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Research Article

An Examination of Relationships Between Vegetation and Rainfall Using Maximum Value Composite AVHRR-NDVI Data

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Abstract: Global vegetation monitoring with remotely sensed data has the potential of improving our knowledge about the characteristics and spatial distribution of the earth's land cover. The purpose of this study was to assess vegetation response to different rainfall regimes using bi-weekly MVC (Maximum Value Composite) AVHRR (Advanced Very High Resolution Radiometer) data. The results from this research showed that the NDVI (Normalised Difference Vegetation Index) has the potential for evaluating vegetation state, which is related to seasonal variations in climatic conditions. Extreme climatic events such as droughts and abundant moisture conditions can have a strong impact on vegetation development and can be identified by utilising vegetation indices. Forested areas are less likely to reflect changes in their vegetation state than grassland cover types to different moisture conditions. The relationships between NDVI and rainfall showed that concurrent and the previous two months' rainfall totals have a stronger impact on vegetation state, which suggests that the total rainfall of the past two months still has an effect on vegetation development.

Key Words: remote sensing, AVHRR, NDVI, rainfall, vegetation, lag time

AVHRR-NDVI Verilerini Kullanarak Bitki Örtüsü İle Yağış Koşulları Arasındaki İlişkilerin İncelenmesi

Özet: Uzaktan algılama yöntemleri ile elde edilen verileri kullanarak vejatasyonun yıl içerisindeki degişiminin izlenmesi ve incelenmesi, yerküre bitki örtsü hakkındaki bilgilerimizi artıracak bir potansiyele sahiptir. Bu araştırmanın amacı, 15 günlük periyodlar halinde hazırlanan NOAA AVHRR uydusuna ait verileri kullanarak, doğal bitki örtüsü ile farklı yağış koşulları arasındaki ilişkileri incelemektir. Bu amaçla, yöntem ve test alanının seçimi yapılmıştır. Sonuçlar yağış koşulları ile bitki arasındakı ilişkilerin Normalleştirilmiş Fark Bitki İndeksi (NDVI) yoluyla tesbit edilebileceğini ortaya koymuştur. Özellikle otsu bitkilerin kuraklık koşullarından daha çok etkilendiği, buna karşılık orman alanlarının daha az tepki verdikleri NDVI değerlerinden anlaşılmaktadır. Yine bitkilerin yağışlara hemen tepki göstermedikleri ve yağışlarin etkilerinin belli bir sure sonra ortaya çıktığı gözlenmiştir. Özellikle son iki ayda meydana gelen yağışların bitki örtüsü uzerindeki etkilerinin en yüksek seviyeye ulaştığı belirlenmiştir.

Anahtar Sözcükler: uzaktan algılama, AVHRR, NDVI, yağış, vejetasyon

Introduction

Vegetation monitoring is essential for dealing with many environmental issues such as biodiversity, global climate change and agricultural practices. In recent years, most mapping and monitoring of vegetation cover–especially over large areas and regions–has been dependent on the use of remotely sensed data, because of the spatially comprehensive view provided by such data (Malingareau et al., 1986; Goward et al., 1991).

Remote sensing methods such as digital image processing techniques are based on brightness values of the land cover types and enable the characterisation of the land cover. Because vegetation differentially absorbs visible incident solar radiant and reflects much of the near infrared (NIR), data on vegetation biophysical characteristics can be derived from visible and NIR and mid-infrared portions of the electromagnetic spectrum (EMS) (Tucker, 1979; Goward et al., 1991; Yang et al., 1998). Many researchers have been able to obtain useful and reliable results in determining vegetation state using vegetation indices, such as the Normalised Difference Vegetation Index (NDVI), which are closely related to percent cover, leaf area index (LAI), and plant canopy (Malingareau et al., 1986; Marsh et al., 1992; Di et al., 1994; Reed et al., 1994; John et al., 1998). The NDVI approach is based on the fact that healthy vegetation has a low reflectance in the visible portion of the EMS due to chlorophyll and other pigment absorption and has high reflectance in the NIR because of the internal reflectance by the mesophyll spongy tissue of a green leaf (Campbell, 1987). NDVI can be calculated as a ratio of red and the NIR bands of a sensor system and is represented by the following equation:

$$NDVI = (NIR - RED) / (NIR + RED). \quad (1)$$

NDVI values range from –1 to +1. Because of high reflectance in the NIR portion of the EMS, healthy vegetation is represented by high NDVI values between 0.1 and 1. Conversely, non-vegetated surfaces such as water bodies yield negative values of NDVI because of the electromagnetic absorption quality of water. Bare soil areas represent NDVI values which are closest to 0 due to high reflectance in both the visible and NIR portions of the EMS (Lillesand and Kiefer, 1994). NDVI is related to the absorption of photosynthetically active radiation (PAR) and basically measures the photosynthetic capability of leaves, which is related to vegetative canopy resistance and water vapour transfer (Malo et al., 1990).

Extreme variations in climatological inputs often have the most rapid and significant impacts on vegetation state. This was clearly illustrated in the Midwest in 1988 when dry climate conditions prevailed and in 1993 when very wet climate conditions profoundly affected landscapes and ecosystems. In this study, MVC AVHRR data will be used to assess and evaluate changes in vegetation state after extreme hydrologic events. The main objective of this study is to examine relationships between rainfall and NDVI and to explore if there is a lag time between vegetation growth and climate variables such as rainfall.

Materials and Methods

Study area

The area selected for this study encompasses the south-eastern part of the Black Hills region of South Dakota (Figure 1). The site lies in a transition area between the Black Hills and Great Plains. Most of the lowland valleys and Great Plains section of the area are dominated by grassland and alfalfa culture, while the slopes of the Black Hills are covered by Ponderosa pine. Because of its varied topography, climatic conditions and natural environment the area offers the potential of studying the impact of extreme hydrologic events on vegetation states and patternes.

Data sources and processing

This study utilizes imagery from the south-eastern portion of the Black Hills in South Dakota, USA. AVHRR data for 1989, 1991 and 1993 were selected to correspond years of drought, normal and abundant moisture conditions. The AVHRR data were extracted from the Conterminous United States AVHRR digital data set published on CD-ROMs by the U.S. Geological Survey/EROS Data Center.

The preprocessing of the AVHRR data and production of MVC images had been already performed by the EROS Data Center (EDC). The methodology and procedure for creation of MVC images follows several steps and stages. In the first step, usable AVHRR scenes for compositing, which do not contain major clouds, were selected. Second, the solar illumination variability along an orbit was corrected by using the solar zenith angle. The satellite zenith angle is computed in degrees, in which the nadir is represented as 90 degrees. In the third stage, radiometric calibration of the AVHRR visible and NIR channels was completed. Radiometric correction of channels 1 and 2 is a very important issue because the AVHRR sensor does not have an on-board calibration capability. Reflectance values for visible and NIR bands are converted to byte data. The data ranged from 0 to 255, which represents 0 to 63.5% reflectance. Any feature that has more than 63.5% reflectance is considered to be non-vegetative.

Calculation of NDVI was performed in the fourth step. NDVI can be calculated as a ratio of red and NIR bands of a sensor system (equation 1). To avoid negative values of NDVI, the data were scaled to the range of 0 to 200. As a result, NDVI values between 0 and 100 represented non-vegetative features such as clouds, snow, ice and water. Conversely, values equal or greater than 100 display vegetation cover.

In the fifth step, geometric registration was completed. Creation of MVC images require that each near cloud-free image be registered to a common map projection. This is very critical because from day to day each 1 x 1 km pixel must represent the same ground location on every candidate image. The Lambert

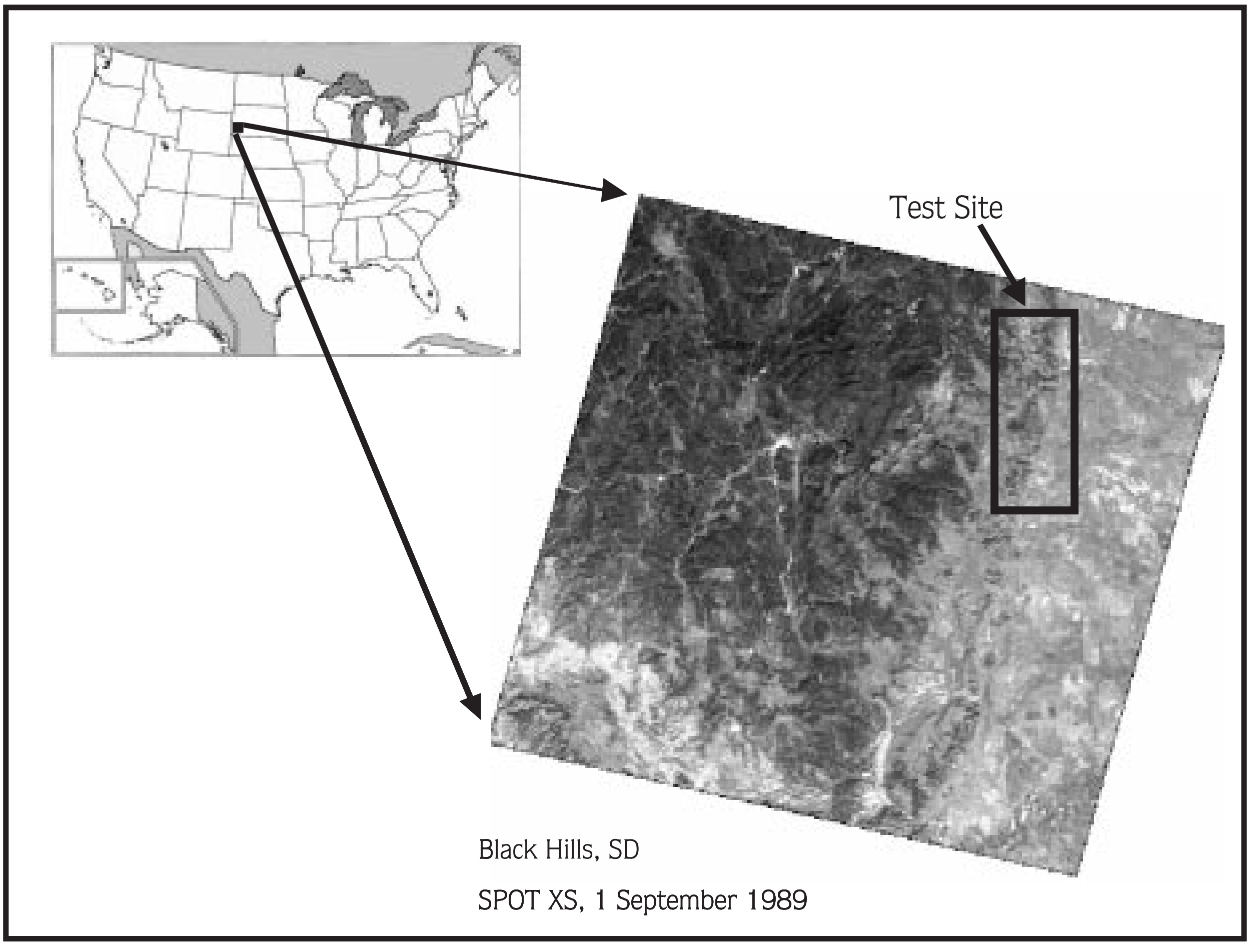

Figure 1. The study area is located in the south-eastern part of the Black Hills region, South Dakota, USA.

Azimuthal Equal Area projection (LAZEA) was chosen for geometric registration, because this projection is appropriate for the U.S. due to its visual presentation and equal-area characteristics. Digital Line Graph (DLG) with a scale of 1:2,0000,000 was chosen as a base map to register images. The base map, before image-to-image registration, was converted to raster format with 1 x 1 km resolution and was registered to the LAZEA projection. The cloud-free images were registered to the base map. The root mean square error (RMSE) of the registration was less than one pixel (less than 1 km). Using nearest neighbour resampling, the raw data (channels 1-5) and NDVI were geometrically corrected.

The last stage was the production of MVC images, which was completed by using procedures described by Holben (1986). The method for determining the portion of each image to pixel having the maximum NDVI value was retained over several successive days such as 10 and 15 d. To achieve this purpose, the NDVI values were examined to determine maximum value. This procedure reduces the number of cloud-contaminated pixels because values for vegetative areas are higher than cloud-contaminated ones during clear day observation. Therefore, MVC images depict the maximum vegetative greenness for the composite period. Around fifteen daily AVHRR images were used in producing one bi-weekly maximum value composite image.

Results and Discussion

NDVI values were computed for the study area for each climatic condition and were plotted against precipitation for each bi-weekly period (Figure 2). Some general observations can be made from analysing the NDVI curves for each year. As expected, all three years were clearly different from each other in terms of mean

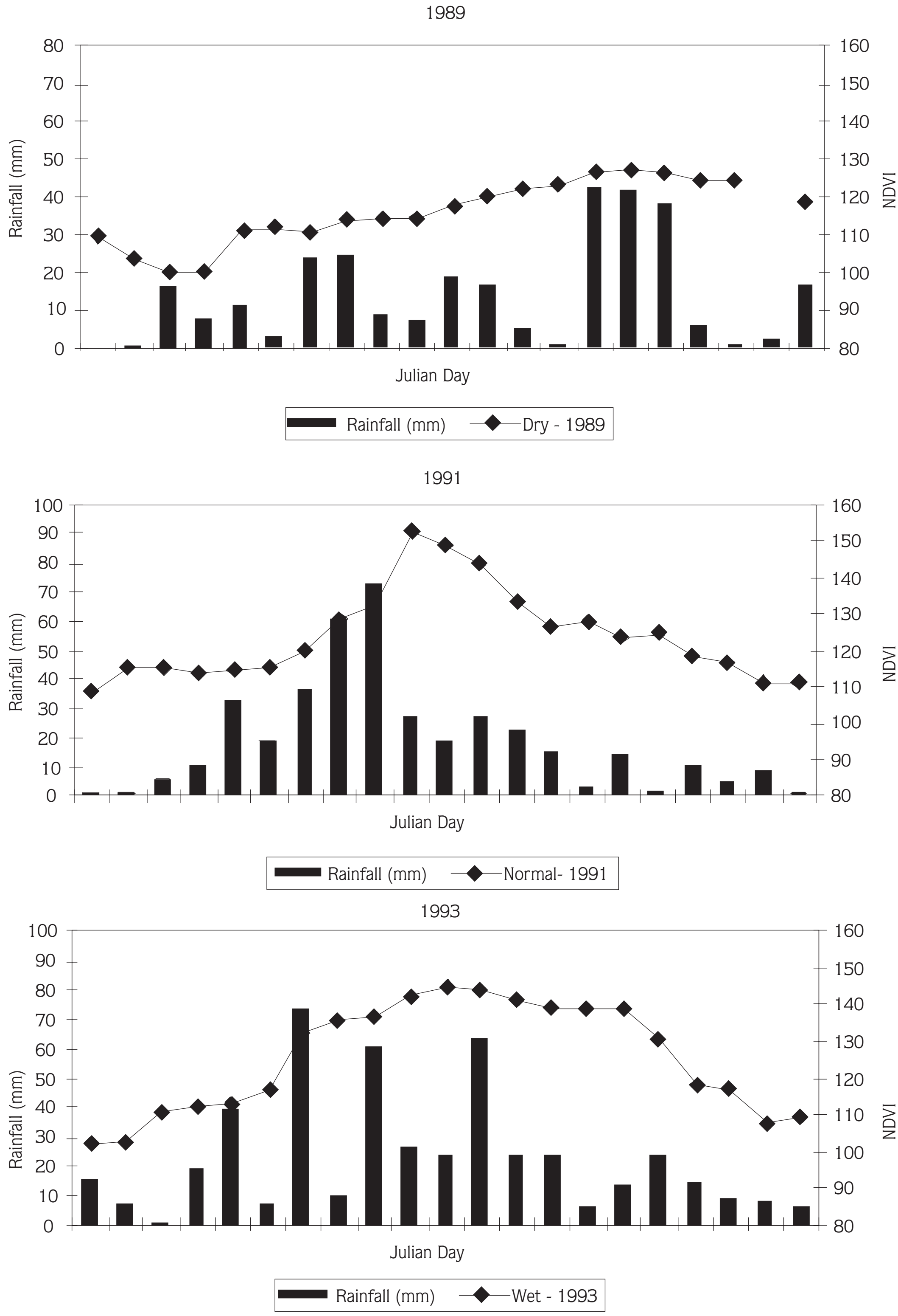

Figure 2. Plots of mean NDVI and bi-weekly total precipitation.

NDVI values. It seems that the NDVI values are directly related to, and are a result of, the amount of precipitation which occurred during the growing season. A visual comparison of the graphical data reveals that NDVI values are high in 1993 and 1991 when normal and above-normal amounts of precipitation were recorded. Conversely, in 1989, because of the very low amount of precipitation, this year showed generally lower NDVI values when compared to a wet year. There are definite responses in NDVI to hotter, drier years, as there are to wetter periods. These results suggest that there is a very high drought influence on the NDVI and a moderate influence of moisture on the NDVI. There are also substantial variations in each moisture regime for dry, normal and wet conditions.

It is clear from Figure 2 that intensity as well as the timing of rainfall events have an impact on vegetation development and production. This is clearly represented in 1989, when most of the rainfall in the study area occurred in August and following months, which corresponds to the end of the growing season; vegetation species did not respond to these late rainfall events as they did in the early growing season. Therefore, the late rainfall events did not affect or increase NDVI, because vegetation cover had already reached the end of its growing season.

Time lags could occur between rainfall events and the subsequent response by vegetation. In general, vegetation is more responsive to multi-month total rainfall events than concurrent or single-month precipitation. Numerous previous studies have discussed the lag between rainfall and NDVI (Malo et al., 1990; Cihlar et al., 1991; Devanport et al., 1993; Yang et al., 1997).

Precipitation was summed one day at a time providing accumulated precipitation for several periods prior to each of the bi-weekly MVC (maximum value composite) periods, such as the concurrent bi-weekly period (C), the past month (P1), the past month and concurrent month (C + P1), the past two months (P2), and the concurrent month and past two months (C + P2). This result provides information for a closer examination of the effect of rainfall on the phenological cycle throughout the year and especially during the growing season. First, a series of correlation coefficients were computed between each vegetation type and rainfall with C, P1, CP1, P2 and CP2 period averages of rainfall prior to image acquisition dates in order to evaluate how lag time affects vegetation response to climate (Table 1). It is observed that the highest correlation occurred when a much longer time period was introduced. Conversely, the lowest correlation coefficient was obtained from concurrent months. For each vegetation type, in 1989 (dry) and 1993 (wet), the maximum correlations were obtained with concurrent bi-weekly periods plus two months prior to image acquisition dates with an *r* of 0.82, 0.67 (grassland and forest, respectively) and 0.93 and 0.84 (grassland and forest, respectively). In 1991 (normal year), the maximum correlations were obtained with the past two months, with an *r* of 0.97 (grassland) and 0.77 (forest). These results confirm the findings of previous studies (Malo et al., 1990; Cihlar et al., 1991; Devanport et al., 1993; Yang et al., 1997).

Second, to better understand and present lag time relationships between vegetation and rainfall, the scatter plots of NDVI versus rainfall for five levels (C, P1, C + P1, P2, C + P2) were generated (Figures 3-5). The best fit was found to be the polynomial function. In looking at

Table 1. Correlations between NDVI (mean, grassland and forest) and rainfall at various time intervals. Columns, from left to right denote correlation of NDVI with rainfall in concurrent month (C), one month earlier (P1), two months earlier (P2), in the concurrent plus two previous months (C + P2), and in the two previous moths (P2). Columns also include correlation coefficient (r), and significance level (p).

		C		P1		C + P1		C + P2		P2	
Years	NDVI	r	p	r	p	r	p	r	p	r	p
1989	Grassland	0.35	0.124	0.55	0.010	0.64	0.002	0.82	0.000	0.77	0.000
	Forest	0.23	0.302	0.43	0.054	0.53	0.015	0.67	0.001	0.66	0.000
1991	Grassland	0.42	0.054	0.86	0.000	0.78	0.000	0.92	0.000	0.97	0.000
	Forest	0.21	0.350	0.57	0.023	0.49	0.023	0.70	0.000	0.77	0.000
1993	Grassland	0.41	0.061	0.74	0.000	0.75	0.000	0.93	0.000	0.91	0.000
	Forest	0.35	0.11	0.68	0.000	0.67	0.000	0.84	0.000	0.83	0.000

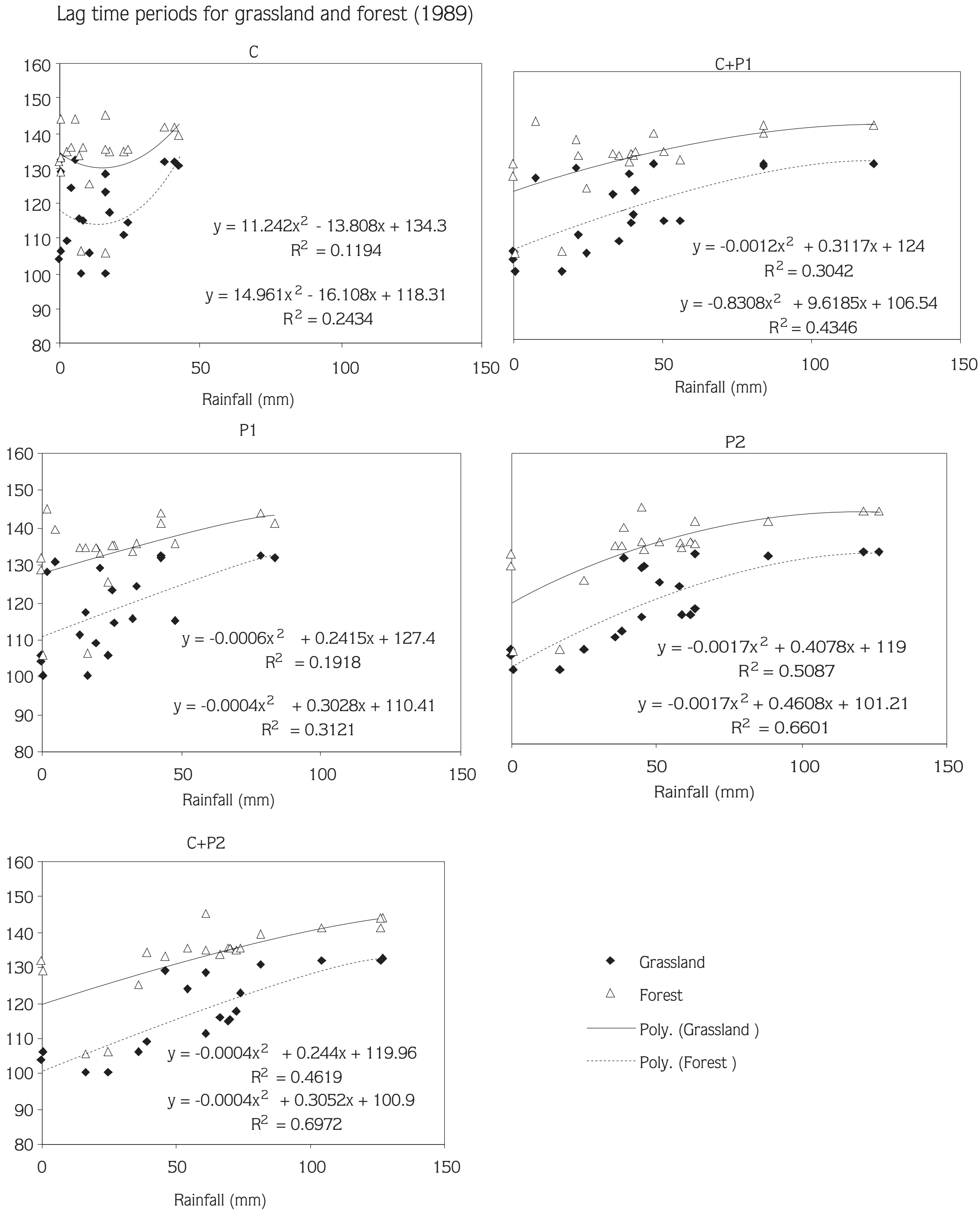

Figure 3. Relationships between rainfall and NDVI at different lag periods for grassland and forest during the dry year (1989).

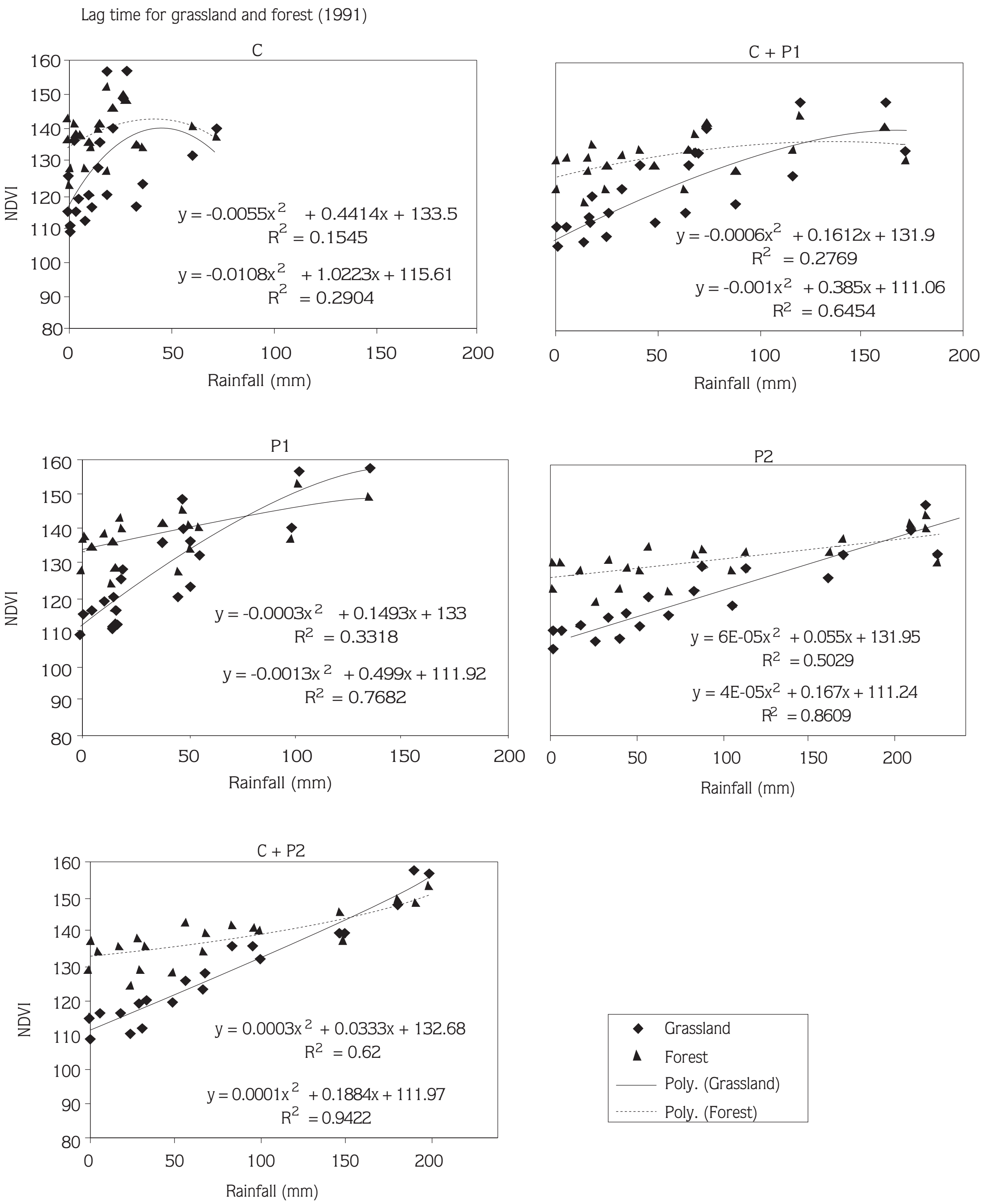

Figure 4. Relationships between rainfall and NDVI at different lag periods for grassland and forest during the normal year (1991).

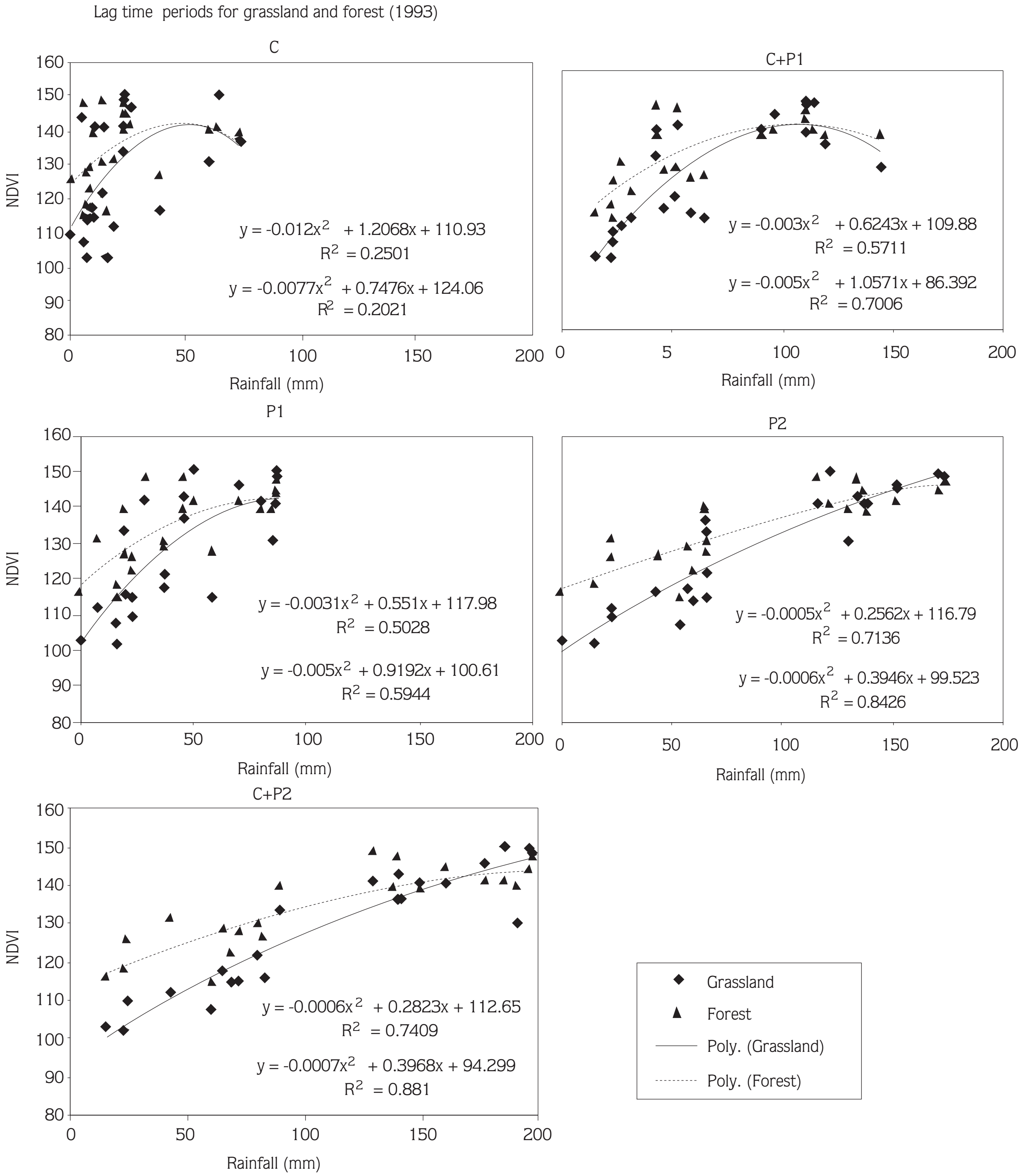

Figure 5. Relationships between rainfall and NDVI at different lag periods for grassland and forest during the wet year (1993).

Figures 3–5, it is obvious that the longer the time period, the stronger the relationship between vegetation and rainfall. Comparison of the strength of correlations between rainfall periods (C, C + P1, P1, P2, C + P2) provides information concerning vegetation response to climate variations. The strength of correlation increases when shifting from rainfall of the concurrent period (R^2 of 0.21, 0.27 and 0.64) to rainfall of the previous month (P1) with an R^2 of 0.31, 0.73 and 0.64 (1989, 1991 and 1993 respectively). The level of correlations increases when introducing other rainfall, such as C + P1, P1, and P2. The C + P2 period generally has the highest R^2 for each vegetation cover type in all three years. For example, grassland represents the highest correlation with an R^2 of 0.69, 0.94 and 0.88 (1989, 1991 and 1993, respectively). Forest also has a higher correlation with the C + P2 period over the three years (R^2 of 0.46, 0.62 and 0.74). These results suggest that the total rainfall of the past two months still has an effect on vegetation development and that grassland areas are more sensitive to climate variations than forest.

Conclusions

In conclusion, rainfall pattern has a significant impact on vegetation development during the growing season. There are obvious responses in the NDVI to drought conditions as there are to abundant moisture conditions. Fluctuations in rainfall events could lead to water surplus or deficit and could influence the phenological cycle of different vegetation formations during the growing season. Another important factor that can have an impact on vegetation state is the rainfall pattern (timing and duration of rainfall events). The frequency of rainfall events in a certain time period, such as bi-weekly period or monthly periods, is also important for vegetation development. Other important factors that may affect vegetation state are the local climate and land cover characteristics of the area. Rainfall characteristics may not be the only factor that influences NDVI values, because other local factors, such as topography, soil characteristics and human practices, should be considered in order to explain climate effect on vegetation cover.

The relationships between NDVI and rainfall showed that C + P2 and P2 rainfall totals have a stronger impact on vegetation state. The correlation coefficients between NDVI and rainfall were statistically significant for all types of vegetation formation, which in turn demonstrates a relationship between rainfall and NDVI. Finally, this study has demonstrated that monitoring vegetation cover using vegetation indices could lead to a better understanding of environmental phenomena and may improve our knowledge about global climate change and the greenhouse effect.

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