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# Assessing Mesquite-Grass Vegetation Condition from Landsat

## Two vegetation index models, TVI6 and GVI, are highly correlated with green yield, green cover, and plant moisture content.

### Introduction

Landsat data are suitable for use in inventorying the kind, quality, distribution, and condition of natural vegetation found on range and forest lands (Poulton, 1975). Landsat multispectral scanner (MSS) data are unique because information about vegetation condition can be quantitatively related to differences in the amount of reflected or transmitted energy recorded in each of four spectral bands (Deering *et al.*, 1977).

Foliage of green plants differentially absorbs and reflects energy in the visible (0.5 to 0.7 μm) and near infrared (0.7 to 1.1 μm) regions of the spectra measured by Landsat (Rouse *et al.*, 1974). The theoretical relationship between reflectance of energy from green and standing dormant herbaceous vegetation and soil in each of the Landsat MSS spectral bands is illustrated in Figure 1 (adapted from data provided by Coulson *et al.* (1965), Pearson and Miller (1972), and Deering and Haas (1978)). The red band energy (MSS 5 scans from 0.6 to 0.7 μm) is strongly absorbed by chlorophylls in green vegetation, whereas near-infrared band energy (MSS 6 scans 0.7 to 0.8 μm and MSS 7, 0.8 to 1.1 μm) is strongly reflected by the mesophyll portion of the leaf (Gates *et al.*, 1965). The magnitude of difference between the red and near-infrared bands increases as the vegetation scene becomes more "green," and conversely becomes less as vegetation becomes dormant or dead

Abstract: *Landsat multispectral scanner (MSS) band values, band ratios, and vegetation index models were compared with selected rangeland vegetation parameters collected at six test sites within the honey mesquite/lotebush/mixed grass association in north-central Texas. The comparisons at four dates showed that two vegetation index models, TVI6 and GVI, are highly correlated (P = 0.01) with green yield, green cover, and plant moisture content. The green vegetation index (GVI) developed by Kauth and Thomas (1976), was highly correlated and superior to other models in relationship to wet green yield, dry green yield, and cured vegetation cover. TVI6, developed by Rouse et al. (1974), was more highly correlated with green vegetation cover and vegetation moisture content. Both TVI6 and GVI are superior to other models in their relationship with green cover. None of the Landsat MSS parameters tested was significantly correlated with dry total yield, percent bare ground, or moisture of the soil measured at the surface or at a 20 cm depth. It is concluded that Landsat MSS data are sensitive to seasonal changes in vegetation growth conditions and inherent ecological differences within a relatively uniform vegetation/soil system.*

Reflectance from plants growing in their natural environment is an integrated response from the plant's reproductive structures, leaves, branches, dew, dust accumulation, and innumerable other factors. However, much of the signature response originates from the leaves (Janza, 1975; Bauer, 1975). The effect on reflectance results from the characteristics of the leaf structure itself, its maturation and quantity, and its relative ground cover and density (Gates *et al.*, 1965).

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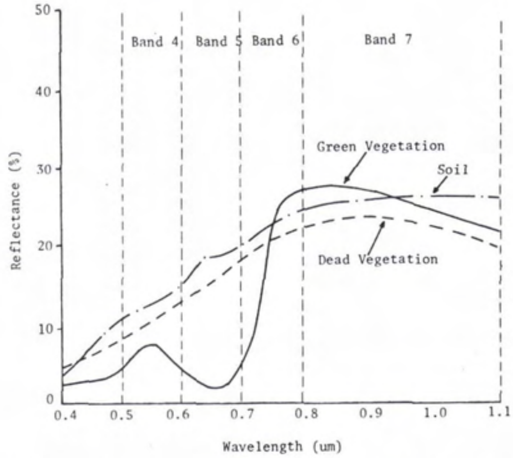


FIG. 1. Reflectance of soil, green vegetation, and dead or dormant vegetation. Adapted from data by Coulson *et al.* (1965), Pearson and Miller (1972), and Deering and Haas (1977).

(Deering *et al.*, 1977). Several investigators have taken advantage of the spectral difference among MSS bands to derive band ratios and "vegetation index" models that relate to vegetation conditions (Carneggie *et al.*, 1974; Maxwell and Johnson, 1974; Rouse *et al.*, 1974; Thomas, 1975; Kauth and Thomas, 1976; Richardson and Wiegand, 1977; Deering *et al.*, 1977).

The objective of this study was to relate the index values from Landsat models and individual MSS bands to selected vegetation measurements obtained from ground sample sites on rangeland with a similar vegetation-soil community. A central question to the study was what rangeland vegetation parameters in a mesquite-grass plant association are related to Landsat MSS data?

## FIELD STUDY AREA

Six test sites were located in separately fenced pastures on the W. T. Waggoner Ranch in Wilbarger County, Texas. The test sites, approximately 100 ha each, were established in areas where different brush control methods had been applied to a vegetation community described previously as the honey mesquite/lotebush/mixed grass association (Haas *et al.*, 1976). Brush control treatments were applied by the Waggoner Ranch to reduce dense stands of honey mesquite (*Prosopis glandulosa* var *glandulosa*) and provided a wide range of ecological conditions among the test sites (McDaniel, 1978). Control of honey mesquite by chemical and mechanical methods is common throughout north-central Texas, and various stages of plant succession within a similar plant association are widespread.

Multistemmed honey mesquite (1 to 3 m high and 14 to 17 percent canopy cover) dominated the overstory vegetation on two of the six sites. The dominance of honey mesquite was reduced on the other four test sites by fire, or by chemical or mechanical brush control practices. Lotebush (*Condelia obtusifolia*) was present, but of minor significance at all test site locations.

All test sites were on a similar deep hardland range site (Rogers *et al.*, 1976). Herbaceous vegetation included mainly mid and short grasses with Texas wintergrass (*Stipa leucotricha*) and buffalograss (*Buchloe dactyloides*) the dominants. The Tillman clay loam soil series, a member of the fine, mixed Thermic family of Typic Paleustolls, is the dominant soil series. The soil is described as a reddish, fine-textured soil more than 1.5 m deep (Koos *et al.*, 1962).

## LANDSAT DATA REDUCTION

Landsat digital data from the Landsat 1 and Landsat 2 satellites were analyzed. Overpass dates, satellite number (Landsat 1 launched 23 July 1972 and Landsat 2 launched 25 January 1975), and I.D. numbers for MSS computer compatible tapes used in this study were as follows:

| | | |
|---|---|---|
| 18 March 1976 | Landsat 1 | 5-337-16072 |
| 23 May 1976 | Landsat 2 | 2-487-16292 |
| 21 August 1976 | Landsat 2 | 2-577-16265 |
| 5 October 1976 | Landsat 1 | 5-535-15522 |

Coincident field and Landsat sampling dates were selected on the basis of known seasonal changes in the phenology and photosynthetic activity of flora within the test sites. The 18 March 1976 overpass occurred during a period of winter dormancy, while the 23 May 1976 overpass coincided with the spring growth and "green-up" period. The 21 August 1976 overpass was during a period of summer dormancy because of seasonal drought, while the 5 October 1976 overpass coincided with the fall growing period. All data were cloud free and of good quality. The six test sites were evaluated from a single set of computer compatible tapes per date.

Processing of Landsat MSS data was accomplished through the Texas A&M University Remote Sensing Center Data Analysis Laboratory and Data Processing Center (Rouse *et al.*, 1974). Two distinct stages of computer processing and analysis were performed. First, computer generated band-5 greymaps were produced and test site areas were located. Second, site processing reports (SPR) for four sub-areas within each of the six test site areas were produced. The SPR provides a summary of mean Landsat band radiance values for any area specified by coordinants on the greymaps. For a specified test site or sub-area within a test site, the SPR calculates a mean radiance value (mwatts/sqcm-str-micrometer), standard deviation, and correlation coefficient (normalized covariances) for all four bands of MSS digital data. In addition, different band ratios and vegetation index models are calculated and included in each SPR. The program for generating SPR provides a solar angle correction factor used to minimize the effects of seasonal solar elevation differences (Rouse *et al.*, 1974).

### Field Data Acquisition

Detailed vegetation data were obtained from 40 $m^2$ quadrats located within each 100 ha test site area. Ten quadrats were placed 40 m apart on each of four line transects. All transect lines began and ended 100 m within the outside boundaries of a test site and each line was placed parallel to the other 100 m apart. Means for each measured parameter from each transect line were considered a sub-area for later comparison with the Landsat MSS data. Sample size was determined to be appropriate according to the procedures of Stein's two-stage sampling technique (Steel and Torrie, 1960). No differences in any vegetation or Landsat parameter tested were found among sub-areas within a test site according to analysis of variance test.

Percent canopy cover for green grass and broadleaf forbs (herbage), standing dormant or cured herbage, litter, and bare ground was estimated within each quadrat (Daubenmire 1968). Fresh weight of green herbage and standing cured herbage was also estimated using a weight-estimate procedure (Pechanec and Pickford, 1937). Clipped green grasses and forbs, and standing cured grasses and forbs, were bagged separately and then weighed fresh in the field. Samples were later oven dried at 20°C for 48 hours and then reweighed to determine moisture content. Yield of honey mesquite green foliage and twig growth (photosynthetically active portions of the plant) were estimated by a double sampling procedure similar to that suggested by Rittenhouse and Sneva (1976) and by Scifres *et al.* (1974). Methods and results for estimating honey mesquite yield are reported in McDaniel (1978) and McDaniel and Haas (1979).

Soil core samples were taken randomly near 3 of 10 quadrats along each sample line to determine soil moisture content at the surface and at 20 cm depth. Soil samples were immediately placed in cans and sealed before weighing in the field. Samples were later oven dried at 105°C for 48 hours and reweighed to determine moisture content (Brady, 1974).

### Data Analysis Procedures

Field-measured parameters, including wet and dry weights of green and cured herbage, soil and vegetation moisture content, the percentage cover of green herbage, cured herbage and litter, and the percentage of bare ground, were analyzed using a space in time design (Steel and Torrie, 1960). Data from individual Landsat MSS bands, band ratios, and selected index models were analyzed in like manner. Total sample size for all test sites and sample dates was 96 (4 sub-areas per test site, 6 test sites, 4 sample dates). Duncan's multiple range test was used to evaluate differences among means (Steel and Torrie, 1960).

Least-squares regression techniques were used to determine functional relationships between field-measured parameters and selected Landsat MSS bands, band ratios, and index models. Multiple linear regression models were also employed to test combined field parameters with selected Landsat MSS models. Care was taken to avoid inclusion of highly correlated independent variables in a single model, such as wet and dry weight measurements.

Spectral signature diagrams were developed by plotting individual MSS bands against seasonal changes and sample sites from which the data were obtained. Index models, suggested by the literature as being related to vegetation conditions, were also plotted for comparison against field data. These models were evaluated statistically using the coefficient of determination ($r^2$) and F-values as an index for the selection of the models best related to a particular field parameter. The MSS ratios and index models tested are shown in Table 1.

### Field Conditions at Overpass

Moisture content of vegetation reflected the pattern of alternating "green" and "dormant" conditions over the four sample periods used in the study (Table 2). Moisture content of grasses and forbs at the six test sites was highest in the spring (47 percent) and fall (51 percent), and significantly ($P = 0.05$) reduced in the winter (18 percent) and summer (14 percent). The moisture content of herbage varied among study sites within a sample date, but there was no clear pattern as to a particular site having a higher moisture content throughout the study (McDaniel, 1978).

Standing green and cured herbage cover increased or decreased according to seasons, while bare ground cover remained relatively constant throughout the study (Table 2). Green herbage cover dominated the scene in the spring (52 percent) and fall (51 percent), whereas cured herbage cover was less prevalent (8 percent and 10 percent, respectively). During the winter and summer dormant periods, green herbage cover averaged only 14 percent and 12 percent, respectively, compared to cured herbage cover estimated at 49 percent and 33 percent. One location (site 5) had the dead cured herbage component removed fol-

TABLE 1. LANDSAT MSS DERIVED RATIOS AND INDEX MODELS COMPARED WITH VEGETATION AND SOIL PARAMETERS TAKEN FROM RANGELAND IN NORTH-CENTRAL TEXAS

1. Landsat MSS band ratios
   a. R6/4
   b. R6/5
   c. R7/5
   d. R7/4
2. Landsat MSS index models
   a. Transformed Vegetation Index or
      $TVI7 = [(MSS7 - MSS5)/(MSS7 + MSS5) + 0.5]^{1/2}$
      (Rouse *et al.*, 1974)
   b. Transformed Vegetation Index 6 or
      $TVI6 = [(MSS6 - MSS5)/(MSS6 + MSS5) + 0.5]^{1/2}$
      (Rouse *et al.*, 1974)
   c. Green Vegetation Index Model or
      $GVI = (-0.290\ MSS4) - (0.564\ MSS5) + (0.600\ MSS6) + (0.491\ MSS7)$
      (Kauth and Thomas, 1976)
   d. Soil Brightness Index or
      $SBI = (0.433\ MSS4) + (0.632\ MSS5) + (0.506\ MSS6) + (0.264\ MSS7)$
      (Kauth and Thomas, 1976)
   e. Perpendicular Vegetation Index or
      $PVI = [(Rgg5 - Rp5)^2 + (Rgg7 - Rp7)^2]^{1/2}$
      where $Rgg5 = 0.851\ Rp5 + 0.355\ Rp7$
      $Rgg7 = 0.355\ Rp5 + 0.148\ Rp7$
      $Rp5 = MSS5$
      $Rp7 = MSS7$
      (Richardson and Wiegand, 1977)
   f. Perpendicular Vegetation Index 6 or
      $PVI6 = [(Rgg5 - Rp5)^2 + (Rgg6 - Rp6)^2]^{1/2}$
      where $Rgg5 = -0.498 + 0.543\ Rp5 + 0.498\ Rp6$
      $Rgg6 = 2.734 + 0.498\ Rp5 + 0.457\ Rp6$
      $Rp5 = MSS5$
      $Rp6 = MSS6$
      (Richardson and Wiegand, 1977)
   g. Differenced Vegetation Index
      $DVI = 2.40\ MSS7 - MSS5$
      (Richardson and Wiegand, 1977)

lowing a winter burn and had significantly more green herbage cover in the spring and fall compared to the other sites. Bare ground increased at this location following the burn.

Total standing crop (forbs and grasses), reported on a dry weight basis, declined on the six test sites with each succeeding sample period: 1347 kg/ha in March; 1085 kg/ha in May; 860 kg/ha in August; and 838 kg/ha in October. Standing crop, separated into green and cured components, followed seasonal trends similar to the cover estimates, with highest green yields recorded in the spring and fall (Table 2). There was a significant date by test site interaction for herbage yield. The interaction can be attributed to unequal grazing pressure at the test sites and the elimination of all standing crop by fire before the March sample period at site 5.

Total standing crop expressed on a wet weight basis also fluctuated seasonally, with greater weights recorded when vegetation was succulent in the spring and fall (Table 2). Green herbage constituted 85 percent of the total wet yield in the spring and 90 percent in the fall. In contrast, 78 percent of total yield in the winter and 54 percent in the summer was wet cured or "brown" herbage.

Soil moisture did not follow the same seasonal pattern found with herbaceous vegetation over the four sample periods. Soil moisture was greatest at the surface and 20 cm depth in the winter (18.8 percent and 17.3 percent, respectively) and fall (12.4 percent and 16.9 percent, respectively) as compared to the spring (3.8 percent and 9.0 percent, respectively) and summer (1.7 percent and 6.2 percent, respectively).

## LANDSAT MSS DATA

Lower mean radiance values were recorded for each of the four Landsat spectral bands when averaged across the six test sites in May and October compared to March and August (Figure 2). The lower amount of radiant energy detected by the Landsat bands in May and October is probably related to the amount of solar energy absorption by vegetation during periods of active growth. Conversely, higher mean radiance values recorded in

TABLE 2. MEAN VALUES FOR PERCENT GROUND COVER, WET AND DRY HERBAGE WEIGHTS, AND PLANT MOISTURE CONTENT AT SIX TEST SITES DURING FOUR SAMPLE DATES IN 1976

| Sample Site | Date | Green Herbage Cover % | Cured & Litter Herbage Cover % | Bare Ground Cover % | Wet Green Herbage Yield (kg/ha) | Wet Cured Herbage Yield (kg/ha) | Dry Green Herbage Yield (kg/ha) | Dry Cured Herbage Yield (kg/ha) | Total Plant Moisture (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3/18 | 15.7d[1] | 54.9b | 8.4b | 246ef[1] | 1279bc | 110g | 1227bc | 12.6g |
| 2 | 3/18 | 22.2d | 36.4c | 17.3b | 400ef | 371de | 180f | 357de | 29.6f |
| 3 | 3/18 | 15.0d | 28.3c | 36.0a | 539e | 531d | 302e | 504d | 25.1f |
| 4 | 3/18 | 16.6d | 40.6c | 10.8b | 475e | 1017bc | 228ef | 920bc | 23.2f |
| 5 | 3/18 | 7.3c | 59.2b | 7.7b | 167f | 2773a | 63g | 2612a | 9.4gh |
| 6 | 3/18 | 7.4c | 72.3a | 5.9b | 219f | 1467b | 166f | 1456b | 7.4gh |
| 1 | 5/23 | 55.1ab | 11.3d | 8.5b | 1748b | 417de | 773b | 407de | 45.5d |
| 2 | 5/23 | 51.7b | 4.4e | 25.2a | 1260c | 203e | 613c | 201e | 44.8d |
| 3 | 5/23 | 44.4c | 5.9e | 35.5a | 1845b | 165e | 824ab | 161e | 50.8c |
| 4 | 5/23 | 48.4b | 9.4d | 11.6b | 1758b | 452d | 845ab | 436d | 41.9c |
| 5 | 5/23 | 61.2a | 0.5e | 27.6a | 2381a | 16f | 941a | 15f | 59.9b |
| 6 | 5/23 | 53.4ab | 15.5d | 11.2b | 1528bc | 651d | 664bc | 632d | 40.4d |
| 1 | 8/21 | 11.7de | 48.5b | 7.0b | 355ef | 804c | 229ef | 793c | 5.8h |
| 2 | 8/21 | 11.1de | 21.3d | 36.9a | 455e | 245e | 327de | 242e | 18.3f |
| 3 | 8/21 | 19.9d | 20.2d | 33.3a | 868d | 255e | 656bc | 240e | 19.5f |
| 4 | 8/21 | 10.7de | 49.2b | 10.6b | 508e | 940c | 436d | 932c | 5.7h |
| 5 | 8/21 | 6.3c | 27.6c | 35.6a | 207f | 514d | 157f | 480d | 11.2g |
| 6 | 8/21 | 12.5de | 32.1c | 13.3b | 333ef | 423de | 234ef | 358de | 22.0f |
| 1 | 10/5 | 52.7b | 13.4d | 13.0b | 1429bc | 318e | 647bc | 284e | 47.0c |
| 2 | 10/5 | 57.7ab | 4.1e | 20.7b | 1327c | 41f | 593ce | 35f | 54.1b |
| 3 | 10/5 | 47.2b | 2.1e | 37.5a | 1529bc | 7f | 566cd | 6f | 62.2a |
| 4 | 10/5 | 35.4c | 29.5c | 10.9b | 824d | 394de | 437d | 380de | 33.0e |
| 5 | 10/5 | 62.8a | 1.2e | 34.1a | 2505a | 23f | 963a | 20f | 61.1a |
| 6 | 10/5 | 48.4b | 10.3d | 10.6b | 1844b | 298e | 814ab | 282e | 48.9cd |

[1] Means within a column followed by different letters are significantly different (P = 0.05) according to Duncan's multiple range test.

March and August may indicate greater surface reflection when the vegetation is mostly dormant.

Mean radiance values, averaged over all test sites, show MSS4 and MSS5 radiance values to vary seasonally much more than MSS6 and MSS7 values (Figure 3). MSS4 and MSS5 radiance values decreased during May and October (active growing seasons) and increased in March and August (dormant seasons). Vegetation moisture, green wet or dry yield, and green herbage cover also vary seasonally, but are inversely related to the MSS4 and MSS5 spectral values. MSS6 radiance values declined slightly during the spring and fall seasons of growth and increased in the dormant seasons, but to a lesser degree than those of MSS4 and MSS5. MSS7 mean radiance varied less than the other MSS bands, but tended to decline over the period of the four sample dates.

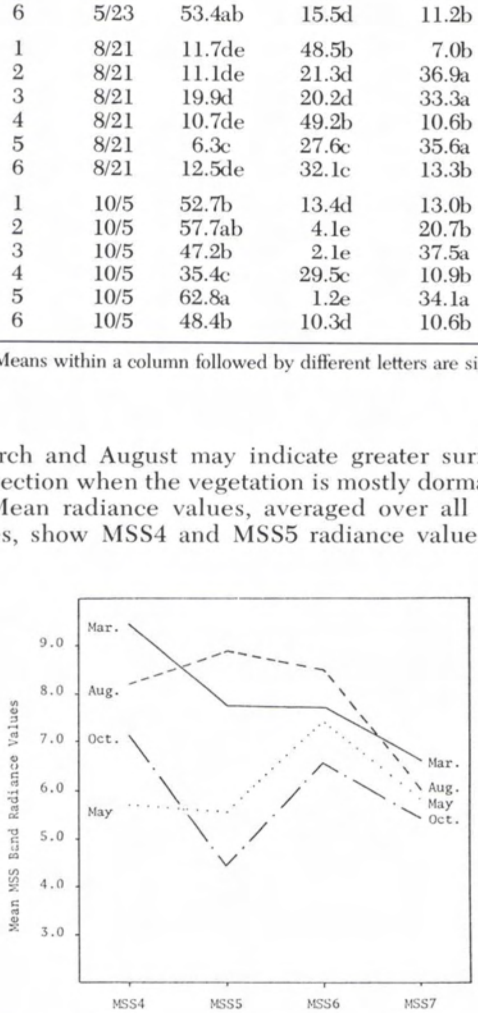


FIG. 2. Landsat mean MSS radiance values from four overpasses on 18 March, 23 May, 21 August, and 5 October 1976.

Previous investigators have reported radiant energy in the visible bands (MSS4 and MSS5) to be strongly absorbed, and energy in the near-infrared bands (MSS6 and MSS7) to be more reflected when vegetation is actively growing (Pearson and Miller, 1972; Tucker and Maxwell, 1976). Because of these characteristics, a ratio of visible band radiance values to those of a near-infrared band can show a quantitative relationship with the greenness of a vegetation scene (Rouse *et al.*, 1974). This study shows MSS6 and MSS7 radiance

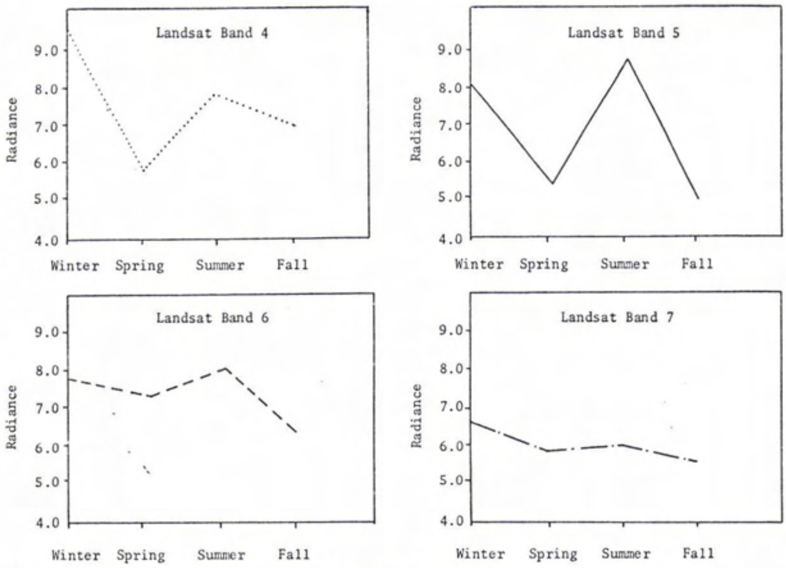


FIG. 3. Mean radiance values (mwatts/sqcm-str-micrometre) for four Landsat MSS bands from test site area in the winter (18 March), spring (23 May), summer (21 August), and fall (5 October) 1976.

values do not vary as much seasonally as MSS4 and MSS5 values. Therefore, the more responsive visible bands appear to determine the relative sensitivity of band ratios or vegetation index model to changes in vegetation growth conditions.

## LANDSAT DATA/VEGETATION PARAMETER CORRELATIONS

Least-squares regression analyses were performed to evaluate the relationship between the

TABLE 3. SIMPLE LINEAR CORRELATION COEFFICIENTS (r) BETWEEN LANDSAT MSS BANDS, BAND RATIOS, AND VEGETATION INDEX MODELS AND SELECTED VEGETATION MEASUREMENTS ACQUIRED FROM SIX TEST SITES ON 18 MARCH, 23 MAY, 21 AUGUST, AND 5 OCTOBER 1976 ($n$ = 96)

| Landsat MSS Digital Data | Vegetation Parameters: Wet Green Yield (kg/ha) | Wet Cured Yield (kg/ha) | Wet Total Yield (kg/ha) | Dry Green Yield (kg/ha) | Dry Cured Yield (kg/ha) | Dry Total Yield (kg/ha) | Green Cover (%) | Cured Cover (%) | Vegetation Moisture (%) |
|---|---|---|---|---|---|---|---|---|---|
| | Correlation Coefficients (r) | | | | | | | | |
| *MSS Bands* | | | | | | | | | |
| MSS4 | −0.802** | 0.490* | n/s | −0.811** | n/s | n/s | −0.809** | 0.713** | −0.710** |
| MSS5 | −0.795** | n/s | n/s | −0.685** | n/s | n/s | −0.901** | 0.713** | −0.860** |
| MSS7 | n/s | n/s | n/s | n/s | n/s | n/s | −0.587* | n/s | −0.560* |
| MSS7 | n/s | n/s | n/s | n/s | n/s | n/s | n/s | n/s | n/s |
| *Band Ratios* | | | | | | | | | |
| R7/4 | 0.727** | n/s | n/s | 0.699** | n/s | n/s | 0.677** | −0.651** | 0.607** |
| R7/5 | 0.587* | n/s | n/s | 0.644** | n/s | n/s | 0.516* | −0.536* | n/s |
| R6/4 | 0.819** | n/s | −0.525** | 0.681** | n/s | n/s | 0.889** | −0.782** | 0.833** |
| R6/5 | 0.876** | −0.504** | −0.587* | 0.782** | −0.505** | n/s | 0.945** | −0.846** | 0.910** |
| *Vegetation Index Models* | | | | | | | | | |
| TVI7 | 0.797** | n/s | 0.548* | 0.656** | n/s | n/s | 0.899** | −0.750** | 0.878** |
| TVI6 | 0.883** | −0.511* | 0.482* | 0.792** | 0.510* | n/s | 0.963** | −0.850** | 0.925** |
| PVI | −0.769** | n/s | −0.505* | −0.677** | n/s | n/s | −0.880** | 0.684** | −0.829** |
| PVI6 | −0.718** | n/s | −0.521* | 0.605* | n/s | n/s | −0.836** | 0.626** | −0.798** |
| GVI | 0.906** | −0.515* | 0.570* | 0.834** | 0.514* | n/s | 0.933** | −0.861** | 0.884** |
| SBI | −0.785** | n/s | −0.516* | −0.707** | n/s | n/s | −0.882** | 0.686** | −0.819** |
| DVI | 0.631** | n/s | 0.490* | n/s | n/s | n/s | 0.667** | 0.610** | 0.707** |

n/s Not statistically significant at 0.05 probability level.
* Statistically significant at 0.05 probability level.
** Statistically significant at 0.01 probability level.

Landsat MSS data and the vegetation parameters. Simple correlation coefficients relating Landsat MSS bands, band ratios, and the seven vegetation index models (TVI7, TVI6, PVI, PVI6, GVI, SBI, and DVI) with nine vegetation parameters (wet green, cured, and total yield; dry green, cured, and total yield; green and cured ground vegetation cover; and vegetation moisture) were determined for the pooled test site and sample date data (Table 3).

Regression analyses of individual Landsat spectral bands showed MSS4 and MSS5 to be more highly correlated with the vegetation measurements than MSS6 (Table 3). MSS4 was negatively correlated with wet green yield, dry green yield, green cover, and vegetation moisture. MSS4 was positively correlated with wet cured yield and cured cover. MSS5 was more highly correlated with green cover and vegetation moisture than was MSS4. MSS6 was only correlated with green cover and vegetation moisture. MSS7 was not significantly correlated with any of the vegetation parameters.

All band ratios were significantly correlated with wet green yield, dry green yield, green cover, and cured cover, but none were related to dry total yield (Table 3). The R6/5 was the only ratio significantly correlated with wet or dry cured yield. The simple correlation coefficients of R6/5 were superior to those produced by the other individual bands or band ratios tested. Maxwell and Johnson (1974) and Carneggie *et al.* (1974) reported R7/5 to be highly correlated with green vegetation conditions, but in this study, the R6/5 was the superior band ratio.

Simple linear regressions performed with the Landsat vegetation index models show TVI6 and GVI models to be most highly correlated with the vegetation measurements compared to all other vegetation index models, ratios, or individual MSS bands (Table 3). GVI was most highly correlated with wet green, cured, and total yield; dry green and cured yield; and cured cover. The TVI6 was more highly correlated with green cover and vegetation moisture.

The GVI and TVI6 models were designed to estimate relative amounts of "greenness" in vegetation scenes (Rouse *et al.*, 1974; Kauth and Thomas, 1976). Both models have previously been related to vegetation growth (phenology), green biomass, and vegetation moisture (Deering and Haas, 1978). In this study, using data acquired from all test sites and all sample dates, GVI and TVI6 showed the highest correlation with green vegetation cover (Table 4). Green cover accounted for 93 percent of the variation in TVI6 (Figure 4). When vegetation moisture was included in the equation, the relationship improved slightly, with the two parameters accounting for 94 percent of the variation. Green cover accounted for 87 percent of the variation in GVI, and when wet green yield was included, the two parameters accounted

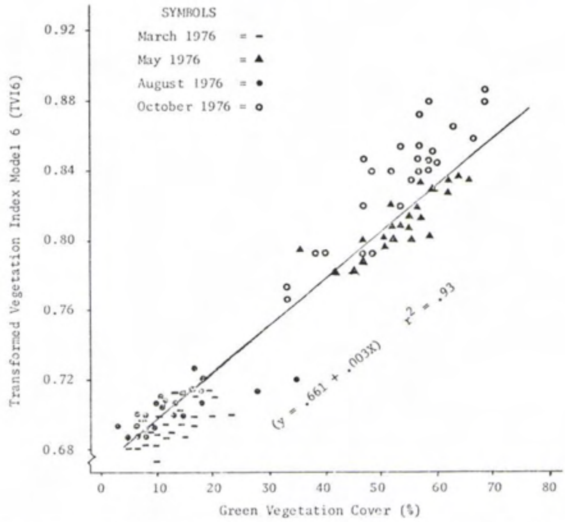


FIG. 4. Relationship between percent green vegetation cover and the Landsat TV16 vegetation index model.

for 89 percent of the variation. Wet green yield did not significantly improve the TVI6 relationship, nor did vegetation moisture improve the GVI relationship. Thus, it can be concluded that, while TVI6 and GVI are both related to green vegetation cover, TVI6 is more highly correlated to vegetation moisture than GVI, and GVI is more highly correlated to vegetation weight than TVI6.

## TEST SITE EFFECTS

Regression analysis performed on data from individual test sites showed the TVI6 and GVI models to be, as expected, most highly correlated with all vegetation parameters, compared to the other Landsat vegetation index models, ratios, or MSS bands (data not shown except for TVI6 and GVI models, Table 5). Results which may be elicited from these analyses, however, are somewhat limited because only 16 observations comprised the data set for ground and Landsat comparisons (four sample dates, four sub-areas per test site). Additionally, the dates selected for sampling represent extremes in vegetation growth conditions for two growing and two dormant seasons; thus, the vegetation parameters tend to cluster into groups related to vegetation growth. Therefore, only linear relationships were tested for the Landsat and ground data, although curvilinear analyses may be more appropriate for comparative data obtained throughout an entire yearly growth cycle (Tucker and Maxwell, 1976).

Linear regression analyses performed to assess the degree of association between TVI6 and GVI to the vegetation parameters showed highly significant ($P = 0.01$) relationships with wet and dry green yield, green and cured vegetation cover, and plant moisture content (Table 5). Neither TVI6 nor

TABLE 4. LEAST SQUARES REGRESSION EQUATIONS RELATING CHANGES IN TVI6 AND GVI WITH VEGETATION MEASUREMENTS ACQUIRED DURING FOUR SAMPLE DATES IN 1976. VEGETATION PARAMETERS WERE GREEN COVER (GCOV), WET GREEN YIELD (WGY), AND VEGETATION MOISTURE (MOIST)

| Least-Square Model | *n* | $R^2$ | Prob F | Sd |
|---|---|---|---|---|
| TVI6 = 0.6609 + 0.003 GCOV | 96 | 0.93 | 0.01 | 0.018 |
| TVI6 = 0.6563 + 0.0023 GCOV + 0.0009 MOIST | 96 | 0.94 | 0.01 | 0.016 |
| GVI = 0.1651 + 0.041 GCOV | 96 | 0.87 | 0.01 | 0.332 |
| GVI = 0.1779 + 0.0281 GCOV + 0.0004 WGY | 96 | 0.89 | 0.01 | 0.311 |

GVI were well correlated with wet cured yield, wet total yield, or dry cured yield, although there were significant relationships at most test sites. Dry total yield was not significantly correlated with any Landsat parameters tested. An analysis of Landsat parameters with soil measurements (i.e., bare ground cover, soil moisture at the surface and 20 cm depth), taken during the four sample periods at each test site, did not show any significant relationships (data not shown).

GVI and TVI6 were always more highly correlated with wet green yield than with dry green yield (Table 5). The regressions of GVI and TVI6 to wet green yield were highly significant at all six

TABLE 5. COEFFICIENTS OF DETERMINATION FROM REGRESSION ANALYSES OF TVI6 AND GVI VEGETATION INDEX MODELS AND SELECTED FIELD PARAMETERS FROM SIX TEST SITES AND FOR ALL SITES COMBINED

| | | Vegetation Parameters | | | | | |
|---|---|---|---|---|---|---|---|
| | | Wet Green Yield (kg/ha) | | Wet Cured Yield (kg/ha) | | Wet Total Yield (kg/ha) | |
| Test Site | n | TVI6 | GVI | TVI6 | GVI | TVI6 | GVI |
| 1 | 16 | 0.873** | 0.970** | 0.564** | 0.519** | 0.422** | 0.564** |
| 2 | 16 | 0.872** | 0.867** | 0.330* | 0.182 | 0.689** | 0.780** |
| 3 | 16 | 0.497** | 0.712** | 0.423** | 0.311* | 0.316* | 0.623** |
| 4 | 16 | 0.669** | 0.889** | 0.610** | 0.261* | 0.199 | 0.641** |
| 5 | 16 | 0.956** | 0.972** | 0.389* | 0.456** | 0.132 | 0.094 |
| 6 | 16 | 0.932** | 0.689** | 0.213 | 0.138 | 0.644** | 0.505** |
| All Sites | 96 | 0.780** | 0.821** | 0.261* | 0.265* | 0.237* | 0.260* |
| | | Vegetation Parameters | | | | | |
| | | Dry Green Yield (%) | | Dry Cured Yield (%) | | Dry Total Yield (%) | |
| Test Site | n | TVI6 | GVI | TVI6 | GVI | TVI6 | GVI |
| 1 | 16 | 0.795** | 0.913** | 0.591** | 0.529** | 0.076 | 0.021 |
| 2 | 16 | 0.637** | 0.703** | 0.336* | 0.181 | 0.146 | 0.292* |
| 3 | 16 | 0.067 | 0.201 | 0.438** | 0.324* | 0.193 | 0.019 |
| 4 | 16 | 0.470** | 0.728** | 0.518** | 0.233 | 0.163 | 0.029 |
| 5 | 16 | 0.943** | 0.967** | 0.387* | 0.454** | 0.115 | 0.160 |
| 6 | 16 | 0.878** | 0.644** | 0.187 | 0.121 | 0.038 | 0.038 |
| All Sites | 96 | 0.627** | 0.696** | 0.260* | 0.264* | 0.026 | 0.020 |
| | | Vegetation Parameters | | | | | |
| | | Green Cover (%) | | Cured Cover (%) | | Plant moisture (%) | |
| Test Site | n | TVI6 | GVI | TVI6 | GVI | TVI6 | GVI |
| 1 | 16 | 0.911** | 0.891** | 0.886** | 0.815** | 0.945** | 0.852** |
| 2 | 16 | 0.920** | 0.874** | 0.730** | 0.693** | 0.912** | 0.737** |
| 3 | 16 | 0.873** | 0.845** | 0.705** | 0.662** | 0.915** | 0.873** |
| 4 | 16 | 0.952** | 0.788** | 0.918** | 0.730** | 0.798** | 0.634** |
| 5 | 16 | 0.961** | 0.979** | 0.822** | 0.842** | 0.949** | 0.977** |
| 6 | 16 | 0.980** | 0.873** | 0.918** | 0.828** | 0.812** | 0.593** |
| All Sites | 96 | 0.928** | 0.871** | 0.723** | 0.741** | 0.855** | 0.781** |

* Statistically significant at 0.05 probability level.
** Statistically significant at 0.01 probability level.

test sites, accounting for as much as 97 percent of the variation in GVI at Site 5 to as little as 69 percent at Site 6. Percent green cover was highly related to TVI6 and accounted for as much as 98 percent of the variation in TVI6 at Site 6, and as little as 87 percent at Site 3.

## Conclusions

Landsat MSS data are sensitive to seasonal change in vegetation growth conditions within a relatively uniform vegetation/soil system. Regression analyses with Landsat MSS data and vegetation data collected at four dates from six study sites show two vegetation index models, TVI6 and GVI, to be most highly correlated with certain vegetation parameters. The GVI was most highly correlated with wet green yield, dry green yield, and cured vegetation cover. The TVI6 was more highly correlated with green vegetation cover and vegetation moisture.

The close relationship of TVI6 and GVI to vegetation parameters associated with actively growing vegetation (i.e., green yield, green cover, and plant moisture content) indicates that quantitative measurement of vegetation condition is possible from Landsat MSS data. Other investigators have indicated that poor results may occur when working with a heterogeneous vegetation-soil complex (Westin and Lemore, 1978; Deering *et al.*, 1977). Implications of this study are that land management practices do not seriously affect the relationship of Landsat MSS models with rangeland vegetation parameters obtained from a common vegetation-soil system, such as mesquite-grass vegetation. Therefore, stratifying relatively uniform vegetation soil systems on Landsat imagery appears a logical first step in employing Landsat MSS data for vegetation surveys. The second step would be to establish the functional relationship of a Landsat index model to different vegetation parameters in the vegetation-soil system being surveyed.

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