

NDVI (MODIS SENSOR) RESPONSE TO INTERANNUAL VARIABILITY OF RAINFALL AND EVAPOTRANSPIRATION IN A SOYBEAN PRODUCING REGION, SOUTHERN BRAZIL

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ABSTRACT:

This study aimed at evaluating the response of the *Normalized Difference Vegetation Index* - NDVI (MODIS sensor, TERRA satellite) of soybean to interannual variability of rainfall and evapotranspiration in Campos Gerais, a region of the state of Parana in southern Brazil. Landsat TM 5 and 7 images were selected for analyzing the spatial soybean field distribution for the region from 2000/01 to 2006/07 and to identify soybean fields. We then identified 175 pixels (250 x 250m) that contained only soybean fields ("pure-pixels") based on the soybean maps obtained with the Landsat TM images. The next step was to extract the NDVI values for these soybean pure-pixels and to analyze the NDVI spectral curves considering the soybean phenology. Data from nearby meteorological stations were obtained and used to calculate the soil water balance for soybean fields in 5 locations distributed in the Campos Gerais region. To obtain actual evapotranspiration values, the water balance was calculated for each year, and for the same period covering the entire soybean growing season. Anomaly values were calculated for each year to verify the interannual rainfall variability. Linear regression models were adjusted between NDVI and i) rainfall and ii) actual evapotranspiration for all time series. Analysis of the evolution of NDVI values allowed identifying the soybean growing season (November to March) and also the dry season for this region according to rainfall anomaly values. Statistical analyses showed that actual evapotranspiration presented best agreement with soybean NDVI in relation to rainfall, probably due to the fact that this variable integrates information of rainfall, temperature and soil water holding capacity for the entire study period.

1 INTRODUCTION

Crops can suffer damage from excess or lack rainfall and investigate this variability in its frequency of occurrence over a crop season becomes essential for agricultural planning systems. Several studies have been made about early warning systems, based on seasonal and interannual climate forecasts (Guillevic, *et al.*, 2002; Nobre *et al.*, 2006; Meinke and Stone, 2005; Ogallo *et al.*, 2008). An objective evaluation system of weather variability as well as the improvement of crop monitoring capabilities for yield prediction can provide knowledge to mitigate weather impacts. Climatic variability plays a major role in promoting meteorological conditions that deviate substantially from mean conditions, including weather extreme events (Seiler *et al.*, 2007). Crop growth, development and yield are affected by climatic variability via linear and nonlinear responses to weather variables (Semenov and Porter, 1995). According to Baethgen (1997) agricultural systems which are currently subject to extreme climatic interannual variability (drought, flood, storms, etc.) are likely to become even more vulnerable under the most commonly expected scenarios of climate change (i.e. increased temperatures, increased rainfall variability). Evapotranspiration (ET) is an essential component of the energy and water budgets in grassland and agricultural ecosystems (Allen *et al.*, 1998) and understanding the processes that affect ET at different temporal scales and under a variety of environmental conditions is important in crop modeling production. In general, remote sensing techniques can not measure evaporation or evapotranspiration directly. However, Engman (1995) mentions that remote sensing does have two potentially very important roles in

estimating evapotranspiration: *i*) to try establish a empirical relationships between remote sensing data and ET to larger areas, including those areas where measured meteorological data may be sparse; and *ii*) remotely sensed measurements may be used to measure variables in the energy and moisture balance models of ET (Bastiaanssen, 2000). Tucker *et al.*, (2001) report that the use of decadal NDVI time series has improved the study of interannual variation in vegetation. Currently, Suzuki *et al.* (2007) examined interannual NDVI data and its relation to ET in northern Asia and significant positive correlations were found between NDVI and ET anomaly interannual variation over vegetated areas. The objective of this study was to evaluate NDVI response to interannual variability of rainfall and evapotranspiration during the entire soybean season for the period 2000-2007 in Campos Gerais region, Southern Brazil.

2. STUDY AREA AND DATA

2.1 Study area

Campos Gerais is a 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. The highest yields for a short duration soybean cultivar are obtained when planted in October and November and in the southern part of this region, many farmers usually start planting in mid-October (Heinemann *et al.* 2002). Soybean cycle lasts 110 days in average and the harvest occurs

between March and April in the following year. According to IAPAR (2000) the climate in this region is subtropical humid meso-thermic, with warm summers (Dec–Mar).

2.2 Meteorological data

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) Jaguariava* (-24.22; -49.67; 900m); *iv) Ponta Grossa* (-25.21; -50.01; 885m); *v) Telemaco Borba* (-24.33; -50.62; 768m).

2.3 Remote Sensing information

2.3.1. Landsat TM images

Twelve images from Landsat 5 and 7, Thematic Mapper –TM sensor were used to identify soybean fields during the time period 2000 to 2007. Landsat scenes were provided by INPE (*National Institute for Space Research – Brazil*) covering the Campos Gerais region. Two phenological stages are important to identify soybean crops in the Campos Gerais region: *i) November* and *ii) February*. In November, during sowing and seedling emergence, there is a strong spectral response from the soil, while in January/February (around grain maturation) the main response is from the crop chlorophyll activity (Rizzi and Rudorff, 2005; Wagner *et al.*, 2007). These authors emphasize that during January to March, the soybean crop is at full growth and covers the soil. In these conditions, soybean crops are well characterized in the images, standing out from other land uses such as bare soil or vegetation having different phenology.

2.3.2 MODIS 250m NDVI composites

This study used multi-temporal values of the Normalized Difference Vegetation Index (NDVI) obtained from the MODIS-TERRA sensor (MOD13Q1 product version 5, 16-day image composite). NDVI values for different samples in Campos Gerais representing “pure-pixels” of soybean, i.e., pixels with soybean crops only (identified using Landsat images as described above) were extracted using the IRI Data Library (<http://portal.iri.columbia.edu/portal/server.pt>), for the period 2000 - 2007.

3. METHODOLOGY

3.1 Soybean field mapping

The mapping of soybean areas was performed by analyzing the 12 Landsat images using the following steps. First, ENVI 4.2 software was used to geo-reference the images presented based on RGB color composites (using channels 4, 5 and 3 respectively). Then, 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. This analysis was conducted using SPRING, a Geographical Information System developed by INPE which operates using Microsoft Office Access data base. The method is based on the constrained least squares method and spectral signatures collected directly from Landsat TM images. This procedure was performed interactively until verifying that the component signatures were adequate representations of mixture components for the analyzed area

Fifty-pixel samples were chosen for the test, as described in the procedure described by Rizzi and Rudorff (2005). 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 (Bins *et al.* 1996), was applied to the segmented image. An acceptance threshold was defined (using maximum Mahalanobis distance method) to classify digital numbers of regions based on their closeness to the mean of the class (in this case, soybean gray levels). It differs from Euclidean distance in that it takes into account the correlations of the data set and it doesn’t depend on the scale of measurements. A thematic map containing ‘soybean’ and ‘non-soybean’ areas resulted from this step. In order to correct errors resulting from the digital classification described above, a thorough visual classification was performed in all images. Google Earth images at high spatial resolution were used as ancillary information to check the soybean fields. The Kappa index was computed to check map accuracy. At the end of all of these steps, one soybean field map was generated for each one of the seven years (2000-2007). A methodology was applied in order to construct a sampling frame and to allocate regular pixels to the soybean fields. A direct expansion estimator and a semi-automated procedure as suggested by Adami *et al.* (2007) were used to generate a grid with regular pixels of 250m by 250m. Each pixel was assigned an identification number. This grid spatial resolution was adopted to match soybean pure-pixels with the NDVI-MODIS pixel size.

3.2 Soybean pure-pixel coordinates collection

From each soybean field map and for each year, the coordinates of several soybean pure-pixels were extracted. In addition, the soybean pure-pixels closest to the 5 meteorological stations were selected for further analysis. This process was needed to perform the water balance from the meteorological data and compare it with the NDVI. Five pure-pixels on the soybean field maps were chosen for each location and for each year, totaling 175 pure-pixel samples.

3.3 NDVI data acquisition and processing

NDVI values were extracted for the same 175 pure-pixels collected in the step described above. Then, NDVI means were calculated for each location and for each year.

3.4 Rainfall anomalies and Linear Regressions analyses

In order to verify the rainfall interannual variation during soybean growing season, anomaly values were calculated for each year separately, from 2000 to 2007. In addition, NDVI curves and amount of rainfall (mm) were plotted together to verify the correspondent variations. However, to investigate the relationship between NDVI, rainfall and actual evapotranspiration for the entire study period (2000-2007), regression analyses for each location were made.

3.5 Water Balance Methodology

The water balance model applied in this study was 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, Jaguariaíva and Telemaco Borba). Soybean water balance was performed at daily time steps for each location and each year (2000-2007). The water balance was also adjusted according to soybean phenology. November 15th was adopted as the main sowing date in this region (Geosafra, 2007). Outputs of potential evapotranspiration (PE), actual evapotranspiration (AE), soil moisture storage (SME), water deficit (DEF) and water excess (EXC) were thus obtained on a daily time step. However, in this study, only actual evapotranspiration was considered and it was necessary to aggregate the above outputs to 16-day means in order to compare them with the MODIS NDVI data.

4. RESULTS

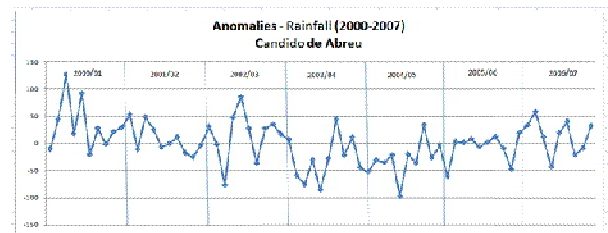
4.1 Rainfall anomalies

Figure 1 contains rainfall anomalies for each location and year from 2000 to 2007. Although state of Parana generally has a seasonal pattern of precipitation, such as, rainy summer and dry winter, it is important to point out the significant rainfall variation for all time series and for each year separately. Due to its location in Southern Brazil, this state is influenced by several macro-climatic factors, such as, migration of air equatorial and tropical masses from Atlantic in summer months; cold air masses (polar front) that come from the South of the continent, (Wrege *et al.*, 1999), and dry air masses from Midwest Brazil, which can bring warm and relative dry weather. So, all this condition leads to high rainfall variability, in terms of amount of rainfall (millimeters) and number of rainy days (frequency). This weather variability influences the agriculture in this region, thus affecting crop productivity. Rainfall anomalies revealed occurrence of drought episodes from 2000 to 2007, but more significantly during 2004/05 year in Candido de Abreu, Cerro Azul and Ponta Grossa locations. This situation was reported by CONAB (2005) which mention a 7.1% yield loss in relation to the previous year yields, in the state of Parana.

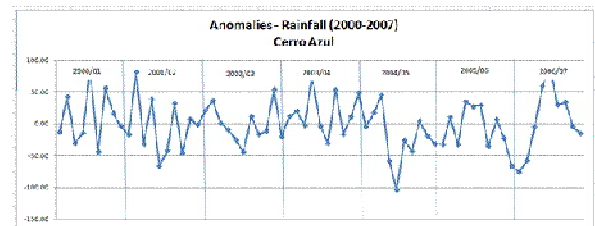
4.2 NDVI temporal analysis

The different phenological stages of soybeans were identified with the NDVI temporal series from 2000 to 2007 for each location (Figure 2). Growth starts around mid November when soybean is planted and the cycle ends in March when the soybean is harvested. A similar pattern was observed for all years and locations indicating that the pixels selected for the analysis were indeed soybean pure-pixels. In 2004/2005 a drop in NDVI values was observed in three locations, according to rainfall anomaly values for Candido de Abreu, Cerro Azul and Ponta Grossa (Figure 1). Rainfall occurrence was low in January and mid February, which coincides with the peak of the reproductive stage of soybean in the study region. Actual evapotranspiration curves presented high values in December, January and mid-February, specially during soybean flowering and grain formation phases and it seems that NDVI response tends to follow this more realistic situation, in terms of biophysical condition, than rainfall occurrence.

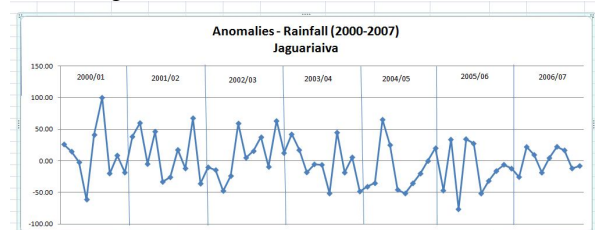
i) Candido de Abreu



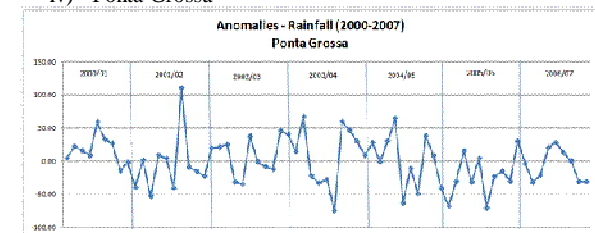
ii) Cerro Azul



iii) Jaguariaíva



iv) Ponta Grossa



v) Telemaco Borba

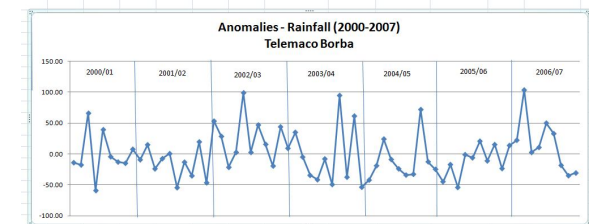
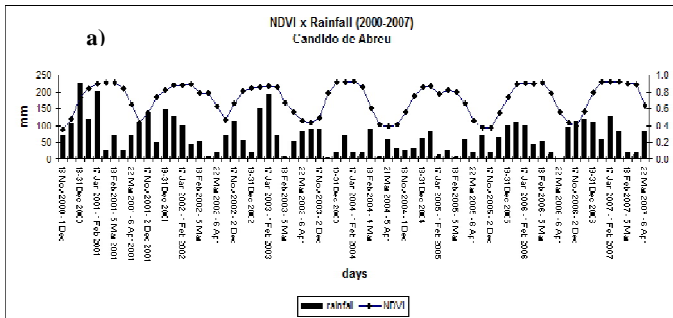


Figure 1. Rainfall anomalies for each year (2000-2007), during soybean growing season and for locations: *i)* Candido de Abreu; *ii)* Cerro Azul; *iii)* Jaguariaíva; *iv)* Ponta Grossa; *v)* Telemaco Borba.

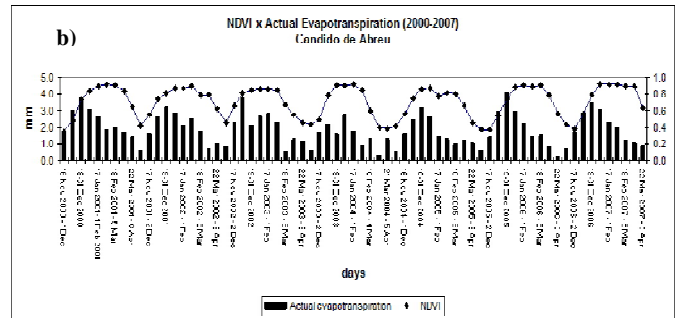
4.3 Linear regression analyses for all time series

Analyses indicated that the simple regression of NDVI with Actual Evapotranspiration (AE) showed much higher R^2 values than the regressions of NDVI in relation to rainfall (Figure 3). Despite this observed decrease in NDVI values during the Jan-Feb 2005 rainfall deficit period, we found better agreement between NDVI and AE. May be due to the

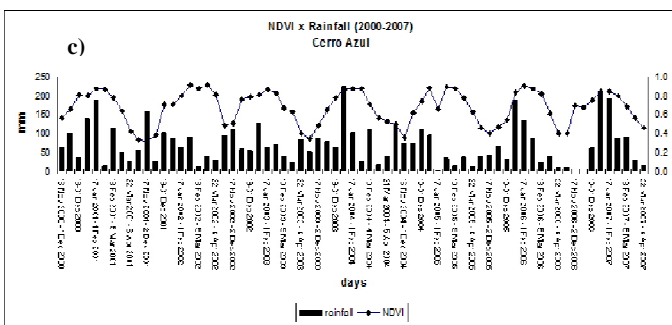
a) Rainfall and NDVI (Candido de Abreu- location 1)



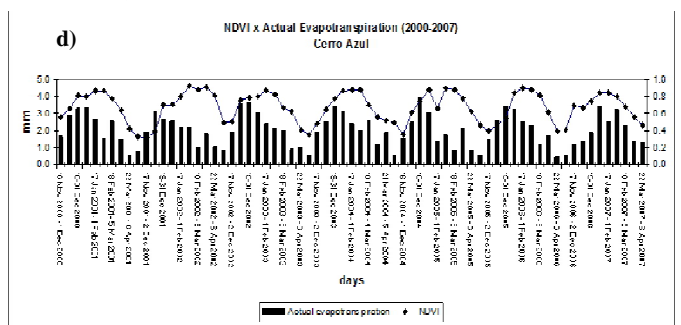
b) Actual Evapotranspiration and NDVI (Candido de Abreu- location 1)



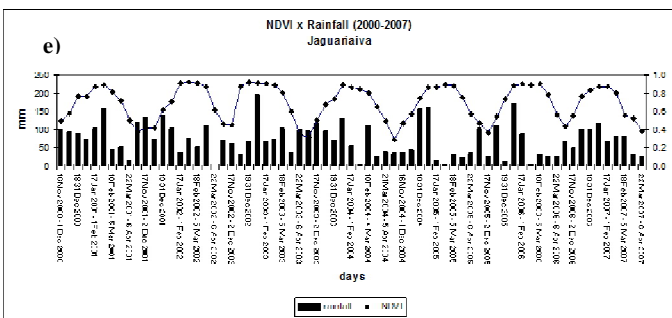
c) Rainfall and NDVI (Cerro Azul – location 2)



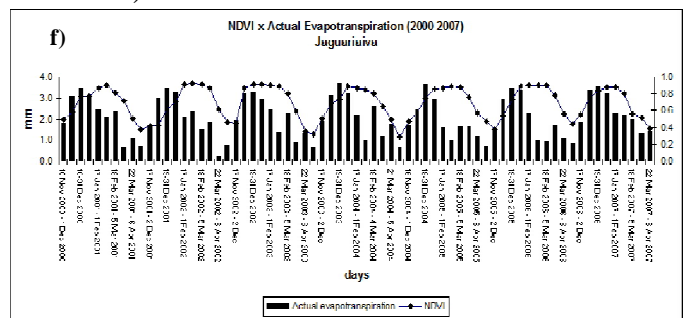
d) Actual Evapotranspiration and NDVI (Cerro Azul – location 2)



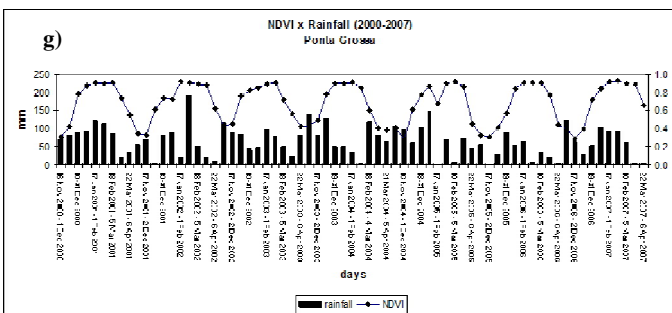
e) Rainfall and NDVI (Jaguariaiva – location 3)



f) Actual Evapotranspiration and NDVI (Jaguariaiva – location 3)



g) Rainfall and NDVI (Ponta Grossa – location 4)



h) Actual Evapotranspiration and NDVI (Ponta Grossa – location 4)

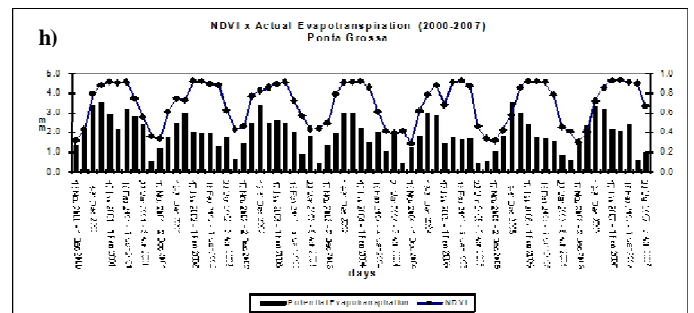
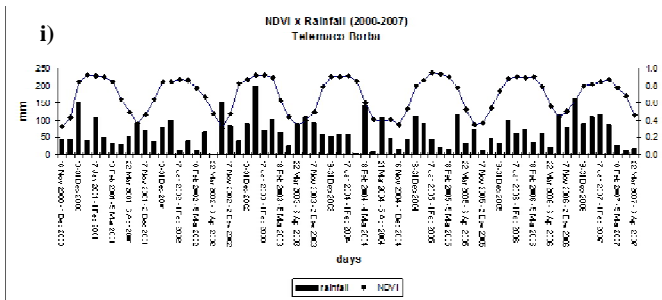


Figure 1 - Continued

i) Rainfall and NDVI (Telemaco Borba – location 5)



j) Actual Evapotranspiration and NDVI (Telemaco Borba – location 5)

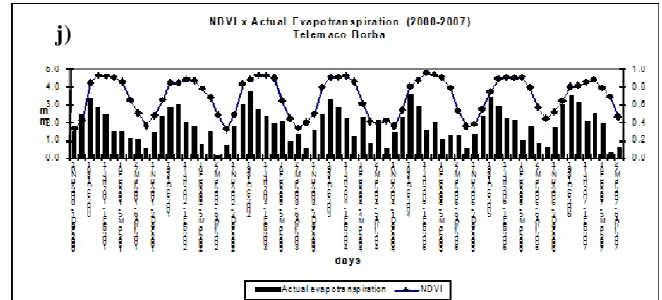


Figure 2. Interannual variation (2000-2007) for NDVI and Rainfall: *a), c), e), g), i)* and for NDVI and Actual Evapotranspiration: *b), d), f), h) and j).*

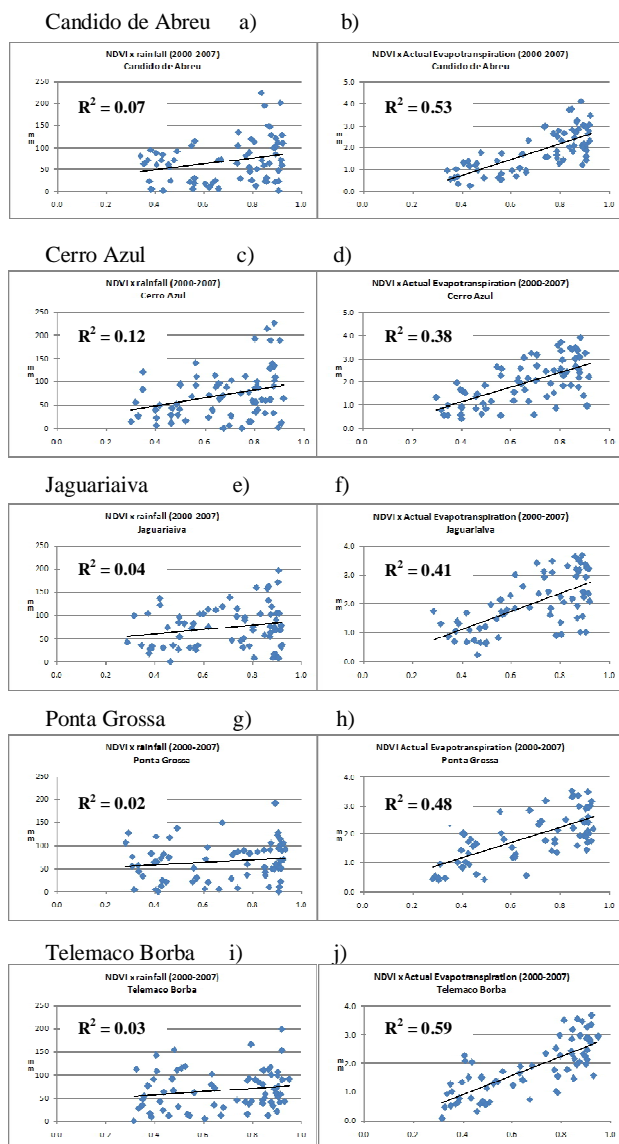


Figure 3. Linear regressions for all time series (2000-2007) between NDVI and rainfall: *a), c), e), g), i)* and for NDVI and Actual Evapotranspiration: *b), d), f), h), and j).*

fact that when the rainfall reaches the land surface, part of the water is diverted as runoff, and part infiltrates and is retained in the upper layers of the soil which is thereafter used for vegetation growth. The vegetation then absorbs the soil water and uses it through the process of evapotranspiration (Sarma and Lakshmi, 2006). Cihlar *et al* (1991) found similar results for the relation between NDVI values from NOAA/AVHRR and Evapotranspiration for different ecosystems. They reported that there was a highly significant association between NDVI and Actual Evapotranspiration values ($r=0.77$) or between NDVI and potential evapotranspiration ($r=0.86$). High correlation was also found between cumulative NDVI and cumulative Actual Evapotranspiration over the entire growing season ($r=0.96$).

5 CONCLUSIONS

Results from the analysis showed that the seasonal and interannual variability of the vegetation index (NDVI) serves as a good indicator for identifying variations, mainly impacts of climate anomalies on vegetation and, consequently, on crops production (in this case, soybean crop). NDVI curves were able to differentiate vegetation responses associated with above and below precipitation during soybean growing season. Actual Evapotranspiration (AE) showed best agreement with soybean NDVI in relation to rainfall, probably due to the fact that this variable integrates information of rainfall, temperature and soil water holding capacity.

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