

RELATIONSHIP BETWEEN NDVI- MODIS/TERRA AND WATER BALANCE COMPONENTS FOR SOYBEAN CROP, BRAZIL

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Abstract: This study aims to evaluate the response of the *Normalized Difference Vegetation Index* - NDVI (satellite TERRA, sensor MODIS) of soybean to water balance components, in a region of Parana state, southern Brazil. Landsat TM 5 and 7 images were selected for analyzing the soybean spatial distribution in the region from 2000/01 to 2006/07 and to identify soybean fields. Based on the soybean maps obtained with Landsat TM images, pixel samples (250 x 250m) containing only soybean fields (“pure-pixels”) were identified. Data from nearby meteorological stations were obtained and used to calculate the soil water balance for soybean fields in 5 locations distributed in this region. The water balance was calculated for each year, and for the entire soybean growing season. Linear regression models were adjusted between NDVI and mean air temperature; rainfall and each one of the soil water balance output variables (*i.e.*, potential and actual evapotranspiration, soil moisture storage, water deficit and water excess). The water balance variables that showed best association with NDVI values were actual evapotranspiration (AE) and soil moisture storage (SMS), when each site was analyzed for the entire study period.

Key words: soybean (*Glycine Max L. Merr*), NDVI, remote sensing, water balance.

Introduction

Soil moisture is the key parameter in the physiological processes of the soil-crop-atmosphere system (Sarma and Kumar, 2006). The use of water balance model has several applications, such as: estimation of global water balance; development of climate classifications; estimation of soil moisture storage; runoff and irrigation demand. Specifically for soybean crop, water balance models can help identify the occurrence of drought stress, especially during critical stages, such as, early reproductive growth - flowering and pod development (Allen *et al.*, 1998). However, efforts have been applied on practical applications of soil moisture estimates in crop yield models for monitoring crop conditions and yield prospects over large areas. Because the chlorophyll status integrates the effects of environmental factors, NDVI has been related to the components of the water balance equation for a wide range of spatial and temporal scales: soil moisture, precipitation and evaporation (Szilagyi *et al.*, 2000). The objective of this study was to evaluate the relationship between NDVI (derived from MODIS sensor) response to soil water balance components, during the entire soybean crop season for the period 2000-2007, State of Parana, Brazil.

2. Material and Methods

This region located in southern Brazil, limited geographically by the coordinates 23°45'00''; 25°50'00''South and 49°10'00''; 51°25'00''West. Agriculture is the principal land use in the region and the three main crops are soybean, maize and dry bean. Soybean cycle lasts 110 days in average and the harvest occurs between March and April in the following year. Meteorological data between 2000 and 2007 were collected from the Parana Meteorological System (SIMEPAR). Mean air temperature (°C) and rainfall (mm) data on a daily scale from five meteorological stations were used in this study: *i) Candido de Abreu* (-24.63; -51.25; 645m); *ii) Cerro Azul* (-24.81; -49.25; 66m); *iii) Jaguariaiva* (-24.22; -49.67; 900m); *iv) Ponta Grossa* (-25.21; -50.01; 885m); *v) Telemaco Borba* (-24.33; -50.62; 768m). The mapping of soybean areas was performed by analyzing 12 Landsat images using the following steps. First, ENVI 4.2 software was used to georeference the images. A mixture model described by Shimabukuro and Smith, (1991) was used to represent sample targets of green vegetation (soybeans in this case), soil, and shade. The next step consisted of using a segmentation approach of growing “regions”, where a “region” is a set of homogeneous pixels grouped according to their spectral and spatial properties. An unsupervised classification based on a ‘clustering’ algorithm, named ISOSEG was applied to the segmented image. In order to correct errors resulting from the digital classification described above, a thorough visual classification was performed in all images. At the end of all of these steps, one soybean field map was generated for each one of the seven years (2000-2007). A direct expansion estimator and a semi-automated procedure as suggested by Adami *et al.* (2007) were used to generate a grid with regular pixel size of 250m by 250m. Finally, different samples of NDVI were obtained from the Terra MODIS sensor (MOD13Q1 product version 5, 16-day image composite) in the region representing “pure-pixels” of soybean, *i.e.* pixels with soybean crops only (identified using Landsat images as described above). The pixels were extracted using the IRI Data Library (*International Research Institute for Climate and Society*) for the 2000 – 2007 period.

The water balance model applied in this study is based on the methodology presented by Thornthwaite and Mather (1955). Thornthwaite (1948) developed a method to estimate Potential Evapotranspiration (PE or ETo), using air temperature as the main parameter which was also used in this study. A crop coefficient (Kc) was used to transform grass ETo into crop potential evapotranspiration (ETc), which is a function of phenological phases, crop species and variety, plant architecture and leaf area. In our research we used the soybean Kc values proposed by Allen *et al.* (1998). The main soil types for these locations are: *Alfisol* (Candido de Abreu and Cerro Azul) and *Oxisol* (Ponta Grossa, Jaguariaiva and Telemaco Borba). Soybean water balance was performed at daily time steps for each location and each year (2000-2007). Mid-November was adopted as the main sowing date for this region. Outputs of potential evapotranspiration (PE), actual evapotranspiration (AE), soil water holding capacity (SWHC), soil moisture storage (SMS), water deficit (DEF) and water excess (EXC) were thus obtained on a daily time step. However, it was necessary to aggregate the above outputs to 16 day means in order to compare them with the MODIS NDVI data.

Results

Simple regressions between NDVI and the water balance output variables were adjusted for all time series (2000-2007) for each location (Table 1). Actual Evapotranspiration was the single water balance variable

that showed the best association with NDVI values than the regressions with any of the other individual soil water balance output variables (air temperature, rainfall, potential evapotranspiration, excess and deficit water).

Table 1. Regression Analysis between NDVI and i) actual evapotranspiration; ii) rainfall, for all time series (2000-2007) and for each location.

Actual Evapotranspiration			Rainfall				
	R ²	a	x1 (Actual Evapotranspiration)		R ²	a	x1 (Rainfall)
Candido de Abreu	0.53	0.43	0.14	Candido de Abreu	0.07	0.63	0.0010
Cerro Azul	0.38	0.44	0.12	Cerro Azul	0.12	0.60	0.0012
Jaguariaiva	0.41	0.42	0.13	Jaguariaiva	0.04	0.62	0.0009
Ponta Grossa	0.48	0.34	0.18	Ponta Grossa	0.02	0.63	0.0008
Telemaco Borba	0.59	0.35	0.18	Telemaco Borba	0.03	0.63	0.0008

Note: all regression coefficients are significant at P < .001

Since Actual Evapotranspiration integrates information on soil water availability, air temperature and humidity, it is reasonable that its values are better related to NDVI response than rainfall or any of the other water balance variables. So, based on this consideration above, simple regressions between NDVI and soil moisture storage (SMS) during soybean growing season were made. Figure 1 shows a correspondence between SMS and NDVI variation of up to 60% (Telemaco Borba location). This is of importance for studies that involve crop modeling and water balance. Figure 2 shows NDVI curve in association with rainfall, AE and SMS for Ponta Grossa.

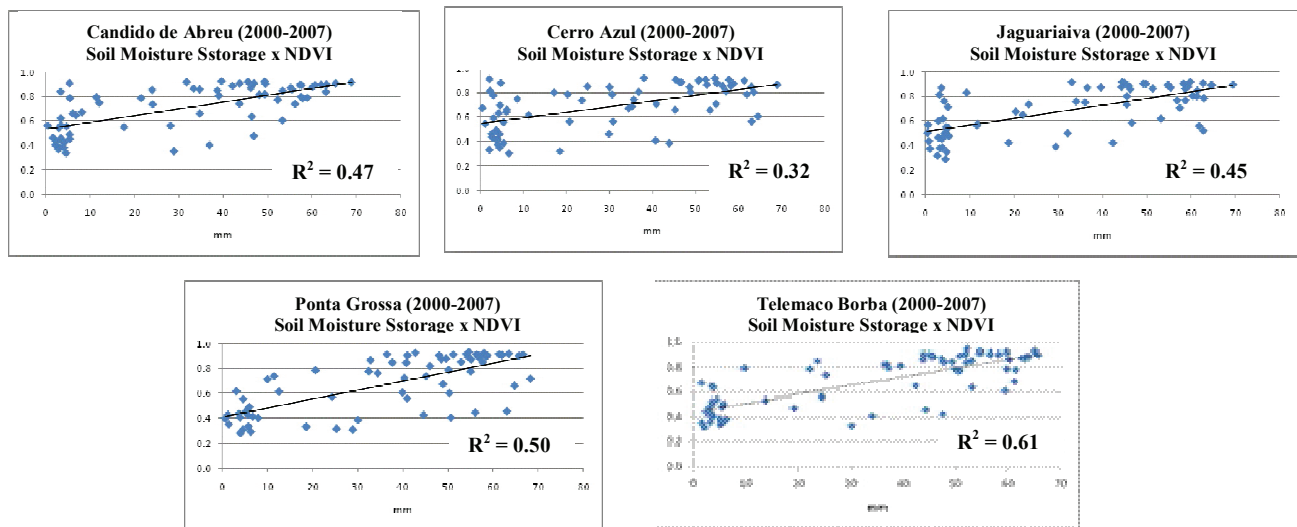


Figure 1. Linear regressions for all time series (2000-2007) between NDVI and Soil Moisture Storage, for each location.

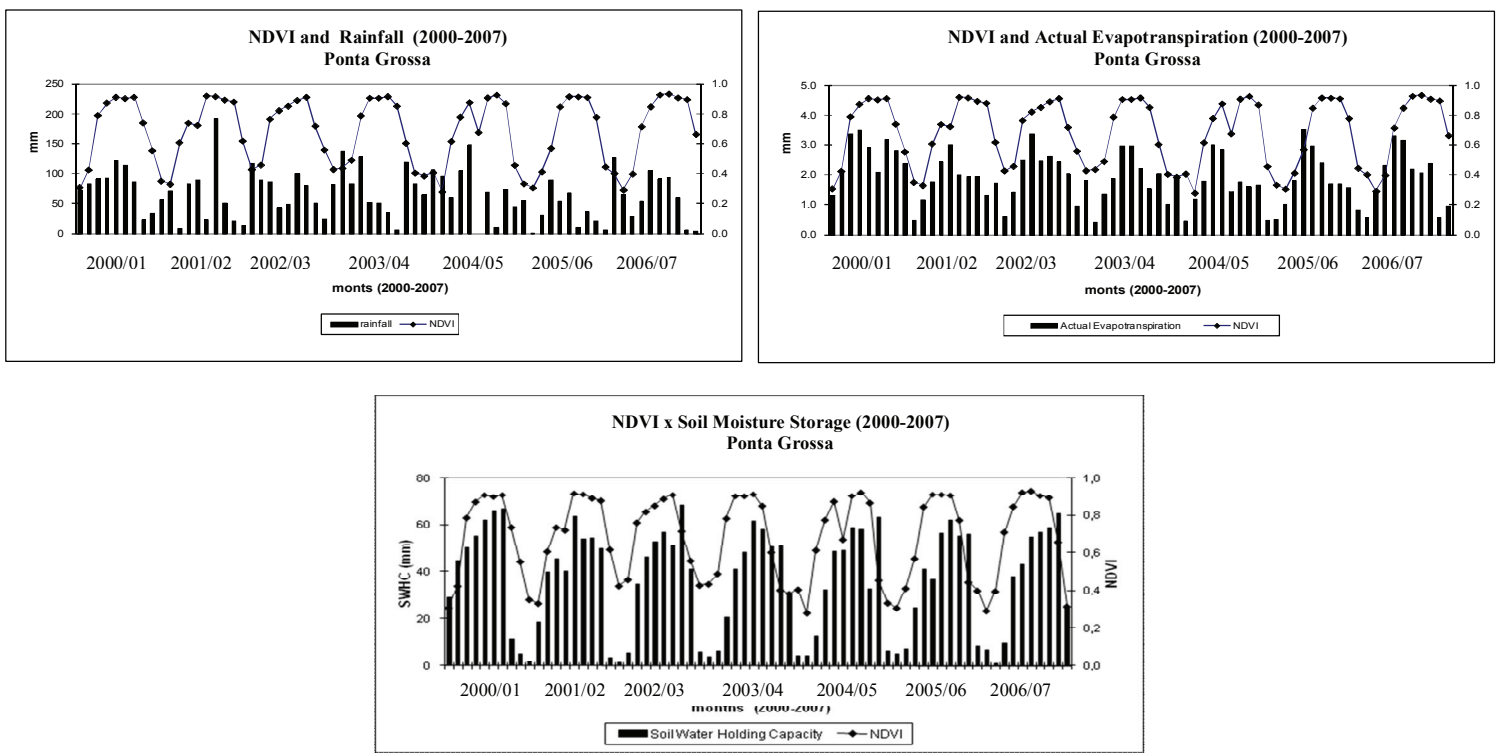


Figure 2. NDVI and *i)* rainfall, *ii)* actual evapotranspiration and *iii)* Soil Moisture Storage e, for Ponta Grossa Location (2000-2007).

Conclusions

The single water balance variable Actual Evapotranspiration (AE) and Soil Moisture Storage (SMS) showed good agreement with soybean NDVI derived from the MODIS-Terra Satellite in Parana, Brazil. These results suggest that AE, SMS and NDVI can be used for crop monitoring and crop yield forecast studies.

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