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Multitemporal MODIS-EVI Relationships With Precipitation and Temperature at the Santa Rita Experimental Range

Abstract: The Moderate Resolution Imaging Spectroradiometer (MODIS) provides temporal enhanced vegetation index (EVI) data at 250, 500, and 1,000 m spatial resolutions that can be compared to daily, weekly, monthly, and annual weather parameters. A study was conducted at the grassland site (less than 10 percent velvet mesquite [*Prosopis juliflora*, var. *velutina*]) and the mesquite site (approximately 30 to 40 percent mesquite cover) of the Santa Rita Experimental Range (SRER) to relate MODIS monthly EVI to temperature and rainfall patterns. Preliminary results show that these two climate attributes altered the shape of the temporal EVI regime, particularly at the grassland. High temporal variability in the precipitation regime resulted in a weaker relationship with EVI than the more consistent temperature regime.

Keywords: MODIS, EVI, Santa Rita, mesquite, temperature, precipitation, multitemporal, Southwest

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Introduction

Accurate measurements of vegetation dynamics (phenology) at regional to global scale are required to improve models and understanding of interannual variability in terrestrial ecosystem carbon exchange and climate-biosphere interactions (Zang and others 2002). An obvious and appealing approach is to relate the net primary production (NPP) to the climate in order to estimate the efficiency of climate variables to the production of vegetation. Knowledge of the efficiency with which vegetation converts the absorbed photosynthetically active radiation (APAR) into biomass permits an estimate of NPP. Climate constraints on NPP have been studied and have indicated greater consistency in estimates of biomass if APAR is excluded from the annual sum when conditions are unfavorable for production (Turner and others 2002).

The role of precipitation seasonality in arid land systems, although recognized as important, is largely unexplored (Neilson 2003). Together with local elevation and temperature, precipitation determines the distribution and location of vegetation ecotones. With constant competition for water between the grass and shrub communities, the arid Southwest United States vegetation dynamics will better be understood when remote sensing and ancillary data are combined on a multitemporal scale. It has been predicted that the increased precipitation with potential future warming will result in greater distribution of shrubs when winter rains dominate and grass when the summer monsoons are dominant (Neilson 2003).

Perennial grass species have variable net photosynthesis rates as a function of temperature, and this affects the season when a plant is most susceptible to carbohydrate depletion with repeated clipping to simulate grazing. It was shown that mesquite

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had a higher net photosynthesis rate than galleta grass (*Hilaria jamesii*) at 21 and 38 °C. but that galleta grass had a higher net photosynthesis rate at 5 °C (Ogden 1980).

The Moderate Resolution Imaging Spectroradiometer MODIS, on board the Terra platform, has a temporal resolution of 2 days and acquires data in 36 spectral bands at 250, 500, or 1,000 m spatial resolution. The high temporal resolution provides the capability of monitoring rangeland health worldwide (Reeves and others 2001). Because many land cover changes that are due to the invasion of shrubs upon grasslands occur at spatial scales near 250 m, MODIS may be useful in studying rangeland conversions. The VI product described in this paper is derived from the MODIS-250, 16-day level 3 made available to public on request through the EOS Data Gateway.

The Enhanced Vegetation index (EVI) was developed and incorporated into the MODIS products (Huete and others 2002; Van Leeuwen and others 1999). The EVI utilizes the ratio of the reflectance in the near-infrared band (MODIS 841-876 nm) and the red band (MODIS 620-670 nm). It also employs the blue band (MODIS 459-479 nm) for the atmospheric correction, coefficients (C_1 and C_2) of aerosol resistance, L for the background stabilization and G , the gain factor, as follows:

$$EVI = \frac{(\rho_{NIR} - \rho_{RED})}{L + \rho_{NIR} + C_1 \rho_{RED} - C_2 \rho_{BLUE}} G$$

where

$$L = 1, C_1 = 6, C_2 = 7.5 \text{ and } G = 2.5$$

Vegetation indices have been correlated with various vegetation parameters such as LAI, biomass, canopy cover, and fraction of APAR (fAPAR) (Huete and others 2002). The EVI was found to have a more linear relationship with these parameters than the NDVI. The objective of this study is to present a temporal trend of the MODIS EVI product and relate it to the temperature and precipitation of the SRER mesquite-dominated site (approximated between 30 to 40 percent mesquite cover and located at $-110^{\circ}54'56.92''E$, $31^{\circ}47'3.75''N$) and grass-dominated site (less than 10 percent mesquite cover and located at $-110^{\circ}53'44.56''E$, $31^{\circ}46'54.01''N$).

Site Description

The SRER (21,500 ha) is 40 km south of Tucson, AZ, and is administered by the University of Arizona. Small areas of steep, stony foothills and a few isolated buttes characterize the range, but the dominating landscape features are the long, gently sloping alluvial fans. Elevations range from 900 m to about 1,300 m in the southwestern part. Average rainfall increases with elevation, from 250 mm at 900 m to almost 500 mm at 1,300 m (McClaran 1995; McClaran and others 2002)

Vegetation at the SRER varies with soil, rainfall, and elevation. Annual vegetation is most abundant in areas with a moderate to low density of perennial grasses and in areas where native grasses persist over the invasive Lehmann's lovegrass (*Erogrostis lehmanniana*, Nees). Since the early

1900s, major vegetation changes have occurred. Where shrub-free grassland once dominated, velvet mesquite (*Prosopis juliflora* var. *velutina*) is now the dominant overstory species (McClaran and others 2002). This site presents a good opportunity for the study of mesquite encroachment into grassland.

Method

We first selected two sites that represent dense mesquite (simply called mesquite site) and the grassland site that has low-density mesquite trees except in the washes. We obtained the temporal vegetation index data from the MODIS-250m, 16-day composite product provided by the EDC-DAAC. Available data from November 2000 to March 2003 were extracted using the Msphinx software and transferred to Sigmoid software for graphics and S-plus for statistical analysis. The 16-day composite vegetation index was averaged into monthly values for comparison with the monthly climate data sets.

We also obtained the climate data from local weather stations. Local temperature from the Tucson International Airport, which is about 32 km from the study sites, provided a good sample of continuous desert environment temperature. We downloaded the monthly rainfall data of the Rodent and the Enclosure 41 rain gauges from the Santa Rita Web site. The Rodent rain gauge is within the mesquite study site, while the Enclosure 41 rain gauge is within 200 m distance from the grassland site. Precipitation data from the SRER Web site for all the rain gauges until January 2003 was available, and that was the cutoff point for all data sets considered in this study.

Results

Figure 1 shows the multitemporal EVI, temperature, and precipitation profiles from November 2000 to January 2003. High temperature months coincide with the summer monsoon period. The period of low precipitation also corresponds to low EVI value. There was a remarkable difference in the temporal precipitation distribution between the monsoons of 2001 and 2002. The monsoon of the 2001 was better distributed throughout the year and, in fact, there was not a well-defined break between the winter and summer rainy seasons. The year 2002 had little precipitation during winter (December to February), a dry spring (March to May), but a wet summer (June to August) and a small amount during fall (September to November). The temperature profile is more consistent than the precipitation curves. The highest temperature appears in June for the 2 years and lowest during December and January.

The peak EVI appeared in August during 2001 for both the grassland and the mesquite sites. During 2002 the grassland had a sharp rise then a sharp drop in the EVI curve during the period of July to December. The EVI of the mesquite and grassland sites dropped and then rose before the monsoon arrived during the period of November 2001 to May 2002, reaching a minimum in March. During the 2002 season, mesquite had an early rise but did not reach the peak attained by the grassland site after the well-pronounced monsoon precipitation arrived.

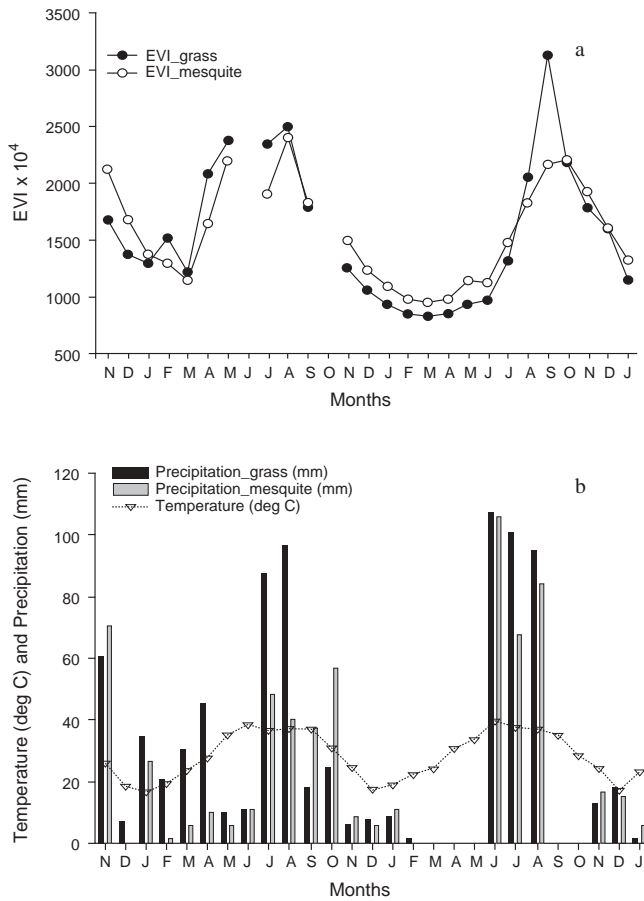


Figure 1—Multitemporal (a) MODIS Enhanced Vegetation Index (EVI) and (b) climate from the Santa Rita mesquite and grassland sites. Data was collected from November 2000 to January 2003. Monthly maximum temperature (°C) was recorded from the Tucson International, and Precipitation at rain gauges Enclosure-41 and Rodent represent the grassland site and mesquite site, respectively.

Figure 2 shows correlation coefficients between temperature, rainfall, and vegetation index from the two sites. The EVI curves of the two sites are predominantly similar, followed by the precipitation and temperature. The grassland site, however, showed a temporal variation that was more correlated to climate attributes than the mesquite site.

Discussion

The EVI, temperature, and precipitation annual sinusoidal curves are out of phase with each other. Temperature is the most consistent variable throughout, followed by the EVI. Warmer months and summer monsoon give rise to high primary production. Low winter temperature reduces the primary production, even when substantial amount of precipitation occurs. Vegetation phenology therefore appears to follow a compromise pattern between precipitation and temperature temporal variations. This vegetation response confirms the importance of monsoon and warm temperature to desert grasslands that characterizes the C_4 photosynthetic pathway (McClaran 1995). Winter and spring rains induce an early takeoff in grassland production compared to the mesquite site. Ogden (1980) reported similar patterns where carbohydrate flow was higher in stems during November to March and dropped during the summer for sideoats grama, while the rain peaked during July to September.

The contrasting variations in precipitation between the 2 years observed in this study did not alter the temperature curves. EVI profiles for the two sites are more separable during the summer monsoon but tend to converge during the spring and early summer months. Precipitation plays a dominant role in evoking these differences. The arrival of precipitation during the spring, as noticed during the 2001 season, stimulated the growth of both the mesquite and grass, but the grass site had a closer relation to precipitation than the mesquite site.

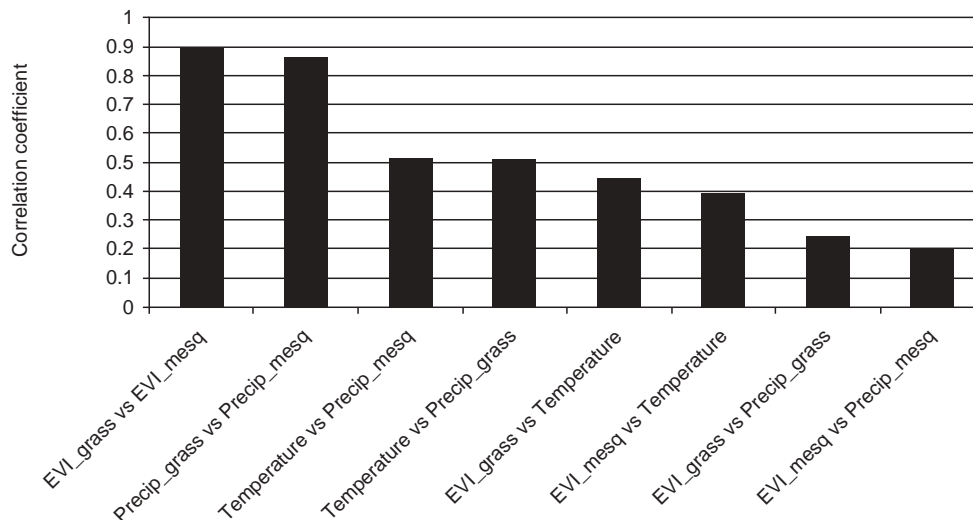


Figure 2—Relationships between enhanced Vegetation Index (EVI), Temperature, and Precipitation for the grassland and mesquite sites of the Santa Rita Experimental Range. The correlation coefficients are ranked from high to low.

Conclusion

It is evident that precipitation is the dominant attribute that controls the growth of grass in arid rangeland. However, initial growth is also possible before summer rain arrives. Mesquite growth is dependent on precipitation arrival time and amount, but responds less to precipitation variability than the grass. The ability of trees to tap into deeper soil moisture provides them with a competitive advantage and makes them less reliant on surface conditions than their grass counterparts. Warming up after a cool winter triggers new growth in rangeland vegetation. Mesquite cover responds better to seasonal temperature regimes than grass. MODIS is providing an opportunity to study the temporal dynamics of rangeland vegetation and should assist in estimating the carbon fluxes over time.

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