

# Using High Temporal Resolution Satellite Data to Assess Shrub Control Effectiveness

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**Abstract**—In 1988 and 1992, personnel with the Jornada Experimental Range in southern New Mexico chemically treated a large grassland area for mesquite (*Prosopis glandulosa*). The treatments were successful in defoliating nearly 100% of the mesquite plants present. Since treatment, plant recovery and invasion has resulted in current mesquite densities of about 2% cover. We assessed vegetation index information derived from meteorological satellite imagery recorded over seven growing seasons (1987-1993). The data were used to track the photosynthetic activity of mesquite canopy from pre-treatment through both treatments. Differences in seasonal landscape greenness characteristics derived by analysis of the satellite data show the effect of the chemical treatment, as well as the recovery of the mesquite. This research demonstrates the potential utility of satellite derived information in assessing vegetation response to implementation of range management strategies. Similar techniques applied over longer time periods could be utilized to monitor ecosystem health and aid in managing arid shrublands.

Much of southern New Mexico once dominated by grassland is now dominated by mesquite (*Prosopis glandulosa*). Mesquite is a thorny, long-lived, winter deciduous shrub that exhibits a C<sub>3</sub> photosynthetic pathway, and initiates vigorous leaf growth during the spring with fruiting during early- to mid-summer (Valentine and Norris 1960). It forms cream colored flowers that develop into seed pods that are four to eight inches long (Gay and others 1984). It is drought resistant, with a tap root system that can grow as deep as 60 feet (Gay and others 1984; Valentine and Norris 1960). The deep tap root often allows mesquite to draw upon ground water reserves. Mesquite also has long lateral roots, long-lived seed and a high germination rate even under adverse temperature and moisture conditions (Hennessy and others 1983). Underground mesquite stems contain dormant buds that sprout when the above-ground biomass is killed (Valentine and Norris 1960). Mesquite has little forage value, but the seed pods are sought out by livestock. New mesquite seedlings are often the result of the dispersal of seeds by livestock, rodents, and rabbits.

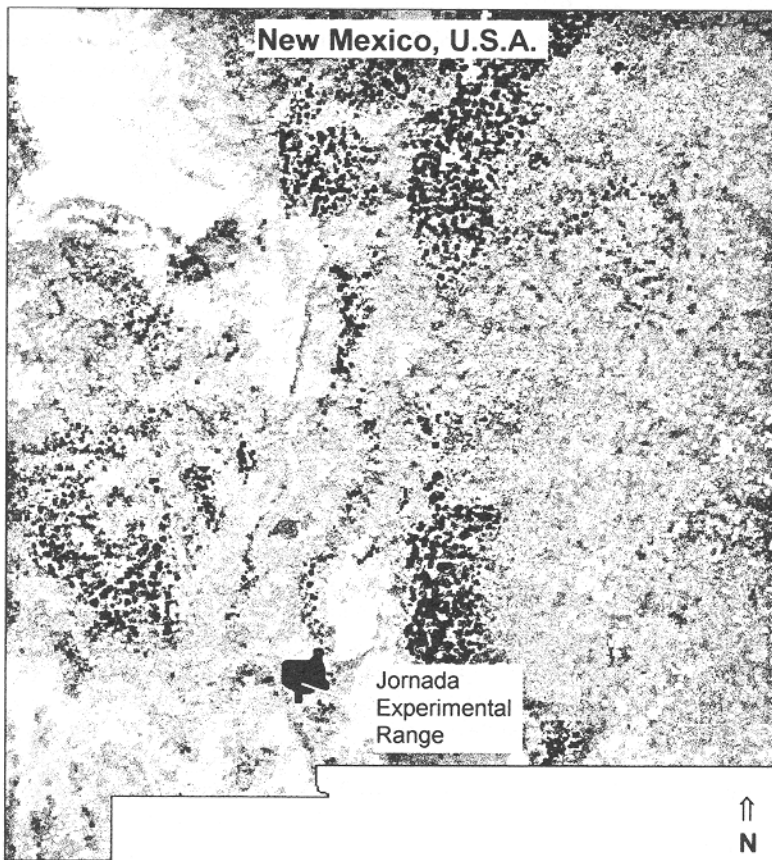
It is believed that mesquite was originally dominant along washes. Native Americans used mesquite extensively, and pockets of mesquite dunes apparently formed around their campsites (York and Dick-Peddie 1969). Also, it has been reported that early ranchers would commonly carry a bag of mesquite pods with them to feed their horses (Gardner 1951). With increased grazing pressure, the expansion of mesquite from these areas was rapid (York and Dick-Peddie 1969). Between 1858 and 1963, the area of the Jornada Experimental Range in south-central New Mexico (fig. 1) dominated by mesquite increased ten-fold (Buffington and Herbel 1965). Mesquite tends to invade sandy soils, and dunes commonly form as grass cover is reduced and erosion increases (Buffington and Herbel 1965; Herbel and others 1983). Once dune formation has occurred, return of the area to grassland is highly unlikely (Gardner 1951).

Research on various treatments to control mesquite has been underway for most of this century, but escalated with the introduction of 2,4,5-trichlorophenoxy-acetic acid (2,4,5-T) in the mid-1940's (Valentine and Norris 1960). Research using 2,4,5-T and other chemicals to control mesquite has been extensive in southern New Mexico (see Herbel and Gould 1995; Herbel and others 1983; Gould 1982; Valentine and Norris 1960). While complete and long-term kill of the plants has not been accomplished, research does show that mesquite can be effectively managed using chemicals, however, this level of management may not be economically feasible (Herbel and Gould 1995). Chemical treatment of mesquite has been shown to decrease mesquite density, increase grass cover (Herbel and others 1983; Herbel and Gould 1995), and decrease soil erosion (Gould 1982). The greatest impact has been when treatment was applied during late May or early June following adequate spring moisture to generate vigorous mesquite growth (Herbel and others 1983). Effective single treatment should result in root kill exceeding 30%, and 50% from repeat treatments (see Herbel and Gould 1995).

In southern New Mexico, dominant perennial grasses are C<sub>4</sub> species that require relatively high night temperatures to produce new growth. Timing of green-up and maximum growth of desert grasses is primarily a function of water availability and temperature (Stephens and Whitford 1993). Because mesquite is growing actively in the spring while the C<sub>4</sub> grasses remain dormant, a temporal sequence of satellite derived images should be useful in detecting the effectiveness of chemical treatment, and the resulting plant community response. Ideally, chemical treatment would result in a decrease in mesquite (C<sub>3</sub> shrub) production and an increase in C<sub>4</sub> grass production (Herbel and Gould 1995). Using a temporal, satellite-derived vegetation index (VI), this ideal

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**Figure 1**—Location of the Jornada Experimental Range in southern New Mexico. The background image is a sample of NOAA-AVHRR satellite data.

treatment outcome resulting in a shift of photosynthetic activity from the spring to the monsoon season, would be seen to decrease VI values in the spring and increase values during the monsoon.

The question asked during our research was: Are these expected changes in plant community growth characteristics detectable with high temporal resolution satellite data? Therefore, the goals of our research were to show the ability of temporal satellite spectra to detect ecosystem response to chemical treatment of mesquite and to demonstrate their utility as a management tool.

## Study Area

The Jornada Experimental Range (JER) lies within the Jornada del Muerto portion of the northern Chihuahuan Desert in southern New Mexico (fig. 1). Elevations on the JER range from 1,180 to 1,375 m. Precipitation is highly variable. Of the 230 mm. average annual precipitation, 52 percent comes in July, August, and September (Gibbens 1991). While summer precipitation is generally from localized, high-intensity, short-duration storms, winter moisture is commonly the result of synoptic, low-intensity, frontal storms (Gibbens 1991). High temperatures and low humidity result in large evaporation losses. Potential evaporation

can be as much as ten times the annual precipitation of the area (Paulsen and Ares 1962). The frost-free period averages 200 days, but the effective growing season (the duration of favorable soil moisture and temperatures) is often less than 90 days (Paulsen and Ares 1962).

The JER lies at the boundary between the North American warm deserts to the south and west and the plains grasslands to the north and east. For this reason, Lowe (1967) refers to the area as an ecotone, with a climate that is intermediate between desert and grassland. Historically, the area has more commonly been referred to as desert grassland (see Dick-Peddie 1975; Humphrey 1958). Pre-settlement, the landscape was a mosaic of grassland with desert scrub occupying the hotter, drier sites (Gardner 1951; Buffington and Herbel 1965; York and Dick-Peddie 1969; Dick-Peddie 1975). Today the inverse is true, Chihuahuan Desert scrub dominates the landscape with grasslands limited primarily to more mesic sites (Dick-Peddie 1975).

The sites selected for this analysis are in a grass/shrub transition zone where active mesquite encroachment is ongoing. Pre-settlement, the area was dominated by black grama (*Bouteloua eriopoda*) (Dick-Peddie 1975; York and Dick-Peddie 1969). Mesquite was historically found along drainages, scattered or in thickets in the uplands (Humphrey 1958), and around Native American campsites (York and Dick-Peddie 1969). Presently, mesquite dominates much of the area around our study sites, and stands have thickened and spread since pre-settlement times. Mesquite can have widely varied sub-dominants depending upon the type of soil and level of degradation of the landscape. Our study area has mesquite growing in association with a grassland community made up primarily of grammas (*Bouteloua spp.*), sporoboluses (*Sporobolus spp.*), and soap tree yucca (*Yucca elata*). As mesquite invasion continues, coppice dune formation commonly occurs with soils and nutrients being stripped from inter-dunal spaces by wind and accumulated around the base of the mesquite plants. This is the condition to the north of the sites analyzed here.

It is very difficult for other species to establish and survive in these inter-dunal spaces. Where upland grasslands remain, grammas, sporoboluses, muhlys (*Muhlenbergia spp.*), and three-awns (*Aristida spp.*) dominate, with scattered individuals or patches of snakeweed (*Gutierrezia sarothrae*), soap tree yucca, mesquite, tarbush (*Flourensia cernua*), and/or creosote bush (*Larrea tridentata*) (Dick-Peddie 1986; Gay and others 1984).

## Methods

Our data were derived from the National Oceanic and Atmospheric Administration's Advanced Very High Resolution Radiometer (NOAA-AVHRR). These operational weather satellites were intended primarily for observation of cloud and sea-surface parameters, but their ability to monitor changes in land characteristics over large areas makes them invaluable for land-based studies (NOAA 1991; Tucker and others 1991). Multispectral data acquired by the AVHRR from NOAA-10 and NOAA-12 were obtained for the 1987

through 1993 growing seasons. Data from the High Resolution Picture Transmission (HRPT) mode of the NOAA sensors have a spatial resolution of 1.1 km at satellite ground track (nadir). Other characteristics include high radiometric resolution (1,024 gray levels), high temporal resolution (daily coverage), 2,400 km scanning view, and a 07:30 equatorial overpass time (NOAA 1991). All data acquired have satellite nadir in or very near the study area.

## Image Preprocessing

We implemented a one-step algorithm for combining geometric and radiometric calibration, and solar zenith angle corrections (Di and Rundquist 1994). An image processing step accounts for per-date sensor scan-angle distortion by georeferencing each pixel to a latitude and longitude coordinate system. Subsequent image processing and analyses were conducted using the Earth Resource Data Analysis System (ERDAS) software on a Personal Computer. All georeferenced images were interactively coregistered to within one pixel locational tolerance, and 10-bit resolution was retained throughout our analysis.

Cloud obstruction in the imagery was minimized through image masking. To accomplish this we used the thermal channel of the AVHRR sensor (10.3-11.7 mm) to locate cloud pixels which are generally cooler than the land pixels. The red image band was utilized to mask pixels lying in cloud shadows. A binary cloud mask was produced for each date of imagery by designating clouds and cloud shadows as zero-value pixels and non-cloud pixels as one. Subsequent multiplication of the cloud mask and reflectance images resulted in elimination of clouds by conversion to a value of zero. Atmospheric attenuation was standardized for all red and near-infrared images using histogram minimization (Jensen 1996). The signal obtained from reflectance at the center of Elephant Butte Reservoir was used as the base value. Histograms were shifted downward for each date of imagery so that reflectance over Elephant Butte Reservoir was the same for all imagery, thereby normalizing atmospheric path radiance throughout the data.

## Vegetation Indices

Successful vegetation discrimination on the basis of satellite data depends upon the contrast in spectral radiance between vegetation and the surrounding soil (Tucker 1979). Mesophyll tissue in actively growing vegetation strongly reflects near-infrared energy, while chlorophyll strongly absorbs red energy for photosynthesis. A mathematical quantity referred to as the Normalized Difference Vegetation Index (NDVI) is routinely calculated from AVHRR data due to its sensitivity to the presence of photosynthesizing vegetation and its ability to normalize atmosphere and background attenuation (Huete and Jackson 1987; Huete and Tucker 1991; Tucker and others 1991). Formulation for NDVI is:  $(NIR - RED)/(NIR + RED)$ , where

NIR equals Near-Infrared reflected energy (0.725-1.10 mm) and RED equals Red-reflected energy (0.58-0.68 mm). Calculation of the NDVI results in pixels with an index value theoretically between -1.0 and +1.0. Vegetation will generally yield positive index values, water will yield negative values, and bare soil will result in values near zero due to the reflectance characteristics of these surface materials (Lillesand and Kiefer 1994; Tucker 1979).

## Site Delineation

Sites used in the analysis of mesquite control effectiveness were delineated through unsupervised classification of 1993 NDVI images. This resulted in identification of one polygon (site) made up predominantly of the chemically treated area, and another to the north that is primarily untreated (fig. 2). We believe that the process of delineating polygons that remain consistent throughout our analysis provides for standardization of soil background (Peters and Eve 1995). These polygons resulted in a consistent spatial unit for all subsequent temporal analyses. Temporal changes in scene reflectance were then measured and compared. Soils at a given location do not change significantly during a growing season. In desert ecosystems with their inherent low vegetation cover, the ratio of vegetation to soil background remains relatively constant (Huete and Tucker 1991). Even though we do not know the exact effect of soil background in each site, relative changes in NDVI temporal patterns are still meaningful. Additionally, we have carefully selected our

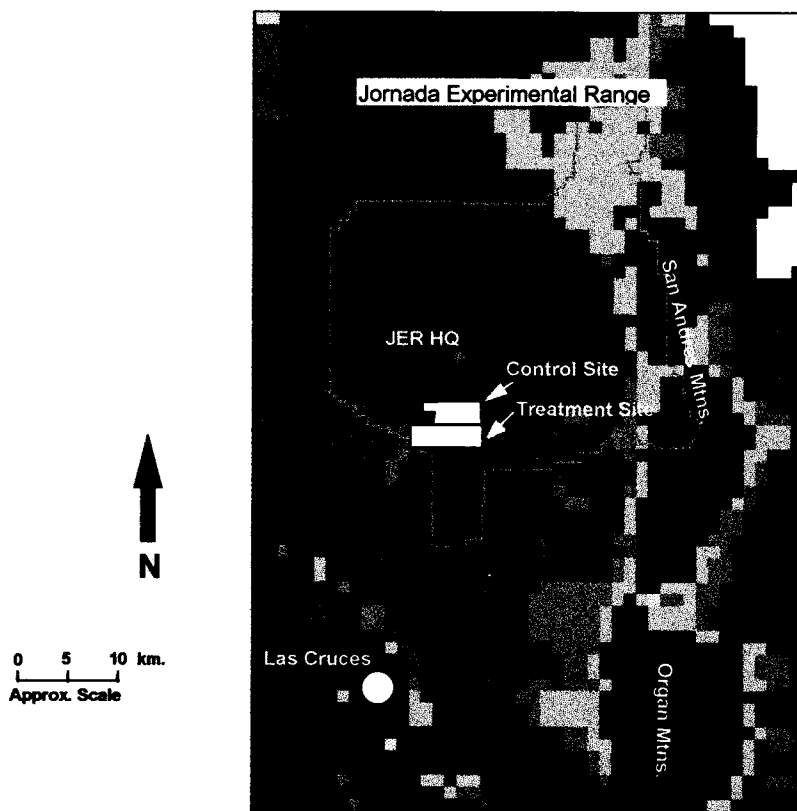


Figure 2—Location of the treatment and control sites on the Jornada Experimental Range.

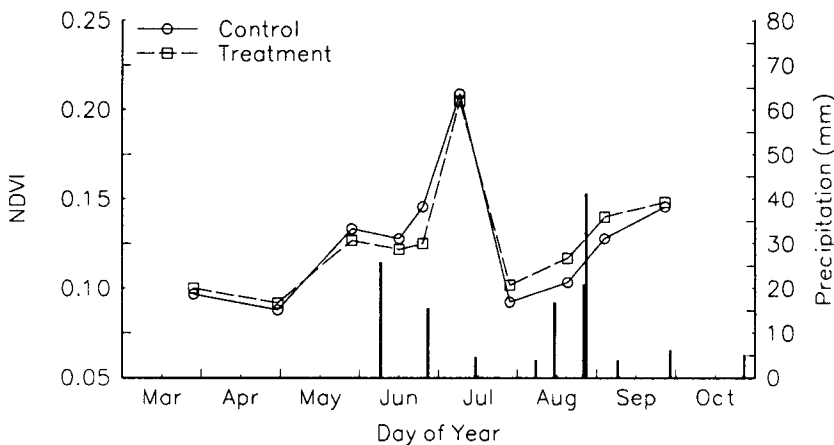
single-date HRPT imagery to minimize the effects of soil moisture and off-nadir atmospheric attenuation.

## Results and Discussion

The level of photosynthetic activity at each site (as measured by NDVI) was graphed for each of seven growing seasons from 1987 to 1993. These seven years exhibit temporally variable precipitation patterns, and variable NDVI growth patterns from year to year. In spite of this temporal variability, year by year comparison between chemically treated and non-treated (control) sites reveals the effect of the treatment on the photosynthetic activity of the plant community. The treatment site comprised 12 AVHRR pixels (14.52 km<sup>2</sup>), and the control site 9 pixels (10.89 km<sup>2</sup>). Each year was analyzed in sequence.

Prior to chemical treatment, the seasonal growth curves for 1987 are very similar for both sites (fig. 3). June was unusually wet, resulting in an NDVI spike in early July. Depending upon temperatures and nutrient availability, this could be photosynthetic activity of shrubs, grasses, and/or annuals. Both sites lie at the boundary of active mesquite invasion. The treatment site still contains the original black grama, along with other grasses and mesquite, while the control site is dominated by mesquite, dropseeds, and three-awns, and almost no black grama (table 1). These community composition differences account for the slight separation in the curves in the spring (treatment site having less photosynthetic productivity) and late summer (treatment site having more activity).

In 1988, precipitation patterns were more typical of this area, with minimal spring precipitation and monsoonal moisture starting in early July. The growth curves for the two sites begin the year almost identically. Upon chemical treatment in early June (fig. 4), the NDVI curve for the treated area drops, indicating defoliation of the mesquite. With the mesquite no longer competing for water and nutrients, the C<sub>4</sub> grasses of the treatment site are able to grow much more vigorously during the monsoon season than in the control site.



**Figure 3**—Temporal NDVI curves for treatment and control sites for the pre-treatment year 1987. Precipitation at Rabbit Rain Gauge is presented on the right y axis.

**Table 1**—Species cover and composition at the treatment and control sites.

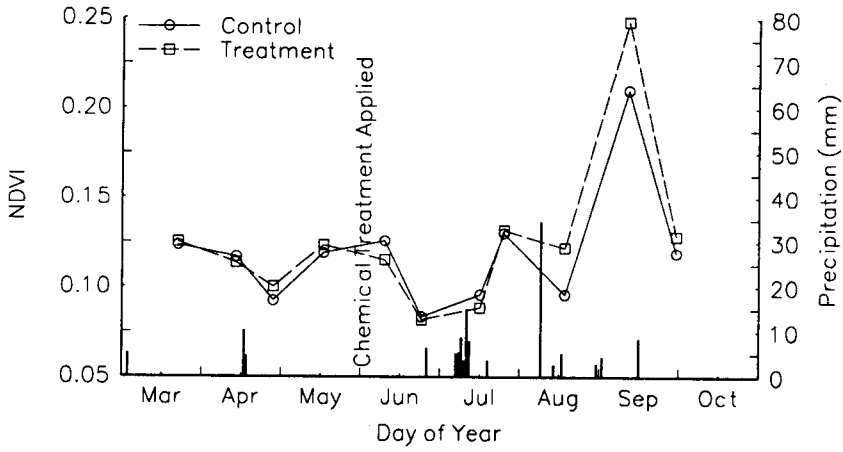
1994 Field Cover and Composition Data		
Species	Control (%)	Treated (%)
<b>C<sub>3</sub> Species</b>		
<i>Prosopis glandulosa</i>	12.70	1.91
<i>Atriplex canescens</i>	1.29	—
<i>Gutierrezia sarothrae</i>	3.38	4.31
<b>C<sub>4</sub> Species</b>		
<i>Bouteloua eriopoda</i>	0.03	13.14
<i>Sporobolus flexuosus</i>	5.80	5.37
<i>Aristida longiseta</i>	0.20	5.57
<i>Erioneruron pulchellum</i>	2.88	—
<i>Muhlenbergia porteri</i>	0.04	0.20
<i>Hilaria mutica</i>	—	0.10
<b>CAM Species</b>		
<i>Yucca Elata</i>	—	0.62
Total C <sub>3</sub> Species	17.37	6.22
Total C <sub>4</sub> Species	8.95	24.42
Total CAM Species	—	0.62

During 1989, the first full season after the chemical application, the effects of the treatment are very noticeable (fig. 5). The control (mesquite) site has a markedly higher spring peak, and the treatment (grass) site is higher from the onset of monsoonal moisture through senescence. This is to be expected as the treatment reduces shrub production and increases grass production.

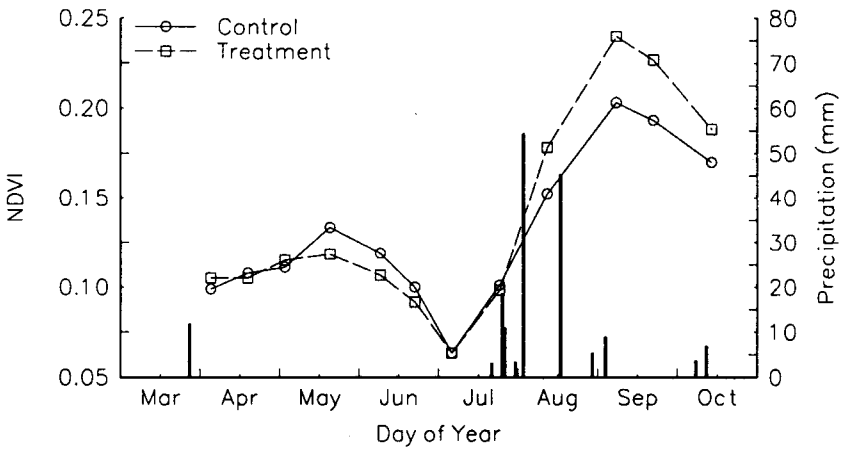
Precipitation timing was unusual in 1990, especially during the monsoon period. From early July through the end of September frequent small rainfall events were recorded (fig. 6). Most of these did not even exceed 10 mm. Such small events are typically ineffective for plant biomass production (W.G. Whitford, personal communication). The temporal growth curves reflect this, as no strong monsoonal peak is obtained. Because of this, it is difficult to interpret plant growth patterns during the monsoon (fig. 6). The low point on the control site in late August appears anomalous. It could be

due to localized wet soil, or unaccounted for atmospheric attenuation. During the spring of 1990, however, the two curves do show the expected separation. The treated site does not exhibit the level of photosynthetic activity that the mesquite dominated site does.

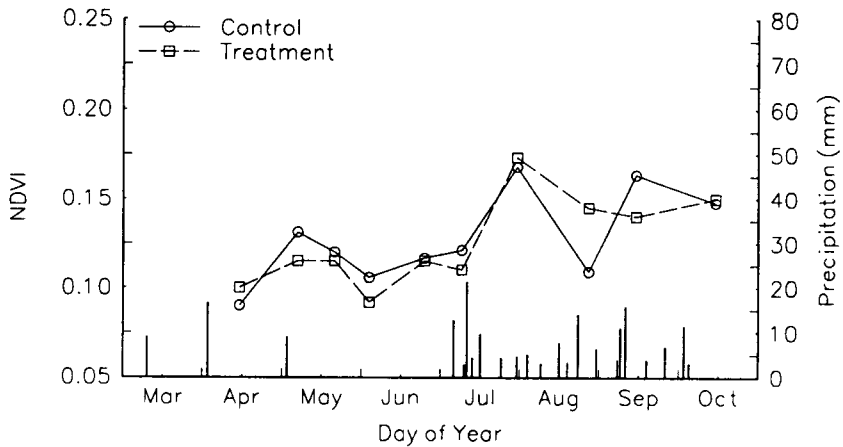
By 1991, the effect of the treatment is no longer evident (fig. 7). The separation in the NDVI curves is very subtle, as was the case during the pretreatment year (1987). Again the treatment (grass) site has slightly less photosynthetic activity in the spring, and a very slightly higher peak during the monsoon season. The similarity in these curves would indicate that the mesquite canopy cover has increased, and the 1988 treatment has lost its effect. One point of interest during the 1991 growing season is the response of vegetation to the large precipitation event in early July.



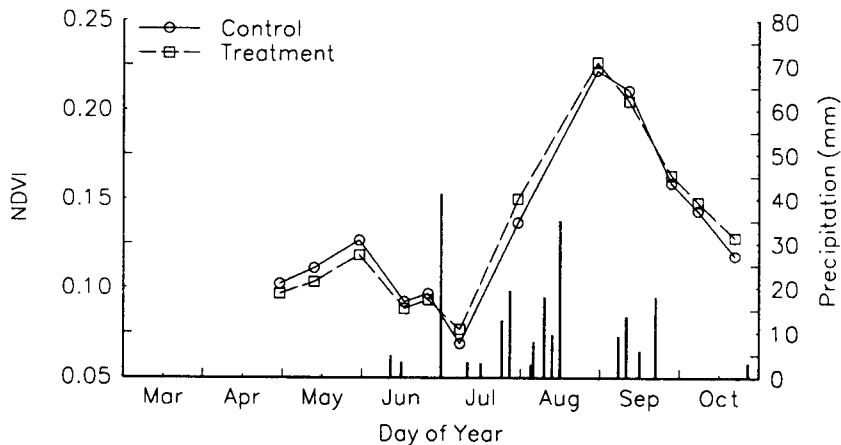
**Figure 4**—Temporal NDVI curves for treatment and control sites for the first treatment year 1988. Precipitation for the Rabbit Rain Gauge is presented on the right y axis.



**Figure 5**—Temporal NDVI curves for treatment and control sites for the first full season post-treatment 1989. Precipitation at Rabbit Rain Gauge is presented on the right y axis.



**Figure 6**—Temporal NDVI curves for treatment and control sites for the second season post-treatment 1990. Precipitation amounts at Rabbit Rain Gauge are presented on the right y axis.



**Figure 7**—Temporal NDVI curves for treatment and control sites for the third year post-treatment 1991. Precipitation amounts recorded at the Rabbit Rain Gauge are presented on the right y axis.

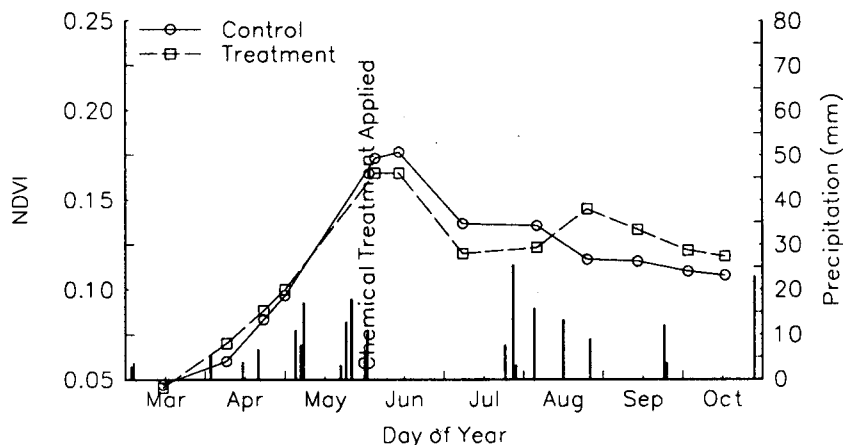
The spring of 1992 was wetter than normal. Both NDVI curves are identical during the early spring season (fig. 8), reinforcing the conclusion from the 1991 curves that the treatment has lost its effectiveness. As in 1988, the curves separate coincidentally with the defoliation of the mesquite resulting from the chemical application. The unusually wet spring generated a large spring growth activity peak, reflecting a high level of spring biomass production. The monsoon season was drier than normal, and vegetation growth response during the spring probably used most of the available nutrients, resulting in minimal photosynthetic activity during the late summer. The treatment (grass) area was more productive than the control area as measured by NDVI. In fact, the control area did not peak at all during the 1992 monsoon.

In 1993, the first full season after the second chemical treatment, the effect is again noticeable (fig. 9). The grass dominated treatment site had lower spring vegetative activity and higher monsoon season. The differences, however, are not as pronounced as they were following the 1988 treatment. Before any comparisons of 1988 versus 1992

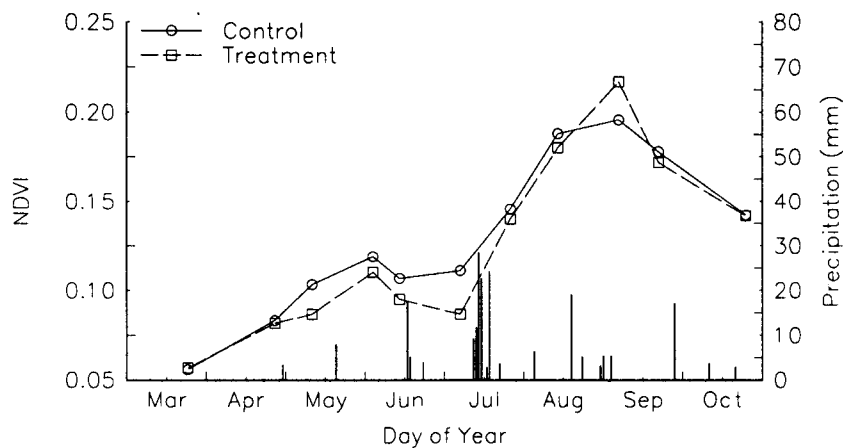
treatment effectiveness could be made, 1994 and 1995 data would need to be analyzed as well.

## Conclusions

We expected chemical treatment would result in a reduction of  $C_3$  mesquite production and an increase in  $C_4$  grass production. This shift would be detected by satellite-derived vegetation index curves as a decrease in the index during the spring and an increase during the monsoon season. The sites analyzed show this expected pattern of response. A satellite-derived temporal comparison of treated versus untreated sites successfully provided an indication of plant community photosynthetic response to chemical treatment of mesquite. Furthermore, we were able to determine the length of time of treatment effectiveness. We believe that our research demonstrates the utility of high temporal resolution satellite data for monitoring regional landscape change. We show that carefully calibrated, satellite-derived inputs could be developed to aid monitoring of ecosystem health and managing arid shrublands.



**Figure 8**—Temporal NDVI curves for treatment and control sites for the second treatment year 1992. Precipitation amounts at Rabbit Rain Gauge are presented on the right y axis.



**Figure 9**—NDVI curves for treatment and control sites for the first year post-treatment 1993. Precipitation amounts at Rabbit Rain Gauge are presented on the right y axis.

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