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ASSIMILATION OF A BIOPHYSICAL PARAMETER ESTIMATED BY REMOTE SENSING USING SPOT 4&5 DATA INTO A SUGARCANE YIELD FORECASTING MODEL

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Abstract

In the context of the SUCRETTE project, (*Système de sUivi de la Canne à sucRE par TélédéTEction*) CIRAD (*Centre International de Recherche Agronomique pour le Développement*) has initiated a project to monitor growth of sugarcane in Reunion Island (55°60' E longitude, 20°90' S latitude). Ground measurements (Leaf Area Index) using a PCA Licor 2000 were taken from June 2002 to December 2002, coupled with SPOT 4&5 (Satellite Pour l'Observation de la Terre) images acquired during the same period. Yield estimates could be improved by combining remotely sensed data with growth models. The objective of this study was to determine a relationship between leaf area index (LAI) and the Normalized Difference Vegetation Index (NDVI) generated from SPOT 4&5 images, and to establish whether there is a benefit in using remotely estimated LAI instead of simulated LAI to estimate yield. A strong relationship between LAI and NDVI was obtained using an exponential function (R^2=0.86). A time series of 12 Spot images was used to produce NDVI profiles for each field. Gaps between dates were filled by fitting an empirical curve. LAI was estimated at a daily time step from the NDVI curve. The growth model Mosicas was forced using the estimated LAI. Actual yields were compared with yields simulated with and without LAI forcing. The coefficient of determination results indicate that R^2 between observed and simulated yields is equal to 0.42 and 0.66 for simulation without forcing and for simulation with LAI forcing, respectively. The root mean square error of 19.3 t/ha without LAI forcing decreased to 12.8 t/ha using LAI forcing.

Introduction

Remote sensing tools can provide information about vegetation in various wavelengths: the solar spectrum (Guyot, 1996), the active and passive microwave (for example, for radar: Prévot *et al.*, 1993) and the thermal range (Moran *et al.*, 1994). It appears that remotely sensed measurements can be related to instantaneous values of various canopy variables.

Rudorff and Batista (1990) showed that yield estimations by Landsat MSS data (linear model with vegetation index) based only on one date or only on agro-meteorological data were less accurate than those based on the combined agro-meteorological-spectral model. The combined model consisted of a multiple linear regression integrating vegetation index and simulated yield, with a standard error ranging between 10 and 14 t/ha for a mean yield of 75 t/ha.

The objective of this study was (1) to establish the relationship between the LAI of sugarcane and its radiometric response formalized by the NDVI, and (2) to establish whether yield estimations from a growth model could be improved by using these data.

Methodology

Several pre-processing steps were needed to use 12 Spot 4&5 multispectral images, ten metre resolution including: ortho-rectification, topographic normalization, numerical count to reflectance values, and finally, inter-calibration of the various sensors. This method involved establishing the relation between the LAI and corresponding NDVI values. NDVI values were calculated using the following equation according to Rouse *et al.* (1974):

$$\mathrm{NDVI} = \frac{(\mathrm{PIR} - \mathrm{R})}{(\mathrm{PIR} + \mathrm{R})}$$

where PIR and R are reflectance recorded by Spot 4&5 satellites in the near infra-red and red part of the solar spectrum, respectively. The relationship between LAI and NDVI was established by comparing 65 ground measurements of LAI with corresponding NDVI values. Each LAI observation was a field mean of three or four 20 m by 20 m sample areas within the field. Thirty LAI2000 measurements were taken on a diagonal line within each sample area.

A NDVI curve was fitted to 12 NDVI data points for each field by the square difference sum method with the R package used to fill gaps between dates. The resulting daily NDVI values were then used to estimate daily LAI values. These values were used as inputs for the Mosicas agro meteorological mechanistic growth model (Martiné, 2003).

Mosicas was used to simulate the final sugarcane yield obtained on 29 sugarcane fields, for both methods namely with and without LAI forcing (updating of LAI variable of the model derived from remote sensing). These fields were selected due to the availability of final NDVI and yield data and SPOT 4&5 images that were not restricted by cloud cover. The range of the field size is from 1.3 to 11 ha with a mean equal to 4.5 ha. The measured yields are from the mill records of sugarcane delivery for each field.

Results

Figure 1 shows the relationship between the NDVI calculated from Spot 4&5 reflectance and ground measured LAI.

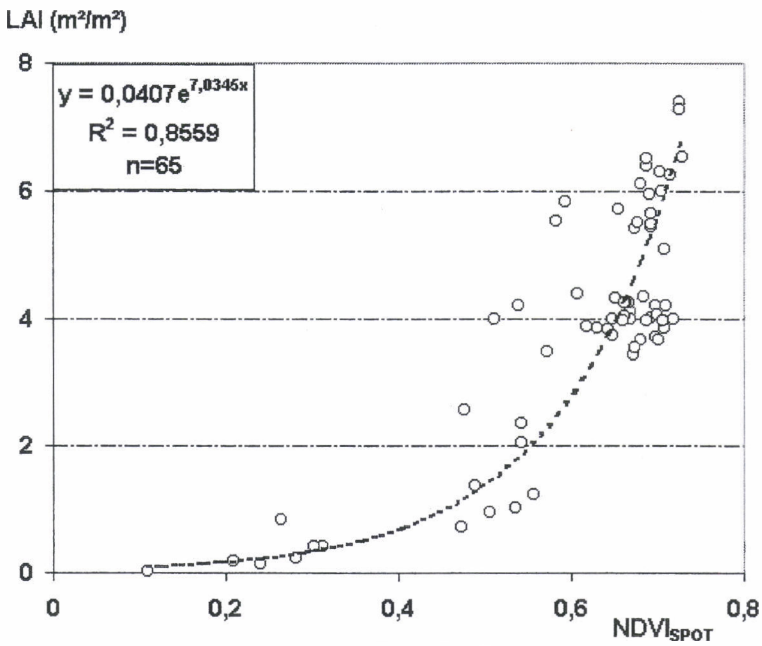

Fig. 1 – Relationship between sugarcane Leaf Area Index (LAI) and SPOT (Satellite Pour l'Observation de la Terre) Normalized Difference Vegetation Index (NDVI).

The coefficient of determination was equal to 0.86 and was significant at $P<0.001$ ($n=65$). The relationship is described by an exponential function with the following formula:

$$LAI = 0.0407 \times EXP(7.0345 \times NDVI_{SPOT})$$

Figure 2 shows an example of the fitted NDVI curve obtained for a field. A logistic equation gave the best fit.

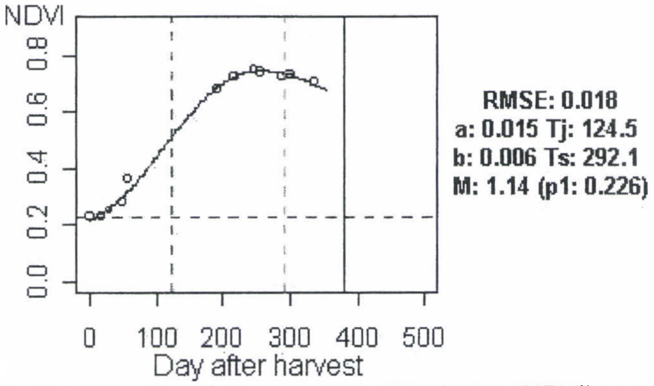

Fig. 2 – Empirically fitted Normalized Difference Vegetation Index (NDVI) curve and NDVI data points for a field grown in the 2002-2003 season.

Yields estimated with and without the LAI forcing strategy are compared with measured yields. Results are presented in Figure 3.

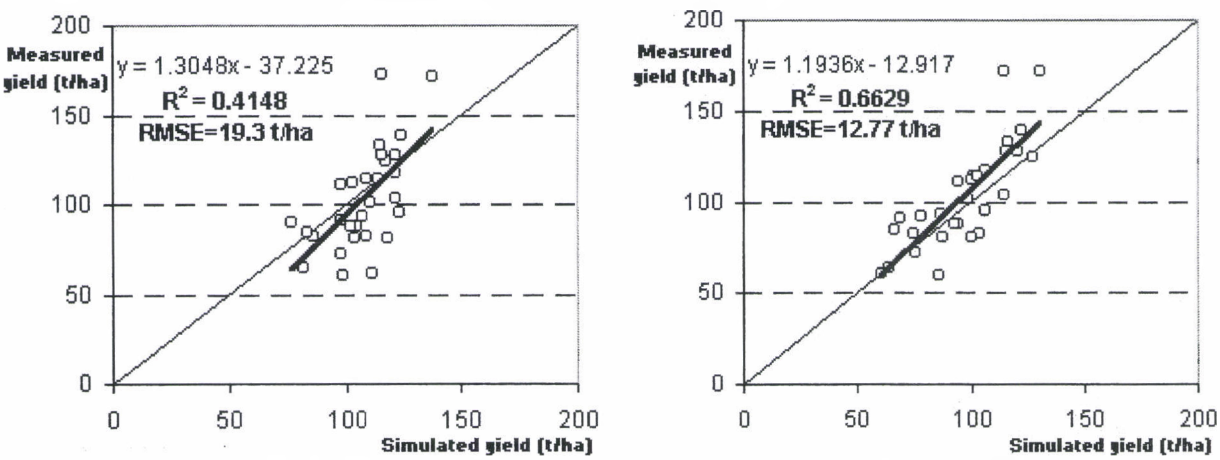

Fig. 3 – Comparison of Mosicas (agro meteorological mechanistic growth model) simulated to observed sugarcane yield with and without leaf area index (LAI) forcing.

The root mean square error of 19.3 t/ha for simulations without forcing decreased to 12.8 t/ha for simulations with LAI forcing (Figure 3). Moreover, the coefficient of determination increased considerably to reach the value of 0.67 with LAI forcing compared to 0.42 without LAI forcing.

Conclusion

A strong relationship was established between sugarcane LAI and the NDVI generated from SPOT 4&5 data. In addition, we could calculate the adjusted NDVI for each field, necessary for obtaining the NDVI values at a daily time step. The root mean square error obtained between the observed NDVI and the NDVI logistic functions was at maximum equal to 0.03 for a mean NDVI of 0.45. Finally, sugarcane yield estimated using growth models like Mosicas could be improved significantly by forcing the model with LAI values estimated from NDVI data from SPOT data. Our research turns to the study of the relationship which can exist between the maximum of NDVI and the final yields of sugarcane. If the relationship between the maximum of NDVI and the final yields is significant, it will be possible to estimate final yields only from the radiometric SPOT data, using fewer images.

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National d'Etudes Spatiales) for scientific and R&D studies, on "La Réunion" island. http://medias.obs-mip.fr/isle_reunion/

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