software SigmaPlot 10.0.54, using as reference the data obtained in the field.

The performance of the models used to estimate biomass, LAI, NDVI, SAVI and EVI were evaluated statistically by four techniques, two precision (root of the average square deviation (RMSE) and correlation index "r" and two accuracy, being the average deviation (MBE) and 'd' Willmott index, proposed by Willmott et al. (1985):

$$d = 1 - \left[\frac{\sum_{i=1}^{N}(Pi - Oi)^2}{\sum_{i=1}^{N}(|P'i| + |O'i|)^2}\right] \quad (14)$$

where (N) is the number of observations, (Pi) is the estimated value (Hi) is the observed value, (P'i = PI - M) and (O'i = Hi - M) and (M) the average of the observed variable. The closer to the unit, the better the correlation between two variables compared and vice versa.

Also, the "c" index was used, which gathers the "r" precision index and "d" accuracy index, to assess the performance of the method's estimates, according to Camargo and Sentelhas (2007):

$$c = r * d \quad (15)$$

and the interpretation of the performance of the estimates by the index "c" is shown in the Table 1.

Table 1 - Criteria for the interpretation of the performance of the estimates of biomass production.

Performance	"c"
Great	> 0.85
Very good	0.76 to 0.85
Good	0.66 to 0.75
Median	0.61 to 0.65
Poorly	0.51 to 0.60
Bad	0.41 to 0.50
Terrible	≤ 0.40

Source: Sentelhas and Camargo (1997)

3. Results and discussion

It is noticeable in Figure 1 that the SAVI and NDVI values have close distribution. Both IV's behave as expected, since the rise during the beginning, reaching the peak at half their development, and gradually decaying by the end of the cycle. It is worth highlighting that cotton, in the studied cultivation system, is defoliated by the farmer around 140 DAE. Anderson (2004), evaluating the NDVI versus EVI vegetation indexes derived from the data from MODIS sensor as season changes indicator, for the different vegetation formations classified, has encountered maximum and minimum values of 0.88 and 0.33, respectively, of NDVI for Soy culture. It is noticeable, in Figure 1, that the NDVI variation was 0.3 at the beginning of the cycle and it has reached near 0.9 after 90 DAE. The sudden decrease of NDVI values, from 100 DAE, expresses the decrease of green phytomass (active) of cotton by the end of the cycle. Rizzi and Rudorff (2007) attempting to estimate soy productivity in Rio Grande do Sul, by an agricultural model implemented in a Geographic Information System - SIG, stated that the variation of NDVI was related to different phonological stages of soy. Low NDVI values were observed during the months of November and April, in coincidence, respectively, with the culture's establishment and senescence. Picoli et al. (2009) working in order to estimate productivity in sugar cane plots in the 2004/2005 and 2005/2006 harvests using the agricultural model in a SIG, based on remote sensoring and weather data, have encountered NDVI values that varied between 0.4 and 0.8 for the beginning and the end of the period of highest biomass accruing, respectively.

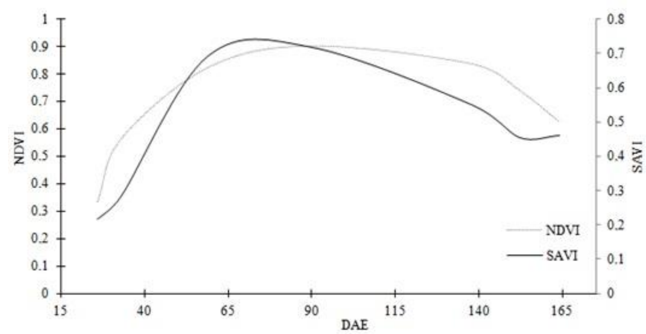


Figure 1 - Evolution of the indices of vegetation NDVI and SAVI, as a function of days after emergence (DAE) of culture.

The equations in Table 2 were generated in the software Excel and concerned the evolution of IV's NDVI and SAVI due to DAE. The correlation coefficient for both IV's were elevated, with 0.98 for NDVI and 0.99 for SAVI. Such values indicate strong correlation between vegetation indexes due to plantation development, here expressed in DAE.

Table 2 - Equations and determination coefficients of the VIs

Variables	Equations	R^2
NDVI	$NDVI = 4^{-7} DAE^3 - 3^{-4} DAE^2 + 2,7^{-2} DAE - 0.210$	0.956
SAVI	$SAVI = 1^{-6} DAE^3 - 4^{-4} DAE^2 + 3,9^{-2} DAE - 0.609$	0.975

The Leaf Area Index was estimated by three different models, however only one of them was consistent. Such model was professed by Rizzi and Rudorff (2007), according to Equation 6 described in such method and named LAI_1. The second method (LAI_2), adjusted by Xavier and Vetorazzi (2004), considerably underestimated LAI, not reaching values above 1.0. LAI_3, reached based on the Soil Adjusted Vegetation Index - SAVI, of which empirical equation is given by ALLEN et al. (2002), is able to estimate LAI up to SAVI values below 0.69, and above these the index saturates, and the results of the equation do not apply.

In Figure 2(a) there is the evolution of LAI and SAVI due to DAE of cotton. For Figure 2(b), there is LAI behavior, compared to NDVI, due to DAE. It is observable that the LAI follows an expected path, since it increases with the culture's growth and development, from 0.8, reaching values close to 5.8 and returning until around 2.0. Such evolution might be explained by the fact that cotton is grown with a higher plant population, thus reaching maximum LAI around 60 DAE. In more narrow seed spacing systems, there is an increase of leaf area, favoring higher sun radiation interception by the cotton plantation (Silva et al., 2006). Beltrão et al. (1990), working with the cultivar CNPA Precoce 1 under rainfed conditions, have reached maximum LAI of 5.53 on DAS (days after sowing) 75 in Souza-PB. Borges et al. (2002) aiming to evaluate growth and development of herbaceous cotton BRS-201 in edaphic-climate conditions and available energy in irrigated conditions in Cariri-CE, has observed that the Leaf Area Index has reached maximum value of 3.7 on DAS 98.

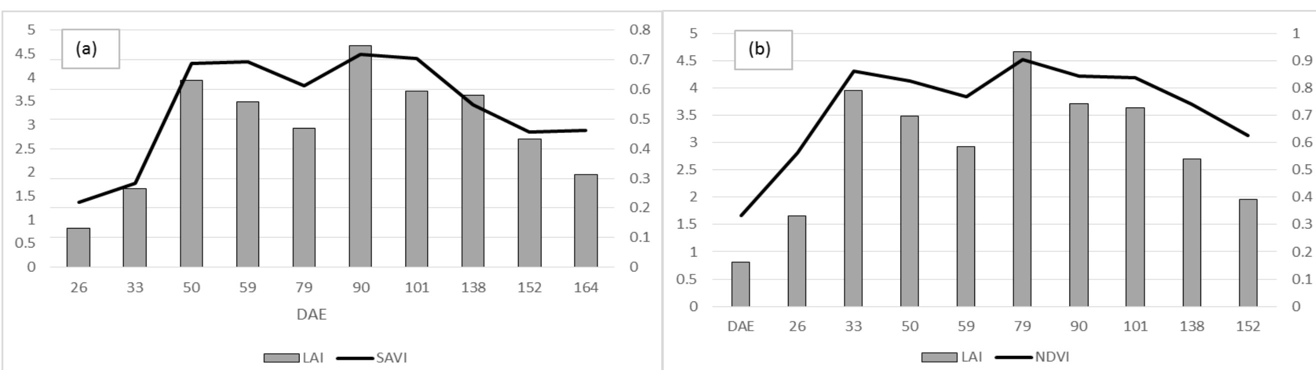


Figure 2 - (a) Developments of LAI and SAVI in function of DEA; (b) Developments of NDVI and LAI in function of DEA.

The LAI is still one of the most important features to study plant's physiologic behavior, which may be used as an indicator of growth rates and effectiveness of water use by the plants. LAI varies throughout the culture's phenology, being consequence of metabolic and photosynthetic activities by the plant. The accruing of dry matter, photosynthesis and breathing may be expressed due to such index (BorgeS, 2002). Brandão et al. (2011) has also observed that NDVI has high correlation (0.95) to LAI in every phenological stages of cotton bushes and has concluded that it is possible to estimate the productivity of the cotton bush using the Leaf Area Index (LAI) obtained by remote sensoring products.

Figures 3(a) and 3(b) represent the evolution of estimated LAI due to IV's. LAI, when related to NDVI, is displayed in a crescent way and its adjustment was performed by an exponential function, with correlation value reaching 0.9657. When analyzing LAI behavior due to SAVI, it is verifiable that it was adjusted in an exponential function, reaching a correlation coefficient of 0.9726. In the present paper, both IV's as LAI were obtained, for the same dates, from the same images. This may indicate high correlation between them.

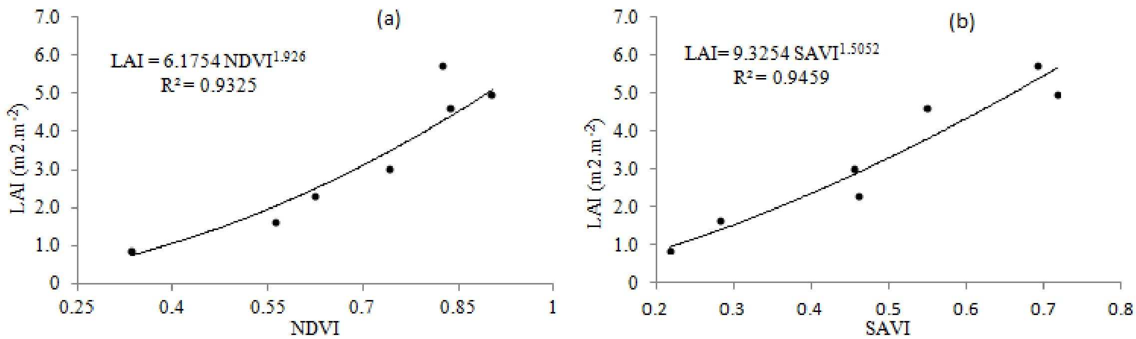


Figure 3 - (a) Evolutions of the LAI as a function of NDVI; (b) Evolutions of the LAI in terms of SAVI.

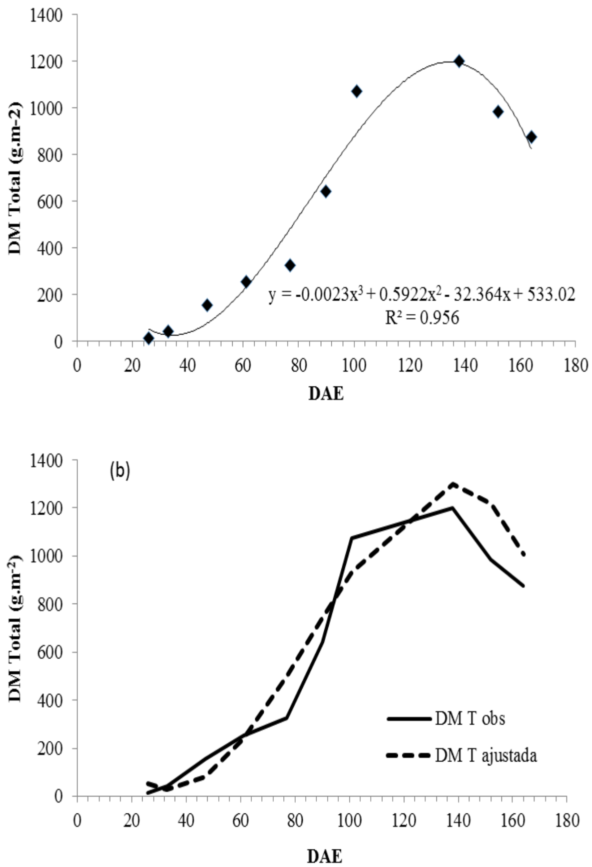
The total dry matter reached 1350 $g.m^{-2}$, when the culture was 138 DAE old. There is a drop after this period, with harvest weight of around 980 $g.m^{-2}$. Due to a series of internal and external factors, the cotton bush usually sheds around 20-25% of buds, and 60-80% of young fruits, up to six days of age. There is a negative correlation between the weight of 100 seeds and fiber percentage, in other words, to a higher oil production in the seeds, which varies from 14 to 28% related to seed weight, there is reduction on the fiber amount in the seeds, which means a lower fiber index. It is worth stating that there was senescence of the lower portion leaves, increase of reproductive organs and, close to the end of the cycle, defoliation, a common practice used to avoid the fiber to be contaminated with remains of dry leaves.

In Figures 4(a) and 4(b) may be observed, respectively, the results of total observed dry biomass (DMTobs) and the comparison between DMTotal observed and estimate, both in the air part. A crescent evolution is noticed from the 50 DAE and it remains so until close to 140 DAE, when DMTotal observed reached values above 1200$g.m^{-2}$. The drop on accruing dry matter starts after 140 DAE, and stabilizes close to the harvest period, with 170 DAE, when the DMTotal values were around 870 $g.m^{-2}$. According to Azevedo et al. (1999), the growth curve of the hearbaceous cotton bush is characterized by a slow beginning and an almost linear growth stage, very fast, which ends at the beginning of flowering.

In Figure 5, there is an behavior of the dry matter estimate models. The models by Monteith (MSa 2) and Bastiaanssen and Ali (MSa 1) had a tendency to overestimate until 70 and after 160 DAE and in the interval between such dates, overestimated the MS production. It is noticeable that the estimate models do not follow the maturation period of the culture and senescence. This might have happened because the estimate models take into account accrued RFAI in the period, and it is crescent.

By the observation of Figure 6 it is noticeable that, when related DML and LAI, the correlation between them is elevated, reaching a determination coefficient of 0.93, and its behavior fits as an exponential function. Silva (2009), aiming to analyze the relations between the spectral response of the BR 106 canopy, from IV's from orbital platform, with LAI, has concluded that IV's NDVI and SAVI may be a good tool to follow corn plantations due to its good correlation to LAI parameter.

Figure 4 - (a) Behavior of MSTotal observed, in $g.m^{-2}$, according to the DAE; (b) Comparison of



MSTotal observed and estimated, in g.m^{-2}, on the basis of DAE.

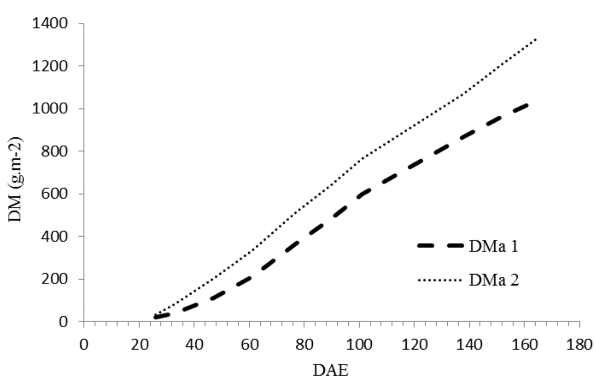


Figure 5 - Behavior of DM estimated by two mathematical models.

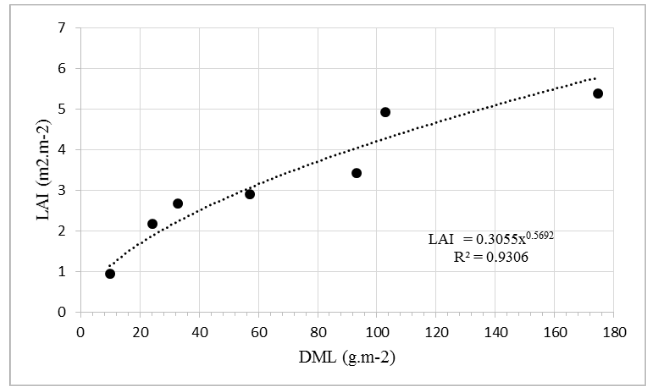


Figure 6 - Behavior of the LAI in function of dry matter of leaves (DML).

The Monteith model takes into account LAI, so for the present paper it was obtained by using MODIS sensor images. It is noticeable that even LAI not being obtained in the field, such measurement has been displayed as effective, since the MS behavior expressed in Figure 6 displays a slight difference between estimated and measured. It is verifiable, in Table 3, that both correlation (0.93) and accuracy (0.87), a good adjustment between estimated and observed values is inferred.

Table 3 - Equations and determination coefficients of the VIs

VARIABLES	r	d	c	Evaluation
DMa 1	0.9338	0.9508	0.8878	Great
DMa 2	0.9304	0.9456	0.8797	Great

4. Conclusions

The VI's extracted in MODIS images have been displayed effective to obtain LAI, and may be useful to follow the evolution of the plantation in the field since they presented good correlation.

In determining biomass the models that displayed active photosynthetic radiation and VI's were coherent, for they reached concordance and reliability values considered optimal.

It is recommended to perform more studies with LAI of cotton obtained in terrestrial truth, for the values here used were only from orbital platform.

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