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Seasonal Variability of Vegetation and Its Relationship to Rainfall and Fire in the Brazilian Tropical Savanna

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1. Introduction

The Brazilian savanna, named locally Cerrado, is the second largest Brazilian biome, covering approximately two million km^2, especially in the Central Highlands (Ratter *et al.*, 1997). This biome is composed predominantly of tropical savanna vegetation and is considered as one of the world's biodiversity hotspots, a priority area for biodiversity conservation in the world (Myers et al., 2000). The Cerrado region is considered the last agricultural frontier in the world (Borlaug, 2002), which has been converted in the last 50 years especially for agriculture and pasture purposes, where natural and mainly anthropogenic annual burning is a common practice. Currently, around 50% of natural vegetation in the Cerrado region has been converted to pastures and crops (PROBIO-MMA, 2007).This conversion has impacted the biological diversity, the hydrological cycle, the energy balance, the climate and the carbon dynamics at local and regional scales due to habitat fragmentation, invasive alien species, soil erosion, pollution of aquifers, degradation of ecosystems and changes in fire regimes (Klink & Machado, 2005; Aquino & Miranda, 2008). The knowledge of spatial distribution, temporal dynamics and biophysical characteristics of the vegetation types, are important elements to improve the understanding of what is the interaction like between vegetation, precipitation and fire.

The objective of this study is to determine the relationship of environmental variables, such as precipitation and fire, with spatial and temporal distribution patterns of main vegetation type of the Brazilian tropical savanna. Thus, we seek to answer the question: how environmental variables, like rain and fire, influence the main vegetation types, like herbaceous, shrubs, deciduous trees and evergreen trees, in the Cerrado biome taking in account the seasonal patterns of the variables involved?

In this study, the potential of multi-temporal satellite data, like TRMM data for precipitation, MODIS vegetation indices products for land cover mapping, and others sensors like GOES and MODIS for fire detection is explored by the use of remote sensing and geographic information systems (GIS) techniques.

1.1 Seasonality of Cerrado vegetation

Phenological parameters of vegetation, such as start and end of the growing season, are strongly influenced by atmospheric conditions (like precipitation, temperature and humidity) at different time scales (intrannual, inter-annual, interdecadal, and so on). Atmospheric conditions at intrannual scale influence the main phenological events that the plant experiences during the annual cycle of growth (Reed et al. 1994). At greater time scales, climate influence on the spatial and temporal distribution of vegetation (Schwartz, 1994). On the other hand, the vegetation influence atmosphere while maintaining or modifying the flows of matter and energy, albedo, roughness, CO_2, which in turn affect the regional and/or global climate.

Savanna ecosystems that cover approximately 20% of the global land surface have mechanisms that control the flow of matter and energy in tropical savannas. These ecosystems are not well understood, which has hindered the inclusion of this biome in studies of regional and global modeling (Law et al., 2006).

1.2 Climate and precipitation regime

Climate patterns from intra-seasonal to decadal and century scales directly influence the timing, magnitude (productivity), and spatial patterns of vegetation growth cycles, or phenology (Reed et al., 1994; Schwartz, 1994).

The Savanna biome has a wet/dry climate. Its Köppen climate group is **Aw**. The ***A*** stands for a tropical climate, and the ***w*** for a dry season in the winter and the rainy season in the summer. During the dry season of a savanna, most of the plants shrivel up and die. Some rivers and streams dry up (Parker, 2000; Ritter, 2006). In the wet season all of the plants are lush and the rivers flow freely. The temperature of the savanna climate ranges from 20° to 30° C. In the winter, it is usually about 20° to 25° C. In summer the temperature ranges from 25° to 30° C. The savanna temperature does not change a lot, although when it does, it is very gradual and not drastic.

Because of its latitudinal position, the Brazilian savanna region is characterized by the transition between the warm climates of low latitudes and mesothermal climates of middle latitudes (Nimer, 1989). This region is considered almost homogeneous on the length and location of the dry and rainy periods (Rao & Hada, 1990). However, Castro et al. (1994) show that this region has a certain degree of heterogeneity due to the variation of length in the dry and rainy periods. This heterogeneity is determined by the interaction of atmospheric circulation systems in the lower and upper troposphere over the region. Some of these systems are: The South Atlantic anticyclone also known as South Atlantic Convergence Zone (SACZ), Polar anticyclone and Chaco low. SACZ is one of the main phenomena that determine the rainfall across the region (Satyamurty et al., 1998). In general, rainfall in the region ranges from 1000 to 1500 mm.

The climate of the Cerrado is tropical warm and semi-humid, with just two seasons, a dry one from May to September and a rainy one from October to April. Monthly rainfall in dry season (that include fall and winter) reduces considerably, reaching zero, resulting in a dry period that varies from three to five months duration (Coutinho, 2000). The rainy season (spring and summer) sometimes has short dry periods named locally "*veranicos*". The mean annual temperatures vary between 22 and 27°C and the mean annual precipitations between 600 and 2.200 mm.

1.3 Fire regime and detection

Fire is one of the most important drivers that influence vegetation function and structure. Fire incidence, in a given area or ecosystem, is part of a fire regime which has specific patterns of fire occurrences, frequency, size, severity, and sometimes vegetation and fire effects as well. For example, savanna fires are often of low intensity and high frequency (often annual), while forest fires are often of low frequency (once every few centuries) and very high intensity (Bowman & Murphy, 2010). Most of the wildland fires occur by the combination of edaphic, climatic and human activities (Roy, 2004). Natural fires are generally started by lightning, with a very small percentage started by spontaneous combustion of dry fuel such as sawdust and leaves. This kind of fire is insignificants in comparison to number of fires started by humans (Roy, 2004). Most tropical fires are set intentionally by humans (Bartlett 1955, 1957, 1961) and are related to several main causative agents (Goldammer, 1988): deforestation activities (conversion of natural vegetation to other land uses, e.g. agricultural lands pastures, exploitation of other natural resources); traditional, but expanding slash-and-burn agriculture; grazing land management (fires set by graziers, mainly in savannas and open forests with distinct grass strata); use of non-wood forest products (use of fire to facilitate harvest or improve yield of plants, fruits, and other forest products, predominantly in deciduous and semi-deciduous forests); wildland/residential interface fires (fires from settlements, e.g. from cooking, torches, camp fires etc.); other traditional fire uses (in the wake of religious, ethnic and folk traditions; tribal warfare) and socio-economic and political conflicts over questions of land property and land use rights.

Satellite-borne sensors can detect fires in the visible, thermal and mid-infrared bands. These sensors have been used most extensively for detecting and monitoring fire activity from landscape to global scales (Justice et al., 2003; Diaz-Delgado et al., 2004; Allan et al., 2003; Brandis & Jacobson, 2003; Miller et al. 2003; Rollins et al., 2004; Bowman et al., 2003). Justice et al. (2003) analyzed global remote sensing data and showed that occurrence of landscape fire is not random across the world, which is strongly influenced by climatic variables, like moisture deficit, wind speed, relative humidity and air temperature.

2. Methodology

2.1 Study area

The study area represents almost all (more than 90%) of the Brazilian savanna (Cerrado) biome, excluding only the southern region, which is characterized by few small isolated patches of savannas with intense anthropic activities like agriculture and ranching. The Cerrado vegetation exhibits a wide range of physiognomies. Following the "forest-ecotone-grassland" concept (Coutinho, 1978), the Cerrado ranges from *campo limpo*, a grassland, to *cerradão*, a tall woodland. The intermediate physiognomies (*campo sujo* - a shrub savanna, *campo Cerrado* - a savanna woodland, and *Cerrado sensu stricto* - a woodland) are considered ecotones of the two extremes.

The soil surface dries out during the dry season, leading the herbaceous and sub shrub plants suffering water stress. Thus, leaves dry out and die, while the underground plant structures are kept alive. The presence of dead leaves by water stress and also by frost greatly increases the litterfall and, consequently, the risk of fire (Nimer, 1977; Coutinho, 2000).

2.2 Methodology

The methodology involves the use of two spatial approaches, regional and local, to analyze the spatio-temporal relationships between environmental variables (precipitation and fire) and vegetation (NDVI).

The analysis unit at the local approach is the point, a specific pixel, which is obtained from the grid of points that were selected using a stratified random sampling. This grid contains separately the following types of vegetation: herbaceous, shrubs, deciduous trees, and evergreen trees of the Brazilian savanna in our study area.

At the regional approach, the entire region is considered another analysis unit, which means the Cerrado vegetation was not classified into four vegetation types. In this case, we calculated a NDVI mean value, keeping together all vegetation types (from grassland to forest) to each 16-days composite of the NDVI time series data.

The procedure applied to the vegetation data is also applied to the precipitation and fire data. The results are seasonal profiles to each variable along the annual cycle which were related using correlation and regression techniques. These seasonal profiles allow calculating a gradient of vegetation seasonality, which is defined by the difference of highest and lowest values of NDVI, precipitation, or fire. In the case of vegetation, the degree of seasonality is directly related to the degree of deciduousness, that is, the degree of leaf biomass loss during the dry season, when most plants suffer some degree of water stress.

The spatial and temporal resolutions of the data are: 250m and 16-day, 1km and 1-day, ~20km and 3 hours, for MODIS NDVI, fire hotspot and precipitation, respectively. These data are arranged to standardize them in the same 16-day temporal scale. Data from 2002, 2005 and 2008 were collected since they are considered as years under normal climatic condition, without the influence of El Niño-Southern Oscillation events.

2.2.1 Vegetation seasonality

The Normalised Difference Vegetation Index (NDVI), normalised ratio between near infrared reflectance (NIR) and red reflectance (red), has been widely used in satellite-based vegetation monitoring and modelling. NDVI is computed as:

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{red})/(\mathrm{NIR} + \mathrm{red}) \tag{1}$$

Index values can range from -1.0 to 1.0, but vegetation values typically range between 0.1 and 0.7. Higher index values are associated with higher levels of healthy vegetation cover, whereas clouds and snow will cause index values near zero, making it appear that the vegetation is less green.

Six Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) tiles (h12v09, h12v10, h12v11, h13v09, h13v10 e h13v11) were joined to create a mosaic for the entire study area. Three annual time-series were prepared for the following years: 2002, 2005 and 2008. Each annual dataset consists of 23 MODIS NDVI data, at 16-day composite intervals, and 250 m spatial resolution. These data were used to classify and analyze seasonal and phenology profiles of the Brazilian Cerrado vegetation.

At this point, the methodology consists first in the classification of vegetation, from the annual NDVI time-series data and using the tree decision technique, into four types: grasses and herbs, shrubs, deciduous trees and evergreen trees. This classification uses the phenological parameter named end of vegetation growing season, which corresponds to the following ranges of NDVI for each vegetation type: grasses and herbs (E1) from 100 to174, shrubs (E2) from 175 to 199, deciduous trees (E3) from 200 to 219 and evergreen trees (E4) from 220 to 255. Ground truth data was used to validate this classification.

The second part consists of selecting representative spatial points of vegetation types (Figure 1), which are obtained from the vegetation classification image. Each point corresponds to a pixel on the image and is defined as our unit of analysis. A stratified random sampling technique was used for the selection of points in the classification image. The number of points to each vegetation types was proportional to its spatial coverage in the study area. So, herbaceous (E1) represents 52% of the points, shrubs (E2) 24%, deciduous trees (E3) 15% and evergreen trees (4) 9%.

The total number of points identified in the study area was N = 639, which are distributed as follows: 251 points of herbaceous, 318 of shrubs, 59 of deciduous trees and 11 of evergreen trees (Figure 1).

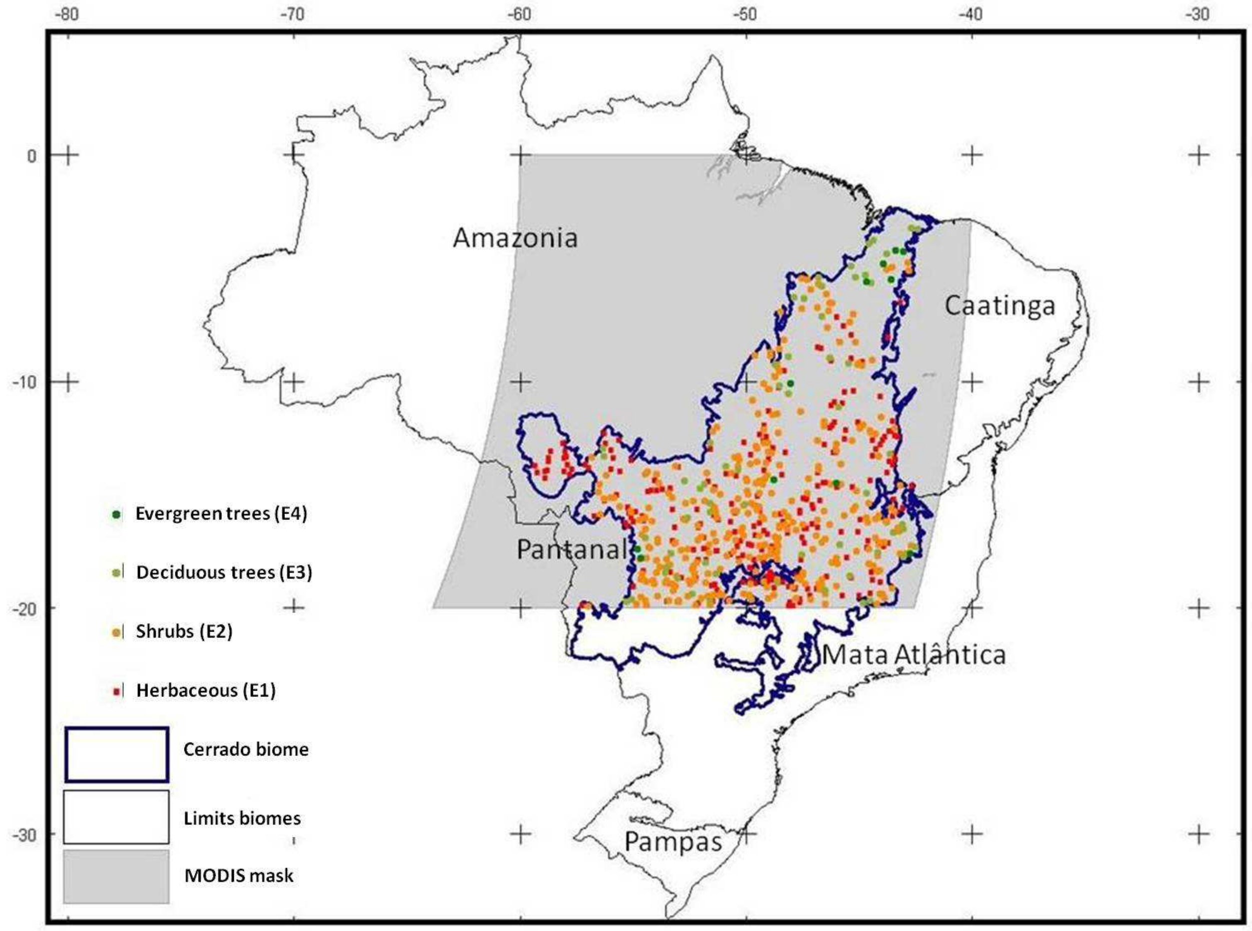


Fig. 1. Location of Brazilian biomes highlighting the savanna (Cerrado) biome. The shaded area is a mosaic of 4 MODIS-13Q1 tiles. Dots of different colors correspond to stratified random sampling of the following vegetation types: herbaceous (E1), shrubs (E2), deciduous trees (E3), and evergreen trees (E4).

2.2.2 Fire seasonality

First, daily data of fire hot spot obtained as latitude/longitude coordinates, in ASCII format, are converted in XYZ vector format data using a geographical information system (GIS) tool. These daily vectors were used to create a new vector data set of 16-days composites accumulating these daily data. Each composite were used to create a raster data set of fire hotspot density by the use of the Kernel density estimator, according to the following equation (Silverman, 1986):

$$\widehat{f}(x;H) = n^{-1}\sum_{i=1}^{n} K_H(x - X_i) \tag{2}$$

Where:

- $X_1, X_2, \ldots, X_n$ is sample of n data points (fire hot spot)
- H is bandwith matrix
- $K_H x - X_i$ is normal probability density function (pdf) with mean X_i and variance H

Kernel Density calculates the density of point features around each output raster cell. The kernel function is based on the quadratic kernel function as described in Silverman (1986). Conceptually, a smoothly curved surface is fitted over each point. The surface value is highest at the location of the point and diminishes with increasing distance from the point, reaching zero at the Search radius distance from the point. Only a circular neighborhood is possible. The volume under the surface equals the Population field value for the point, or 1 if NONE is specified. The density at each output raster cell is calculated by adding the values of all the kernel surfaces where they overlay the raster cell center.

2.2.3 Precipitation

We used two kinds of data for precipitation in the study area for the years 2002, 2005 and 2008. First, Tropical Rainfall Measuring Mission (TRMM) multisatellite rainfall data (3B42 product), which has 0.25 degree spatial resolutions and 3-hours temporal resolution. Second, meteorological station rainfall data scattered throughout the study area, which has 1-hour temporal resolution.

These two datasets (TRMM and observed data) are combined following the approach of Vila et al. (2009), which use the Barnes objective analysis (Barnes, 1973; Koch et al., 1983) for data interpolation. This analysis allows the incorporation of observed data in a grid of estimated data and also improves its spatial resolution. As result, the new precipitation data has 0.2-degree spatial resolution and 1-day temporal resolution.

3. Results and discussion

3.1 Regional analysis

Figure 2 shows seasonal profiles of vegetation and precipitation in the Cerrado region for the three years analyzed (2002, 2005 and 2008). These results show that the Cerrado vegetation seasonality is well defined, which in turn has a direct relationship to the seasonality of precipitation. However, there is a time lag ranging from 1 (16 days) to 3 (48

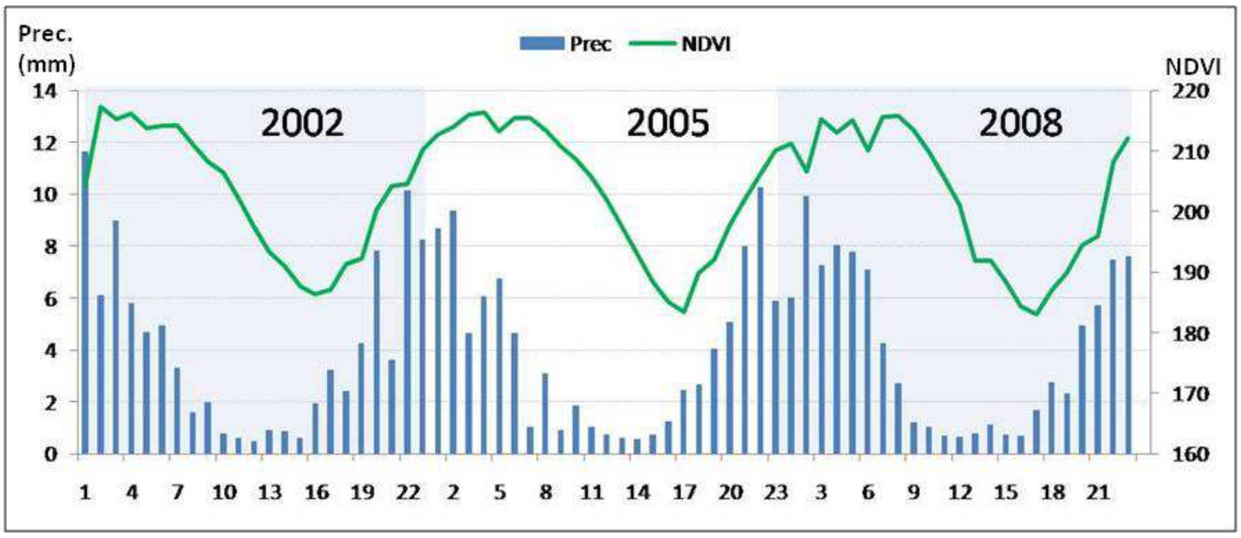


Fig. 2. Annual seasonality of vegetation and precipitation in the years 2002, 2005 and 2008 for the Cerrado biome. Each year consists of 23 16-days composite periods. Precipitation is the daily mean rainfall values for a 16-days composite period in mm (first y axis) and vegetation the mean NDVI values for the same period (second y axis).

days) periods between the beginning of the rainy season and the beginning of the vegetation growing season.

Figure 3 shows seasonal profiles of vegetation and fire in the Cerrado region for the three years analyzed (2002, 2005 and 2008). These results show, as in Figure 2, that the fire occurrence in the Cerrado has well-defined seasonality, which in turn has a direct negative relationship to the seasonality of vegetation. That means, the highest fire occurrence during the growing cycle of fire is related to the greatest loss of plant cover during the dry season, with a time lag ranging from 0 to 3 periods (0 to 48 days).

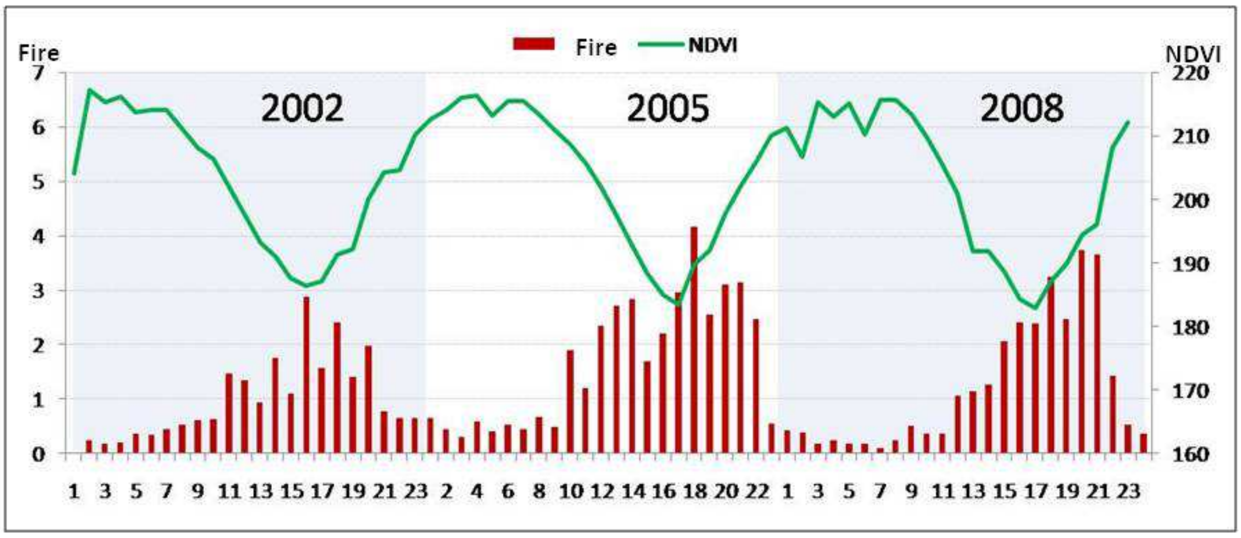


Fig. 3. Annual seasonality of vegetation and fire in the years 2002, 2005 and 2008 for the Cerrado biome. Each year consists of 23 16-days composite periods. Fire is the daily mean value of the density of hotspot within a 10km radius for a 16-days composite period and vegetation the mean NDVI values for the same period (second y axis).

3.2 Local analysis

The results presented show the seasonality of vegetation, rainfall and fire in places (points) defined by the grid points representing the four vegetation types analyzed in the study.

3.2.1 Seasonality of vegetation

Figure 4 shows the seasonal profile of four vegetation types over the three years analyzed. These results show a clear difference, regarding the degree of vegetation seasonality, among the four types of vegetation analyzed, according to the following gradient: herbaceous (E1), with strong seasonality, shrubs (E2), deciduous trees (E3), and evergreen trees (E4), with weak seasonality.

The vegetation phenology metrics are shown in Figure 5. Figure 5a shows annual maximum and minimum NDVI values, indicating the highest and lowest vegetation productivity respectively, for each type of vegetation in the three years analyzed. Figure 5b shows the difference between the maximum and minimum NDVI as a percentage, indicating the degree of seasonality. Also Figure 5a shows a slight difference between the maximum NDVI values, high plant productivity in the four vegetation types, while the difference between the minimum NDVI values, lower productivity, in the four vegetation types is significant. In general, the degree of seasonality of the vegetation (Figure 5b) was consistently detected in the four vegetation types. That is, small plants with low canopy (shrubs and herbaceous) have higher degree of seasonality than tall one with high canopy, which in turn have lower degree of seasonality.

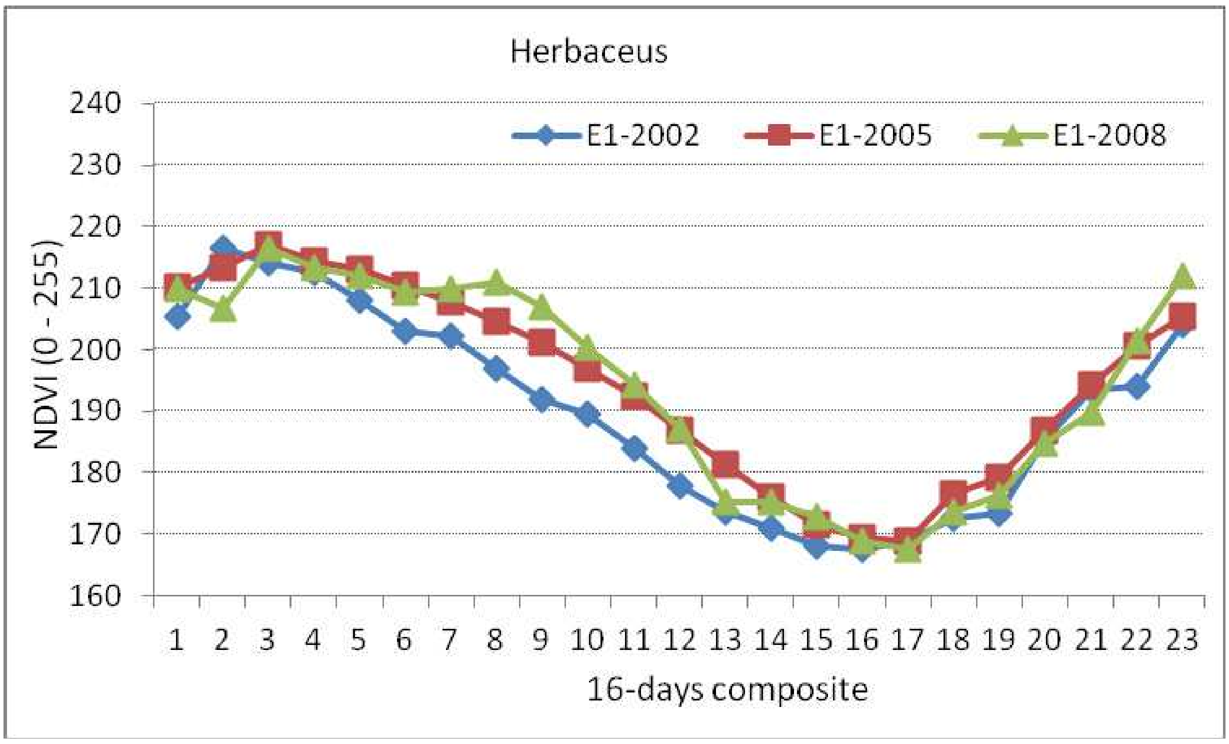
3.2.2 Seasonality of precipitation

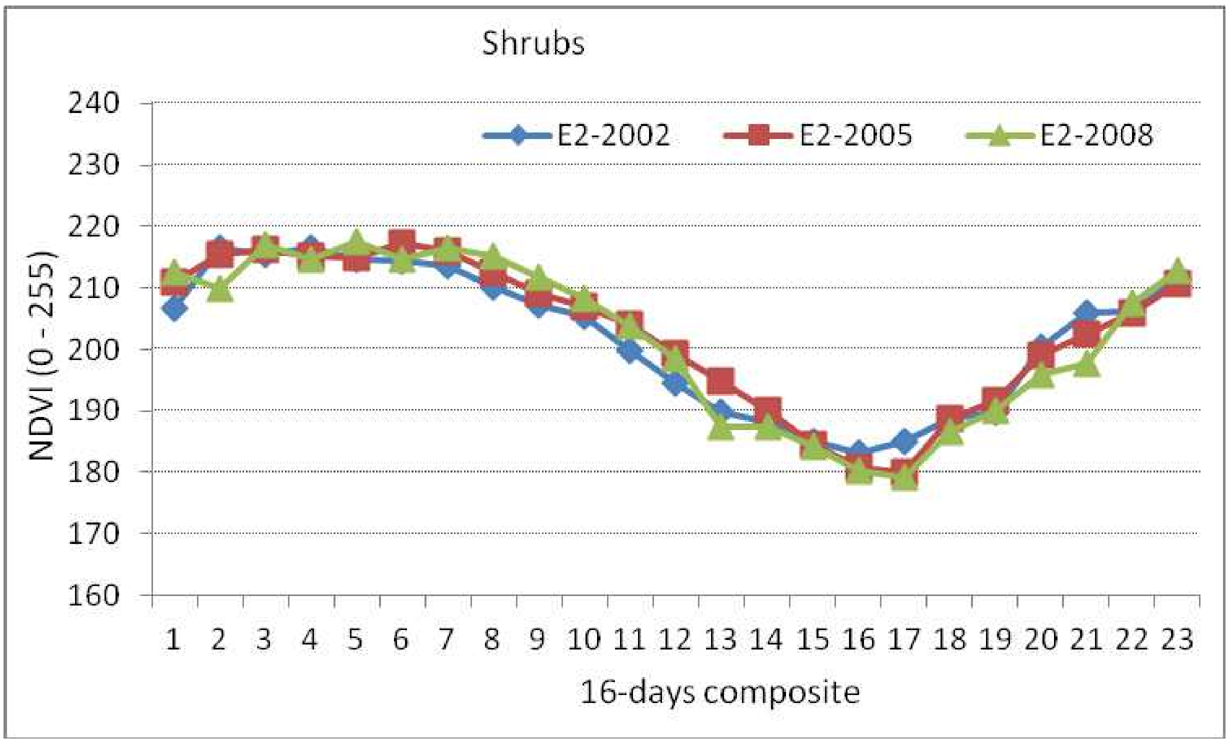
Figure 6 shows the seasonal profile of rainfall recorded in the same sampling points of the four vegetation types over the three years analyzed. These results show, in the beginning of the year during the rainy season, lower rainfall at sites where herbaceous and shrubs were registered than at sites where deciduous and evergreen trees are predominant. This result is a first indicator that shows a relationship between rainfall gradient and vegetation cover gradient. These gradients range from sites with higher precipitation, associated with high canopy plants (evergreen trees), to those with less precipitation, associated with a lower canopy plants (herbaceous).

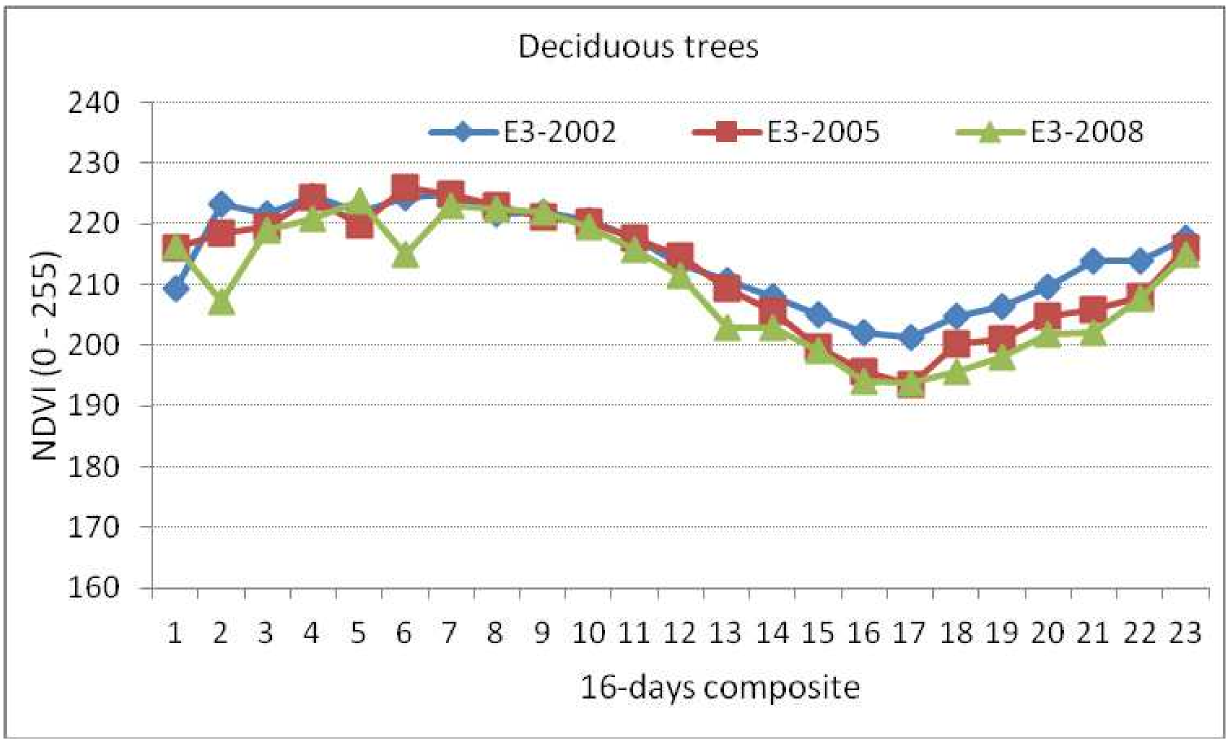
3.2.3 Seasonality of fire

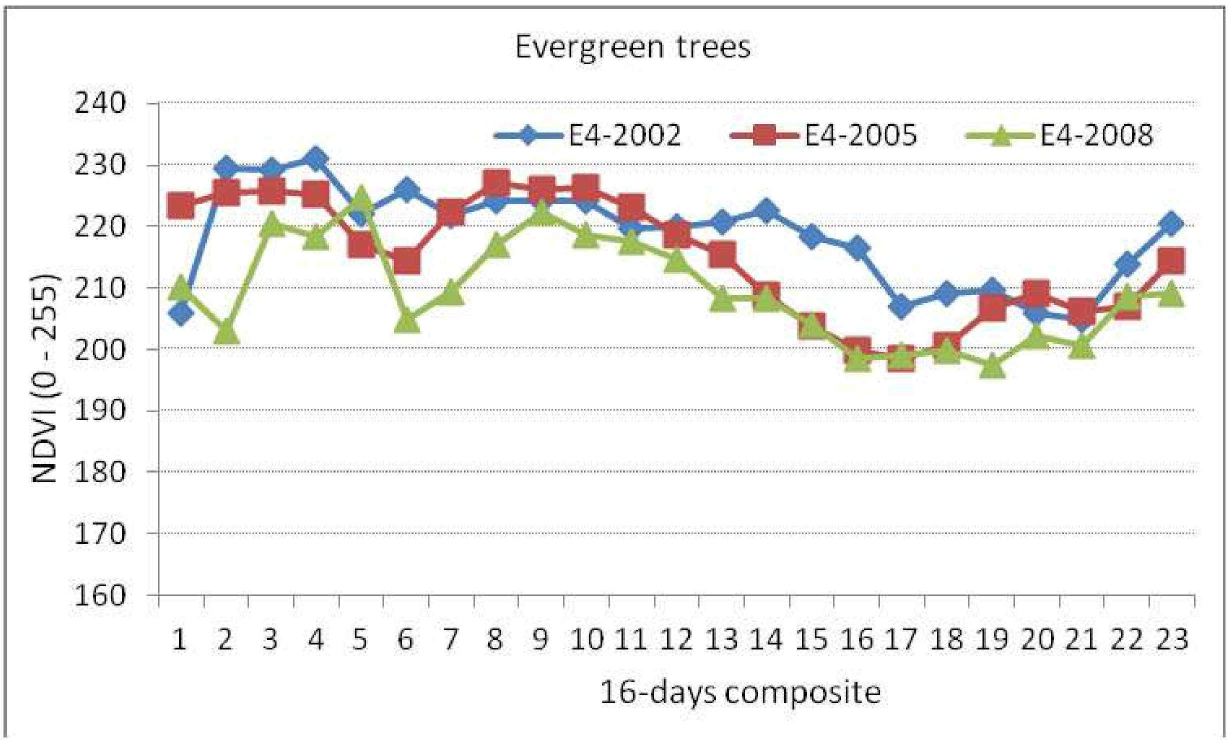
Figure 7 shows the pattern of the fire season recorded in the same sampling points of the four vegetation types over the three years analyzed. The results of fire occurrence throughout the Cerrado region show that there is a pronounced seasonality in all vegetation types analyzed with a peak in the months of greatest drought in the dry season.

The results show a well-defined gradient of fires in the four types of vegetation. This gradient varies from lower fire density in evergreen trees (E4), with shorter periods of time (12 to 22) throughout the annual cycle, to higher fire density in herbaceous plants (E1), with more periods of time (1 to 23, except 2), as seen in Figure 7. Most of the fire occurrences in the four types of vegetation were recorded in 2005 and 2008 indicating the occurrence of an inter-annual variability of fire. The higher fires were recorded between the periods from 15 to 21 taking into account the four vegetation types and the three years analyzed.


Herbaceus
E1-2002
E1-2005
E1-2008
NDVI (0 - 255)
240
230
220
210
200
190
180
170
160
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
16-days composite


Shrubs
E2-2002
E2-2005
E2-2008
NDVI (0 - 255)
240
230
220
210
200
190
180
170
160
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
16-days composite



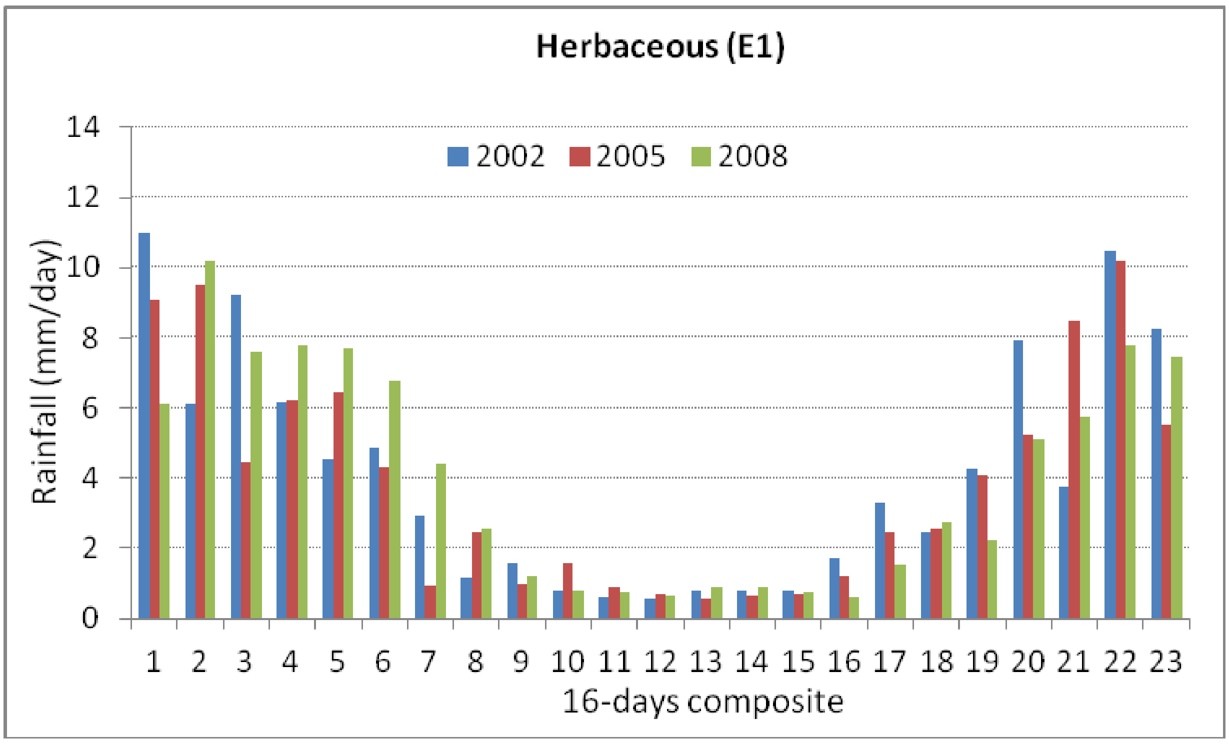


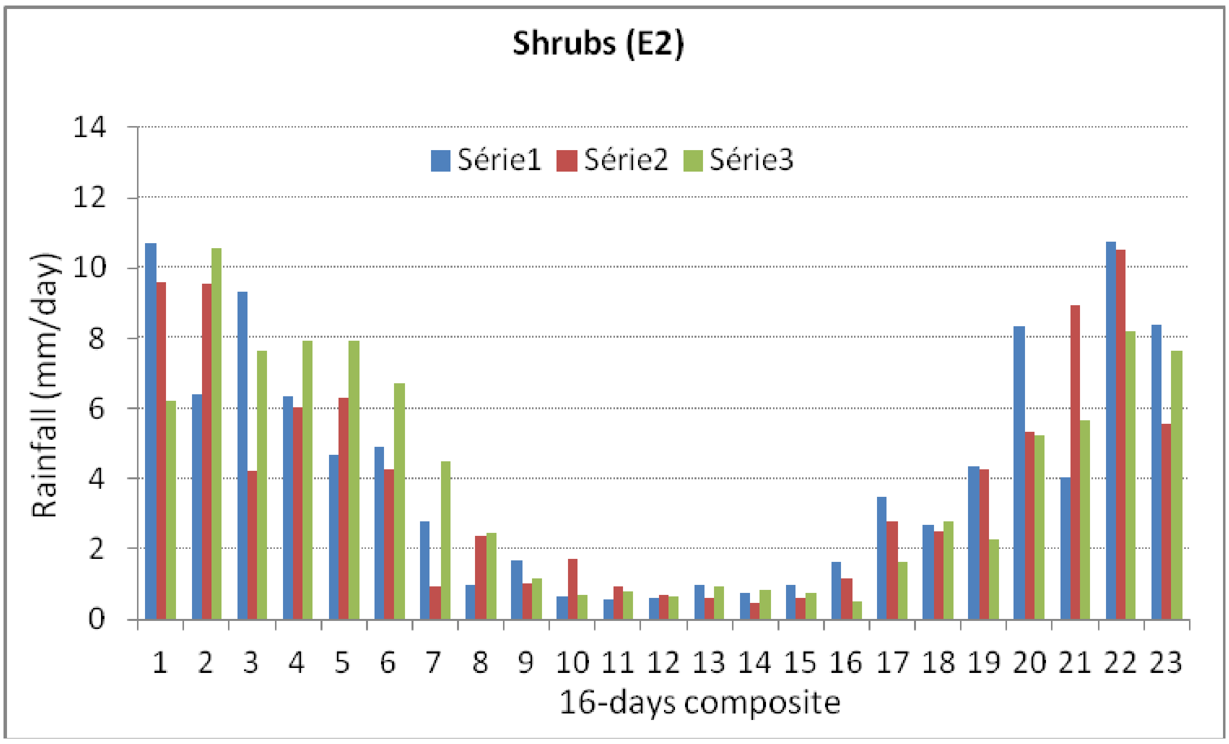
E1: herbaceous; E2: shrubs; E3: deciduous trees; and E4: evergreen trees.

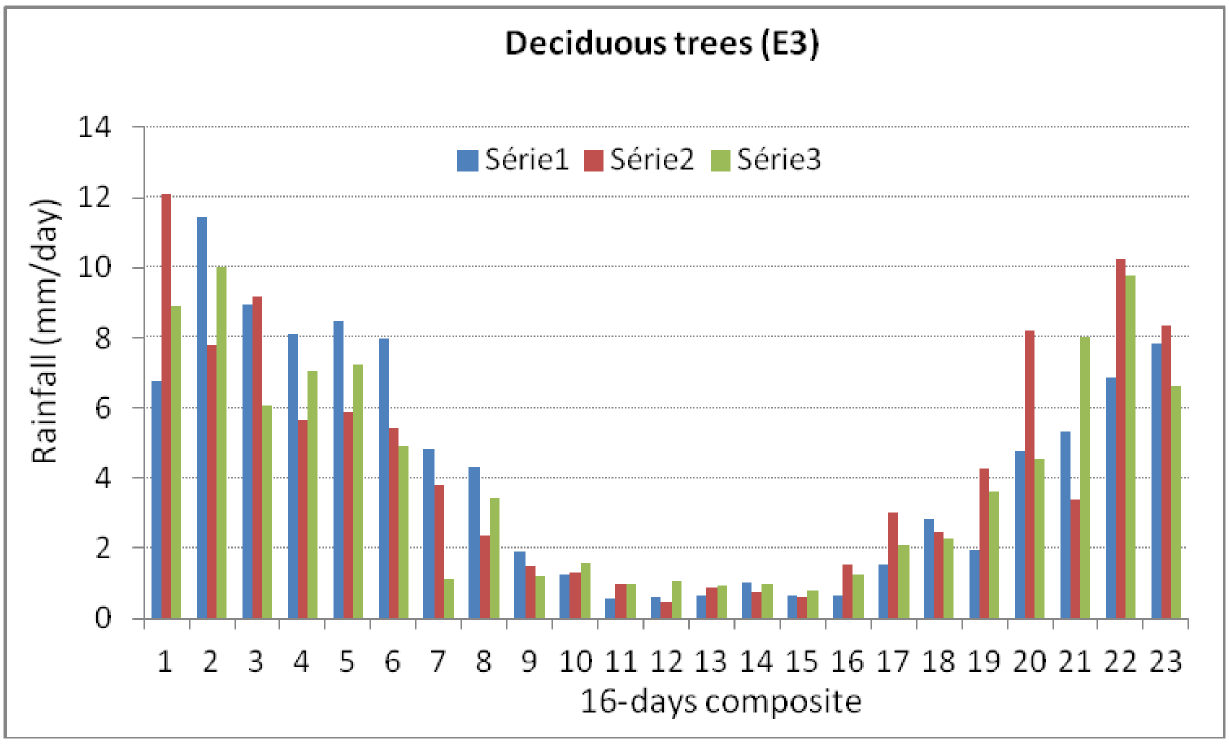
Fig. 4. Annual seasonality of vegetation derived from NDVI data for the years 2002, 2005 and 2008 in the four vegetation type analyzed. Each year consists of 23 16-days composite periods.

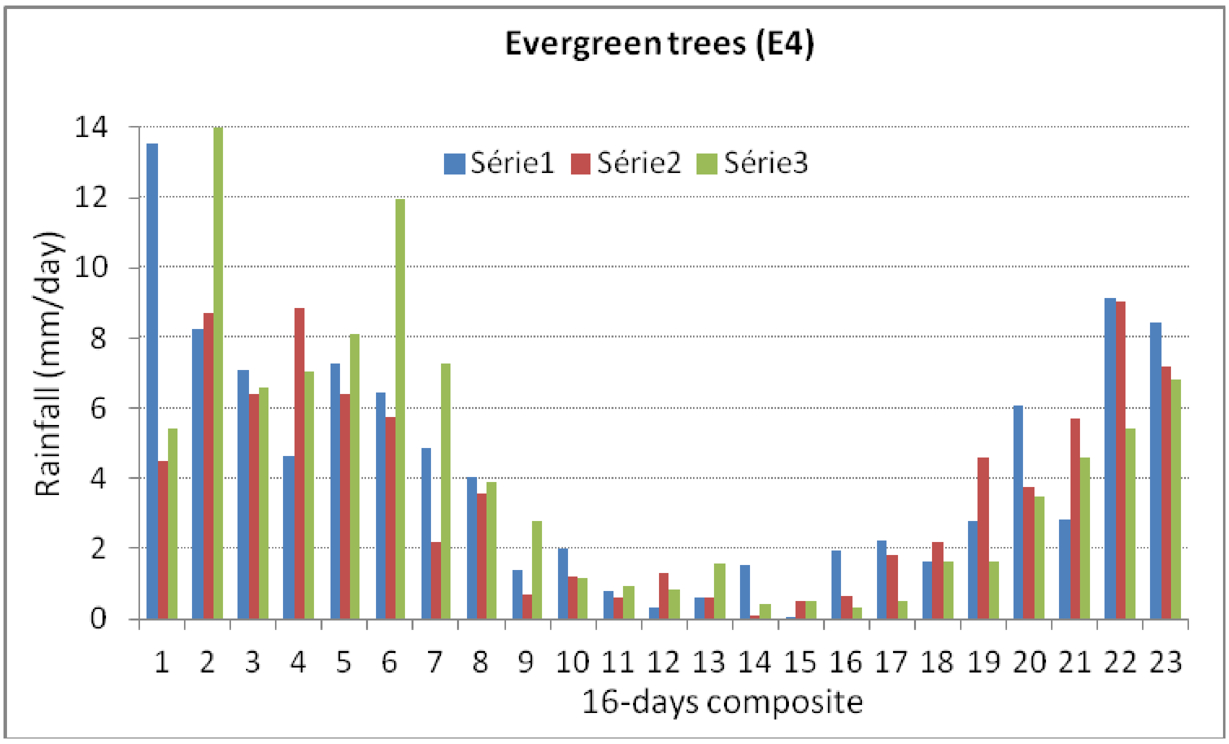
E1: herbaceous; E2: shrubs; E3: deciduous trees; and E4: evergreen trees

Fig. 5. Metrics of vegetation phenology derived from NDVI data used in Fig. 4. Maximum and minimum NDVI values indicate periods of higher and lower plant productivity (left) respectively, and the difference of both, as a percentage, indicates the degree of seasonality of each vegetational type in the three years analyzed.


Herbaceous (E1)
2002
2005
2008
Rainfall (mm/day)
0
2
4
6
8
10
12
14
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
16-days composite

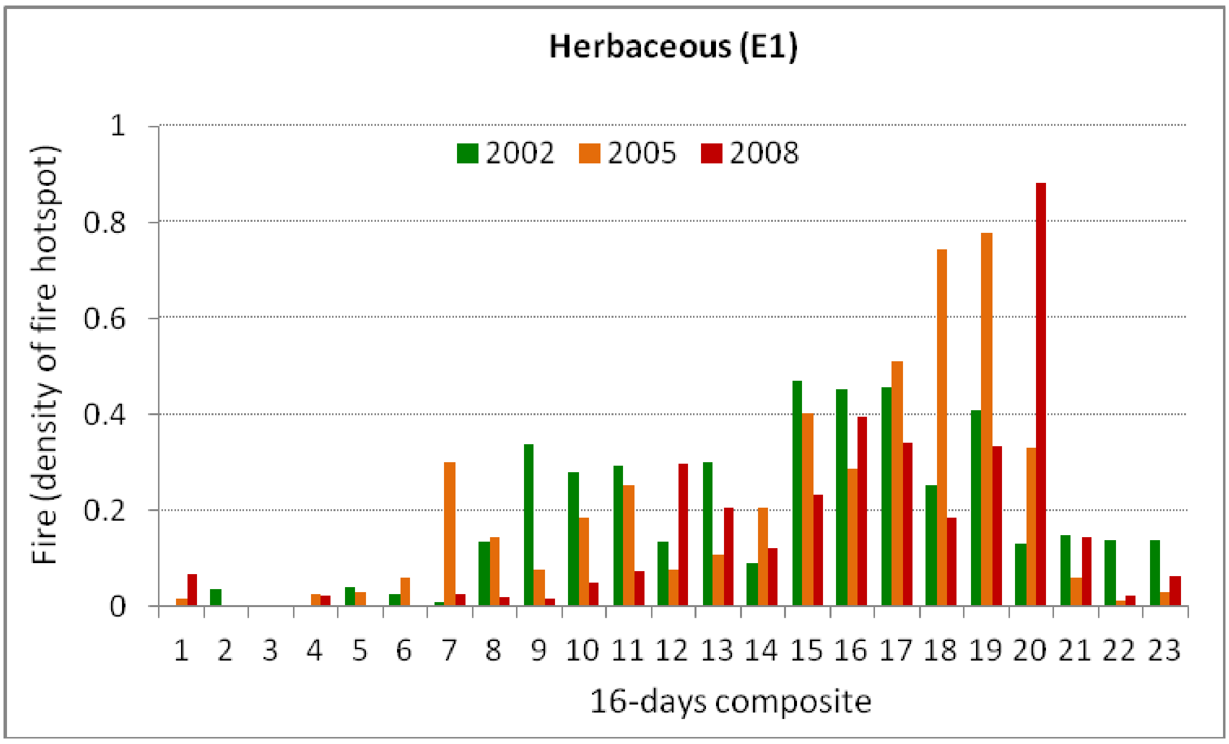

Shrubs (E2)
Série1
Série2
Série3
Rainfall (mm/day)
0
2
4
6
8
10
12
14
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
16-days composite

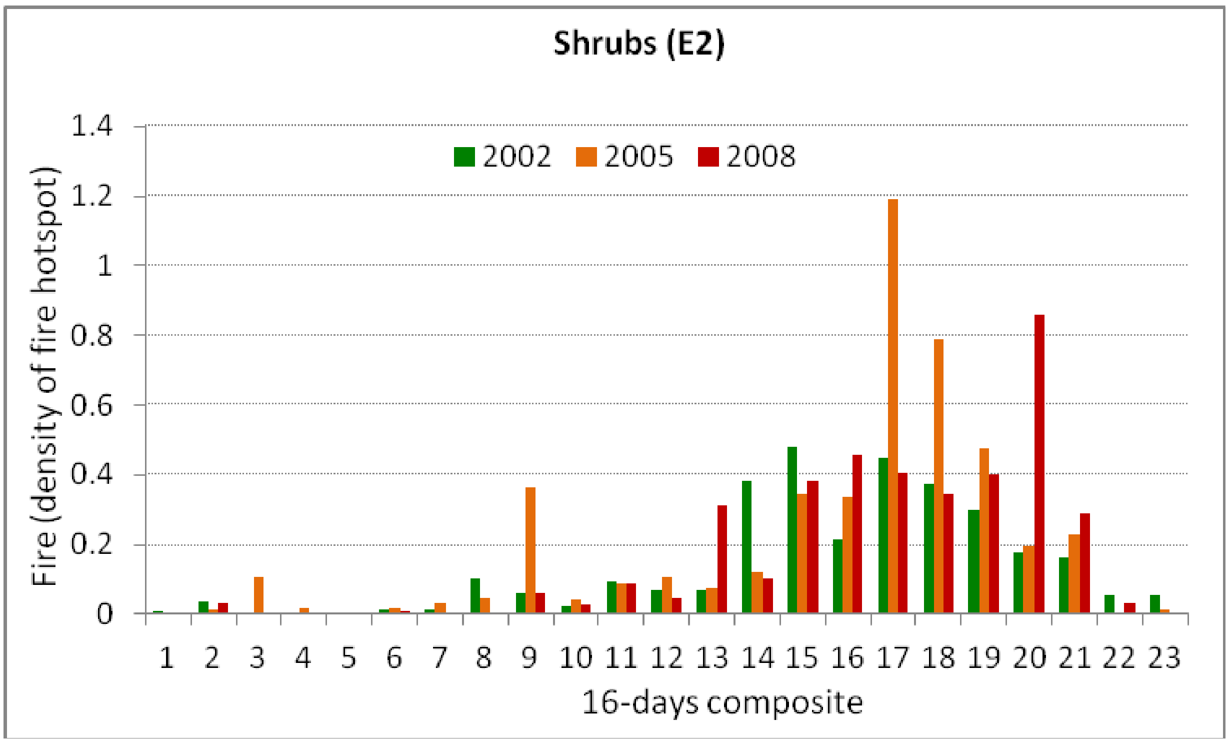


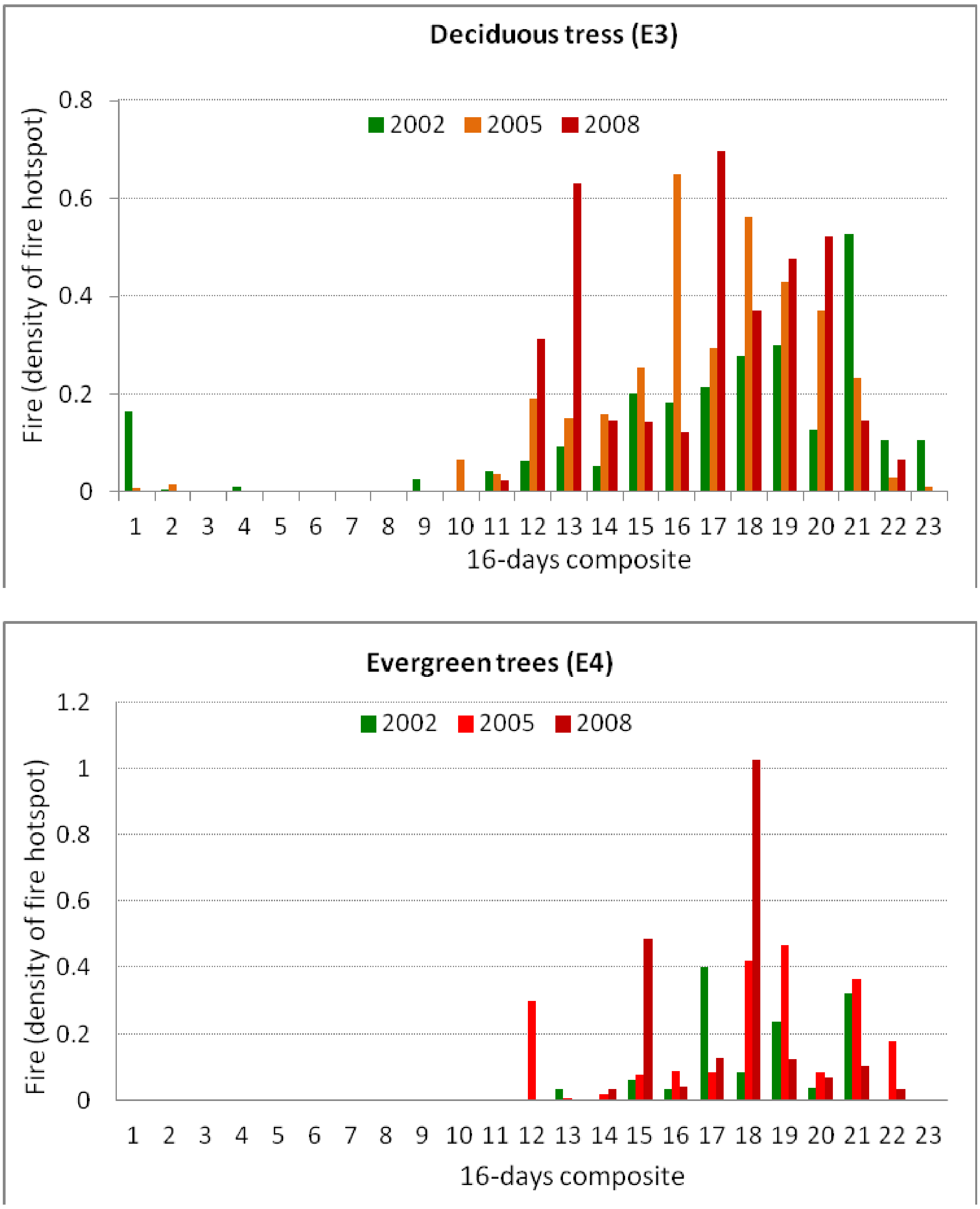


E1: herbaceous; E2: shrubs; E3: deciduous trees; and E4: evergreen trees.

Fig. 6. Annual seasonality of precipitation for the years 2002, 2005 and 2008, in places where we sampled the four vegetation types analyzed. Each year consists of 23 16-days composite periods. Precipitation in mm is the daily mean rainfall values for a 16-days composite period.


Herbaceous (E1)
2002
2005
2008
Fire (density of fire hotspot)
0
0.2
0.4
0.6
0.8
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
16-days composite


Shrubs (E2)
2002
2005
2008
Fire (density of fire hotspot)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
16-days composite



E1: herbaceous; E2: shrubs; E3: deciduous trees; and E4: evergreen trees.

Fig. 7. Annual seasonality of fire for the years 2002, 2005 and 2008, in places where we sampled the four vegetation types analyzed. Each year consists of 23 16-days composite periods. Fire is the daily mean value of the density of hotspot within a 10km radius for a 16-days composite period.

3.2.4 Relationship between vegetation (NDVI) and environmental variables (precipitation and fire)

The results showed in Table 1 indicate significant positive correlation between NDVI and precipitation in herbaceous, shrubs and deciduous trees, and negative correlation between NDVI and fire in the same three vegetation types. In the case of evergreen trees, the correlation between NDVI and precipitation is positive but not significant, and between NDVI and fire is negative, but also not significant. These results are corroborated in subsequent analysis.

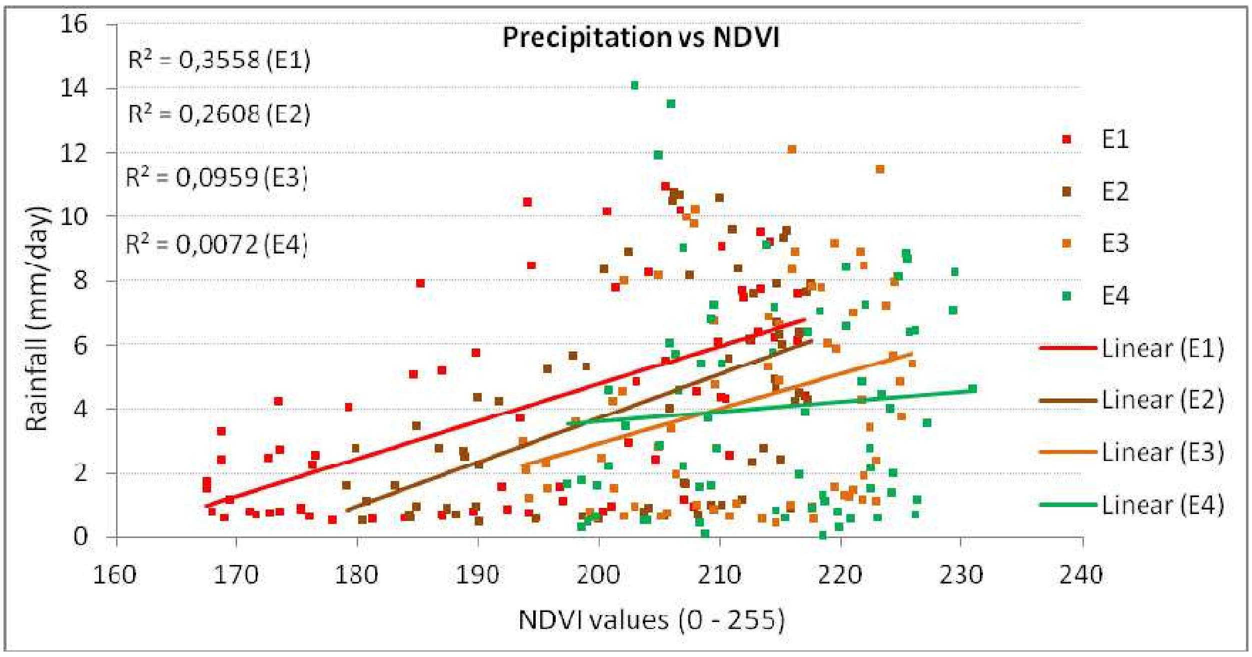
	E1 Prec	E2 Prec	E3 Prec	E4 Prec	E1 Fire	E2 Fire	E3 Fire	E4 Fire
E1-NDVI	**0.60**	0.58	0.67	0.70	**-0.69**	-0.68	-0.66	-0.41
E2-NDVI	0.52	**0.51**	0.60	0.65	-0.68	**-0.72**	-0.70	-0.43
E3-NDVI	0.20	0.19	**0.31**	0.36	-0.61	-0.73	**-0.75**	-0.51
E4-NDVI	0.00	-0.01	0.16	**0.09**	-0.43	-0.57	-0.66	**-0.47**
E1-Fire	**-0.40**	-0.39	-0.43	-0.49	1.00	0.77	0.65	0.35
E2-Fire	-0.31	**-0.30**	-0.34	-0.42	0.77	1.00	0.65	0.41
E3-Fire	-0.25	-0.24	**-0.31**	-0.38	0.65	0.65	1.00	0.47
E4-Fire	-0.09	-0.08	-0.19	**-0.20**	0.35	0.41	0.47	1.00

Table 1. Correlation matrix of vegetation, rainfall and fire variables, highlighting the significant correlations between the following couple of variables: NDVI and rainfall, NDVI and fire, and rainfall and fire; which taking into account the four types of vegetation analyzed (E1: herbaceous; E2: shrubs; E3: deciduous trees; and E4: evergreen trees).

Figure 8 shows the result of the linear regression analysis between vegetation and precipitation for each vegetation type. Each line in this figure with a specific color shows the degree of fit between the points distributed for both variables by type of vegetation. Although this degree of fit between both variables is low, the results indicate that there is a gradient of fit between precipitation and vegetation, here named as precipitation gradient, which ranges from high to low coefficient of correlation (R2) following the sequence: herbaceous-E1 (high R2), shrubs-E2, deciduous trees-E3 and evergreen trees-E4 (low R2).

Thus, as the R2 value increases the influence of precipitation on vegetation increases, so herbaceous is more dependent on rainfall, in the annual cycle, than the other types of vegetation analyzed. That means, herbaceous are strongly dependent on rainfall in order to increase its vegetation cover. In the dry season, these kinds of species lose their leaves or even die.

At the opposite end of the precipitation gradient, where the evergreen trees-E4 are positioned, precipitation has weak influence on the vegetation cover, which means that in



E1: herbaceous; E2: shrubs; E3: deciduous trees; and E4: evergreen trees.

Fig. 8. Regression of precipitation (independent variable) and NDVI (dependent) for each vegetation type analyzed. NDVI values range from 0 to 255 (x-axis). Precipitation in mm is the daily mean rainfall values for a 16-days composite period (y-axis). N = 69.

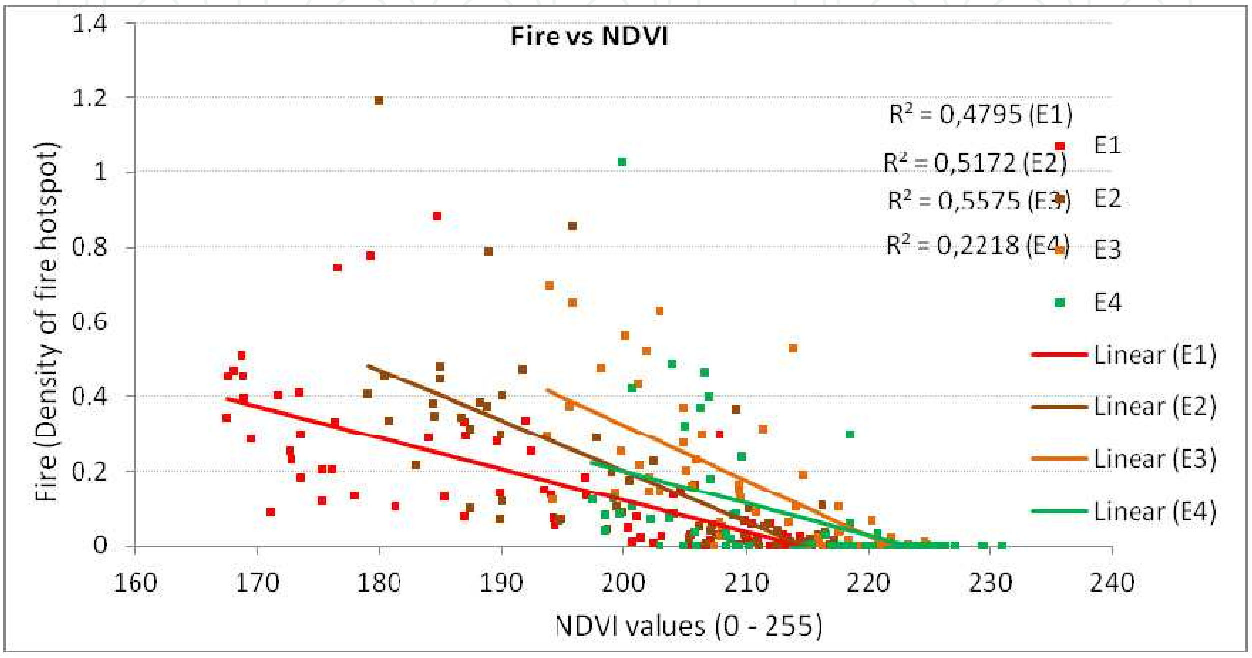
the dry season, evergreen trees are able to capture water from the vicinity of river courses, as occurs in gallery forests, or from deep soil, where the length of tree roots reach deep and moist soil layers, allowing these trees to replace their leaves throughout the year, which gives them their evergreen nature.

An analyses of variance (ANOVA) performed to evaluate these regressions is shown in table 2. Results indicate that, except for the regression between NDVI and Precipitation for the evergreen trees (E4) class, all regressions are significant at the 0.99 confidence level. Moreover, the relationships between NDVI and Fire were significant for all classes.

	NDVI x Prec			NDVI x Fire		
	R^2	F	p	R^2	F	p
E1	0.3558	37.01	<0.01	0.4795	61.72	<0.01
E2	0.2608	23.64	<0.01	0.5172	71.77	<0.01
E3	0.0959	7.11	<0.01	0.5575	84.40	<0.01
E4	0.0072	**0.49**	**0.49**	0.2218	19.10	<0.01

Table 2. Analysis of Variance (ANOVA) of linear regression NDVI x Precipitation (Prec) and NDVI x Fire. Bold values indicate the case where regression was not significant.

Figure 9 shows the result of the linear regression analysis between vegetation and fire for each vegetation type. Each line in this figure with a specific color shows the degree of fit between the points distributed for both variables by type of vegetation. The results indicate that there is a gradient of fit between fire and vegetation, here named as fire gradient, which ranges from high to low coefficient of correlation (R2) following the sequence: deciduous trees-E3 (high R2), shrubs-E2, herbaceous-E1, and evergreen trees-E4 (low R2).



E1: herbaceous; E2: shrubs; E3: deciduous trees; and E4: evergreen trees.

Fig. 9. Regression of fire (independent variable) and NDVI (dependent) for each vegetation type analyzed. NDVI values range from 0 to 255 (x-axis). Fire is the daily mean value of the density of hotspot within a 10km radius for a 16-days composite period. N = 69.

The fire gradient identified above indicates that there is direct relationship between NDVI of the main vegetation types (herbaceous, shrubs and deciduous trees), which make up the Cerrado vegetation, and fire, indicating the role of fire in the maintenance of these vegetation types.

Fire occurs with greater intensity at the end of dry season. First of all, fire consumes part of the burk and organic matter of the plant, after the first rains, in the beginning of the rainy season, these partially burned plant sprouts new shoots with greater vigor.

At the opposite end of the fire gradient, where the evergreen trees-E4 are positioned, the fire occurs in lower proportion in these trees, however, unlike what happens with other types of vegetation, the effect of fire is pernicious, it can damage or even eliminate some species in this vegetation type according to the intensity level.

The multiple regression analysis indicates that there is a direct relationship between precipitation and fire, and vegetation index (NDVI) in the four vegetation types of the savanna vegetation. The multiple coefficients of determinations (R^2) show that the environmental variables as a whole (precipitation an fire) follow a gradient of high influence in vegetation types with low vegetation cover (herbaceous R^2=0.67 and shrubs R^2=0.65) to low influence in that with high vegetation cover (deciduous trees R^2= 0.55 and evergreen trees R^2=0.27). Results from the ANOVA of the multiple regression presented in Table 3 indicate that, when the analysis is performed considering both independent variables, the multiple regression gives statistically significant parameters, for all classes of vegetation. However, an univariate test of significance performed for each independent variable show that precipitation alone is not significant correlated to the vegetation index for both tree classes (E3 and E4).

	Whole model R			Univariate test of significance			
	R^2	F	p	F_prec	F_fire	p_prec	p_fire
E1	0.6001	49.52	<0.01	19.90	40.31	<0.01	<0.01
E2	0.6141	52.52	<0.01	16.59	60.43	<0.01	<0.01
E3	0.5648	42.83	<0.01	**1.12**	71.11	**0.29**	<0.01
E4	0.2220	9.42	<0.01	**0.01**	18.22	**0.92**	<0.01

Table 3. Analysis of Variance (ANOVA) of the multiple regression between NDVI (dependent variable) and precipitation and fire (independent variables). Bold values indicate the cases where regression was not significant.

4. Conclusions

The response of vegetation NDVI is more related to the variation of fire than to variations in precipitation in Cerrado region. Vegetation NDVI responds to variation of precipitation with a time lag ranging from 16 to 48 days, while vegetation NDVI responds to variation of fire with a time lag ranging from 0 to 48 days.

The relationship between vegetation types, derived from NDVI, and precipitation, derived from TRMM, shows a gradient of positive correlations in vegetation types with low vegetation cover, herbaceous (r= 0.60) and shrubs (r= 0.51), to very little or none with high vegetation cover, deciduous trees (r= 0.31) and evergreen trees (r= 0.09). On the other hand, the relationship between vegetation and fire hotspot shows a gradient of negative correlation, which is stronger in herbaceous (r= 0.72), shrubs (r= 0.74) and deciduous trees (r= -0.73) than in evergreen trees (r= -0.52).

Our analyses show that vegetation cover increases are related to increases in precipitation and decreased in density of fire hotspots. We also found high density of fire hotspot in the dry season in deciduous trees, shrubs and herbaceous which suggesting the high removal of CO2 (greenhouse gas) of the land cover to the atmosphere somehow influencing the dynamic equilibrium of this (atmosphere) in the region of the Brazilian tropical savanna.

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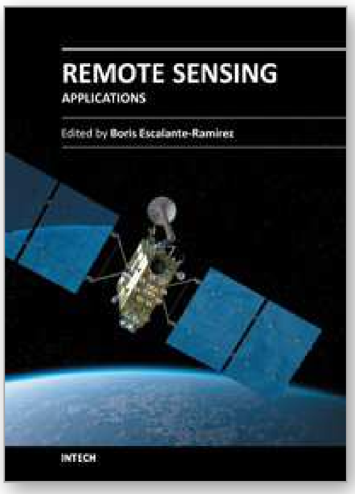

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Nowadays it is hard to find areas of human activity and development that have not profited from or contributed to remote sensing. Natural, physical and social activities find in remote sensing a common ground for interaction and development. This book intends to show the reader how remote sensing impacts other areas of science, technology, and human activity, by displaying a selected number of high quality contributions dealing with different remote sensing applications.

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