BLUE GRAMA (*Bouteloua gracilis*) RANGELAND BIOMASS ASSESSMENT AT THE PEAK OF THE RAINS IN NORTH-CENTRAL MEXICO USING NOAA-AVHRR-LAC

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ABSTRACT:

A ground survey programme was conducted in NW Aguascalientes, north-central México to validate the use of NOAA-AVHRR-LAC for rangeland biomass production monitoring at the rainfall peak. Field measurements of biomass of herbaceous species were made for 22 study sites in September 1990. The sites were 1km^2 and were representative of the blue grama (*Bouteloua gracilis*) rangeland vegetation type which occupy a large part of northern and central México. Mean herbaceous biomass varied from 262 to 2190 kg (DM) ha^{-1}. AVHRR-LAC data were acquired and the NDVI vegetation index was performed. Regressions between NDVI and biomass production were conducted to study their relationship. Variability in NDVI allowed clear identification of levels of biomass from land-cover differences at calibration sites. The correlation between NDVI and biomass production was 0.73 (r^2) when study sites affected by tree species where eliminated from the data set. A single date cannot explain detailed changes in this wide vegetation type unless extensive temporal calibration is performed as well as the discrimination of tree and shrub species on the NDVI.

Key words: NOAA-AVHRR-LAC, rangeland, biomass, double sampling technique.

1. INTRODUCTION

Rangeland monitoring using NOAA-AVHRR data has developed within a large body of research addressing the general subject of multi-temporal vegetation studies using AVHRR-LAC data (Tucker *et al.*, 1985; Kennedy, 1989). In 1990 AVHRR-NDVI data covering NW Aguascalientes, north-central México has been analysed to demonstrate its potential and ability for monitoring the rangeland vegetation.

Owing to the importance of livestock to the economy of México, reliable data on conditions of the rangeland areas are important for economic forecasting as well as resource management. In the past, very little data on the regional variations in forage conditions were available to range managers and extension service of the Ministry of Agriculture and Water Resources.

The objective of this paper is to present the results after a comparative study of AVHRR-LAC-NDVI and biomass production collected in the field during the peak of the rainfall period of 1990.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

This study was carried out in an area of approximately 2400 km^2 *Bouteloua-Lycurus* rangeland belt from south Zacatecas to western Aguascalientes in north-central México (Figure 1). The area lies between longitude 102° 23' and 102° 35' W and latitude 21° 57'and 22° 30' N at an average elevation of 2260 m at sea level.

The thirty years (1943-1973) mean annual temperature in this region was 17° C, with a mean maximum and minimum of 21° C and 15° C, respectively. Mean rainfall was 492 mm. Soils are mainly of volcanic origin and range from sandy loam to clay in texture. The most important species on a biomass basis are sprucetop grama *(Bouteloua chondrosioides)*, wolftail *(Lycurus phleoides)*, blue grama *(B. gracilis)*, *muhly grass (Muhlembergia rigida)* and short grass *(Microchloa kunthii)*.

Figure 1. Map of the Study Area in Aguascalientes, north-central México.

The 1990 rainy season was highly efficient, both in the total precipitation and distribution of the rain which fell. 1990 has been reported as a better year than others in the 1980s for biomass production, receiving 49% (732 mm) more than the long-term average rainfall (SARH, 1990).

2.2 Field Data

2.2.1 Selection of Sample Sites

Twenty-two 1 km^2 study sites were selected after careful examination of Landsat MSS and SPOT images, aerial photographs and 1:50000 topographic and vegetation maps (INEGI, 1988). Reconnaissance on the ground was undertaken to confirm that sites were reasonably uniform and representative of the region. Some sites occurred in isolated small hills at the east and north of the study area. Eight sites were included in rested pastures and the remaining ones (14) were on communal land (Ejido) grazed by cattle, sheep, horses, goats and donkeys.

2.2.2 Sample Size

The following formula described by Curran and Williamson (1985) was employed to calculate the number of samples required to give biomass estimates within a confidence limit of 0.15 error of the mean

$$Sample\ Size\ =\ (CV\ t/e)..................(1)$$

where,
CV= coefficient of variation
t= students t value for n-1 at 95% level of confidence
e= relative error in percentage

Results from several experiments were combined to establish that weights from at least 52 sample plots of 0.5 by 0.5 metres (0.25 m^2) quadrats were required in order to maintain the variance of biomass estimates to within 15% of the mean.

2.2.3 Biomass collection

In order to minimize differences due to growth and phenological stages, the sampling was done during the first two weeks of September 1990, when the rainy season is at its peak.
Sampling plots were distributed in a random order along a central 1 km transect within each study site (Figure 2). The number of estimated quadrats and the proportion harvested depend on the accuracy required. A ratio of 4:1 (52:13) between visually estimated plots and clipped plots was adopted for biomass data collection. The increased number of samples will reduce the effects of small-scale changes along the transect and the accuracy will be improved when estimating mean biomass of the population.

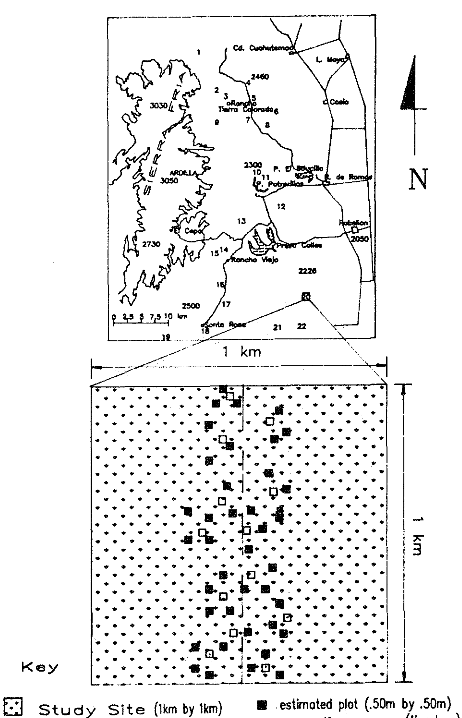

Figure 2. Double sampling scheme for assessing biomass and basal cover into the study site.

During the sampling period, a three man team was able to clip 286 plots and visually estimate 1144 plots in 4400 ha in 10 days. Visual estimates were not compared with the clipped weights during the day work. The person doing visual estimation also had no prior knowledge of which quadrat would be clipped. These precautions were taken to minimize bias.
The actual field estimates were made of wet weights clipped to the ground level. The harvested values of the 22 study sites to which the calibration is made were oven-dried weights at 80° C for 48 hours. A relation between the actual and estimated values of the Tascatita study site is shown in Figure 3.

2.3 Satellite data

2.3.1 Image Processing

Scenes of AVHRR local area coverage (LAC) data of México were obtained from NOAA-NESDIS in Washington, D.C. One scene was selected on the basis of near-nadir viewing and low percentage of cloud cover which coincided with the peak of the rainfall period ground survey. The digital data were analysed at the Silsoe College Remote Sensing Unit on the GEMS interactive image display system.
Each channel were geometrically registered using around 40 ground control points (GCP), maximum error in registration were two kilometers, though registration suggested that the average error do not exceed one kilometer in the vicinity of the study area. An improved geographic positioning of 0.5-1 km was obtained through an interactive process of registering the image to the coastal line of a digitized UTM

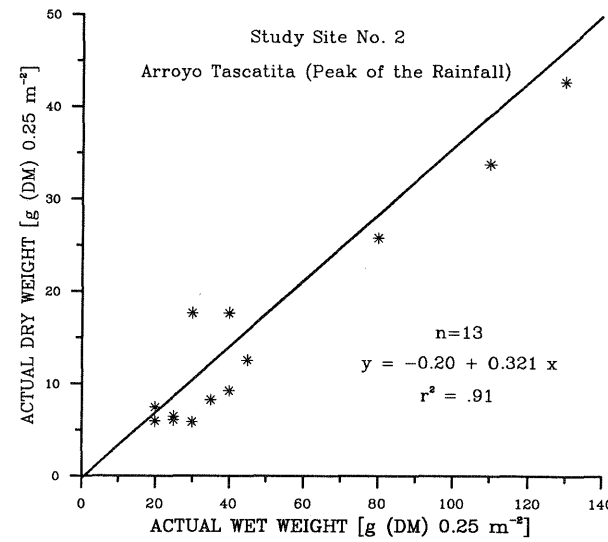

Figure 3. Relationship between actual dry weight over estimated wet weight at rainfall peak in 1990.

(Universal Transversal Mercator) map of México using SPANS and ERDAS systems and then resampled to 50 metres pixel spatial resolution. Afterwards the resulting 'low-high resolution' image was registered and geo-matched to a Landsat MSS (50 m pixel size) image using 25 GCP.

2.3.2 Satellite Vegetation Index

Researches have proposed a number of spectral vegetation indices premised on the contrasts in spectral reflectance between green vegetation and background materials (Rouse *et al.*, 1974). All of the indices are computed, at least in part, by calculating a difference or ratio of visible to near-infrared measurements. This calculation minimizes the effects of variable background brightness while emphasizing variations in the mesurements that occur because of varying green vegetation density. The normalized difference vegetation index (NDVI) is representative of various spectral vegetation indices. The NDVI defined as

NDVI = (Channel 1 - Channel 2 / Channel 1 - Channel 2)

where,
Channel 1 = visible spectral measurement ($0.58\,\mu m$ - $0.68\,\mu m$)
Channel 2 = near-infrared spectral measurement ($0.725\,\mu m$ - $1.1\,\mu m$)

was used to demonstrate a relationship with biomass production.

3. RESULTS

Biomass production estimates in Kg of dry matter per hectare (Kg (DM) ha^{-1} for the 22 ground sites sampled and extracted NDVI values are presented in Table 1. Considerable differences occur from one site to another. Biomass production ranged from 262 to 2190 kg (DM) ha^{-1} and NDVI ranged from 0.24 to 0.36. Geographical variations in rainfall and land use management produced a range of over 1928 kg (DM) ha^{-1} and 0.125 in NDVI at the peak of the rainfall.

3.1 NDVI-Biomass production Relationships

Linear regression and inverse relationships were calculated between biomass production and NDVI, taking the NDVI as the dependent variable (Table 2). Exists some debate as to which the variable, the NDVI or biomass production, should be the dependent variable in a regression analysis. The fact that biomass production determines the satellite reflectance-based vegetation indices-not viceversa-suggests that NDVI should be the dependent variable (Wylie *et al.*, 1988).
Regression analysis revealed a low correlation (r^2=0.542) between mean dry biomass production and NDVI values obtained for the sampling period. The plotted points are shown on Figure 4. Inverse relationship is given on Table 2. Closer examination of Figure 4 reveals that 'unusual observations' with large standardized residuals occur at study sites 8, 10, 11, 18 and 19 in the data set, indicating that the points

Table 1. Summary of the data of biomass production and NDVI from 22 ground sites in Aguascalientes, north-central Mèxico at the peak of rainfall sampling sampling period of 1990.

Study Site (No.)	Peak of the Rainfall Sampling Period			
	Biomass	$S^2x.y$[a]	SEx[b]	NDVI[c]
1	2190	52	151	0.325
2	528	16	51	0.250
3	652	20	39	0.262
4	354	8	19	0.243
5	807	32	65	0.270
6	605	12	29	0.258
7	516	24	111	0.250
8	343	8	19	0.262
9	417	12	33	0.247
10	597	8	127	0.294
11	262	8	14	0.258
12	709	16	27	0.266
13	592	16	76	0.294
14	1100	28	273	0.317
15	1765	32	384	0.321
16	611	8	31	0.262
17	1006	24	92	0.305
18	1008	20	150	0.329
19	1220	20	114	0.368
20	710	20	31	0.266
21	678	12	39	0.262
22	814	16	32	0.274

[a]Variance of the g (DM) m^{-2} estimate from the calibration double sampling regression when n = 13.
[b]Standard error of the mean in Kg (DM) when n = 52.
[c]AVHRR-NDVI recorded from -1 to 1 into 0 to 255.

Table 2. Results from the biomass production-NDVI (a) linear regression analysis and (b) inverse relationships for the original and revised study sites.

Variable	n	a	b	r^2	P
NDVI (a)	22	0.238	0.000054	0.542	<.000
Biomass (b)	22	-2125	10368	0.542	<.001
NDVI (a)	17	0.235	0.000049	0.731	<.000
Biomass (b)	17	-3388	15303	0.731	<.000

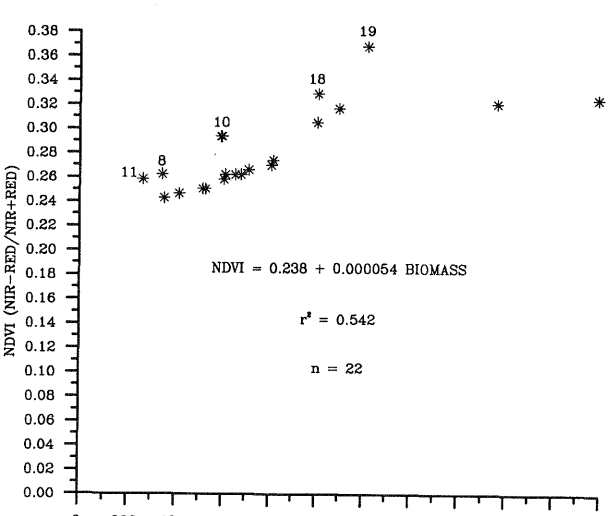

Figure 4. Relationship between LAC-NDVI and biomass production for the 22 study sites at the rainfall peak in September 1990.

lie some distance above the best-fit regression line. These residuals occur in relation to unusually high NDVI values recorded for low intermediate levels of biomass.

Clearly the unusual observations from these five study sites have increased the magnitude of the scatter of the plotted points around the regression line giving high NDVI values than expected only from a rangeland herbaceous species. Sites 8, 10 and 11, located in the central region of the study area, were affected by the introduction of several tree and cacti shrub species such as *Eucalyptus sp* and priclypear *(Opuntia sp)* in the early 1980s by the rehabilitation government program called COPLAMAR. These plantings did not showed up on a SPOT image which was the most recent source of the study area due to was taken during the dry season of 1988.

This variability, however, was also detected on two southern sites (18 and 19) which were located in a region in between an oak (*Quercus*)-rangeland vegetation type increasing the variance explained by the coefficient of determination. The occurrence of large residuals suggests that that perhaps other 'independent' ought to be taken into consideration on future studies *e.g.* biomass and cover of tree species. However, if the five locations with large residuals are omitted from a second regression analysis to re-investigate the relationship between biomass production and NDVI the coefficient of determination increases to $r^2 = 0.73$ at the peak of the rains (Table 2).

The relationship established between these two variables also justifies inverting the relationship and adopting the NDVI as the 'independent' variable, from which to estimate corresponding levels of biomass production (Table 2). The possible causes for such low correlation including are the atmospheric haze and dust during the rainy sesason and poor locational accuracy of the study sites on the imagery.

Multiple regression analysis revealed a positive relationship ($r^2 = 0.79$) between biomass production and three ecological variables (litter, plant height, rainfall) and NDVI at the rainfall peak when large residuals are omitted from the original data set (Table 3).

Table 3. Multiple regression relationship for 17 ground sites at the peak of the rainfall sampling period of 1990.

(a)	a	b	c	d	e	r^2	Cp	P
(a)	-2486	-26.3	28.3	14935	-1.71	.79	2.5	<.000

Model (a): Biomass = a - litter + height + NDVI - rain
Cp = Mallow Statistic

4. SUMMARY AND CONCLUSIONS

There is a marked relation between NDVI measurements and biomass production. The explained variance (r^2) of the correlation is 0.73. This suggests that the NDVI can be used as an indicator for monitoring biomass, offering the potential to predict acceptable carrying capacities from different grazing areas. Further work will be focus on attempting to determine the degree to which NDVI is affected by background materials, particularly in the sparsely-vegetated areas of the arid north.

The aim of the research was to determine the relevance to the Ministry of Agriculture and Water Resources of this methodology to produce the basis for a more efficient livestock industry by the use of this ecological information readily available from satellite data as a technical aid to the producers of this semi-arid region in regard to the changes in vegetation and condition of their rangeland as a function of management and the methods by which they may improve their carrying capacity.

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