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COMPARISON OF LANDSAT-2 AND FIELD SPECTROMETER REFLECTANCE SIGNATURES OF SOUTH TEXAS RANGELAND PLANT COMMUNITIES

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ABSTRACT

We tested the accuracy of an atmospheric correction method that depends on clear water bodies to infer solar and atmospheric parameters for radiative transfer equations by measuring the reflectance signature of four prominent south Texas rangeland plants with the Earth Resource Technology (LANDSAT) satellite multispectral scanner (MSS) and a ground-based Exotech Model 20 spectroradiometer. The rangeland plant reflectance produced by the two sensors were correlated with no significant deviation of the slope from unity or of the intercept from zero. These results indicated that the atmospheric correction produced LANDSAT MSS estimates of rangeland plant reflectances that are as accurate as the ground-based Exotech spectroradiometer.

I. INTRODUCTION

The Earth Resource Technology Satellites (LANDSAT-1 and -2) can yield high quality data relevant to the spectral reflectivity of the earth's surface. Since LANDSAT-1 was launched on August 25, 1972, efforts have been made to transform LANDSAT multispectral scanner (MSS) digital counts (DC) recorded on computer-compatible tapes (CCT) to absolute reflectance values of the earth's surface (Rogers and Peacock, 1973; Herzog and Sturm, 1975)[21,8] so as to enhance the use of these data for earth resources applications. All of the proposed techniques, however, require ground measured solar radiometric data to determine the solar and atmospheric parameters that are needed in relating LANDSAT count rates to reflectance. However, Ahern et al. (1977)[1] have developed a method of using dark targets, such as clear lakes, and atmospheric radiative transfer theory (Turner et al., 1971)[25] to estimate the needed atmospheric parameters without ground measured solar radiometric data. We conducted this study to test Ahern's method. We compared reflectance signatures of four prominent south Texas rangeland plants (Gausman et al., 1977a and b)[5,6] obtained by LANDSAT-2 MSS and by the ground-based Exotech Model 20 spectroradiometer (Leamer et al., 1973)[12]. (Trade names and company names are included for the readers' benefit and do not imply an endorsement or preferential treatment of the product by the U.S. Department of Agriculture.)

II. ATMOSPHERIC RADIATIVE TRANSFER THEORY

The conversion of LANDSAT digital count data in each band to reflectance (R) at the earth's surface requires the use of the following wavelength dependent atmospheric radiative transfer equation (Turner et al., 1971; Rogers and Peacock, 1973; Hulstrom, 1974; Herzog and Sturm, 1975; Ahern et al., 1977)[25,21,9,8,1]:

$$R = \frac{(L - Lp)\ \pi}{ET} 100, \qquad (1)$$

where the atmospheric problem (Fig. 1) for determining R consists of evaluating each of the variables defined as follows:

- L - total radiance detected by LANDSAT at the top of the atmosphere (mw cm^{-2} sr^{-1}),
- DC - digital count data recorded on CCTs,
- A,B - LANDSAT radiance calibration coefficients,
- T - vertical atmospheric transmittance of radiant energy from the earth's surface to the LANDSAT MSS,
- t - total optical depth of the atmosphere,
- tr - Rayleigh optical depth due to scattering by gaseous molecules,
- tm - Mie optical depth due to scattering by aerosol particulates,
- ta - optical depth due to water absorption,
- E - total incident solar irradiance at the earth's surface (mw cm^{-2}) (also known as incoming solar radiation; insolation),
- Eo - solar irradiance at the top of the atmosphere (mw cm^{-2}) (solar constant),
- Ts - slant atmospheric transmittance from the sun to the earth's surface,
- Es - diffuse solar irradiance incident at the earth's surface (mw cm^{-2}),
- Ed - direct solar irradiance incident at the earth's surface (mw cm^{-2}),
- Lp - path radiance detected by LANDSAT at the top of the atmosphere (mw cm^{-2} sr^{-1}),
- Ll - total radiance over a clear lake detected by LANDSAT (mw cm^{-2} sr^{-1}),
- Lv - radiance from a clear lake water volume (mw cm^{-2} sr^{-1}),
- Ls - radiance from a clear lake water surface (mw cm^{-2} sr^{-1}),
- Lg - radiance from sun glint due to wave action (mw cm^{-2} sr^{-1}),
- Rb - background reflectance,
- R - reflectance at the earth's surface, and
- z - solar zenith angle.

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A. RADIANCE DETECTED BY LANDSAT (L)

The first step for solving the atmospheric problem is to convert the DC data recorded on LANDSAT CCT to radiance (L, mw cm^{-2} sr^{-1}) as detected by the LANDSAT MSS at the top of the atmosphere. The equation for this operation is as follows:

$$L_i = A_i \, DC_i + B_i, \qquad (2)$$

where i = LANDSAT band numbers 4, 5, 6, or 7. Table 1 lists the LANDSAT radiance calibration constants (A and B)[15,16,19] that are used for equation (2).

B. ATMOSPHERIC TRANSMITTANCE (T)

The vertical atmospheric transmittance (T) from the LANDSAT MSS sensor to the earth's surface is computed as:

$$T = EXP\ (-t\ sec(sensor\ zenith\ angle)), \qquad (3)$$

where t is the total optical depth of the atmosphere. Even though the LANDSAT MSS sensor scans over a range of zenith angles from -5.78 to 5.78 degrees from the sensor's nadir (Kaneko and Engvall, 1977)[10], it is usually assumed that the sensor zenith angle is zero (vertical). Thus for LANDSAT:

$$T = EXP\ (-t). \qquad (4)$$

Therefore, to be able to calculate T, we only need to know t that is a measure of the atmospheric attenuation of incident solar irradiance due to scattering and absorption. Scattering effects are generally assumed to be due to gaseous molecules (tr; Rayleigh optical depth) and aerosol particulates (tm; Mie optical depth) (Turner et al., 1971; Turner and Spencer, 1972)[25,26]. The optical depth due to water absorption (ta) is assumed to be negligible in LANDSAT bands 4, 5, and 6 but not in band 7 (Pitts et al., 1974)[17]. Total optical depth (t = tr + tm + ta) can be directly measured using a solar radiometer (Rogers and Peacock, 1973)[21]; however, we used Ahern's et al. (1977)[1] method where t is related to Lp through atmospheric radiative transfer theory, using a phase function approximation of atmospheric scatterers given by Turner et al. (1971)[25] and Turner and Spencer (1972)[26].

C. TOTAL INCIDENT SOLAR IRRADIANCE (E)

Total incident solar irradiance (E, mw cm^{-2}) at the earth's surface may be directly measured with a solar radiometer as Rogers and Peacock (1973)[21] and Hulstrom (1974)[9] have shown, or it may be calculated using radiative transfer theory (Ahern et al., 1977)[1].

As a first step to calculating E, it is necessary to know the solar irradiance (Eo, mw cm^{-2}) for each LANDSAT band at the top of the atmosphere such as compiled by Thekaekara et al. (1969)[23] and Thekaekara (1974)[24] for the standard earth-sun distance (Table 2). The earth-sun ratios given for each day of the year in ephemeris tables could be used to further refine values of Eo because these values change by 7% annually with earth-sun distance.

Once Eo is known, then the direct incident solar irradiance (Ed, mw cm^{-2}) at the earth's surface, as measured with a solar radiometer (Rogers and Peacock, 1973)[21], can be computed as:

$$Ed = EoTs\ cos\ (solar\ zenith\ angle), \qquad (5)$$

where the slant atmospheric transmittance from the earth's surface to the sun (Ts) is

$$Ts = EXP\ (-t\ sec(solar\ zenith\ angle)). \qquad (6)$$

The solar zenith angle is known for each LANDSAT overpass date.

Diffuse incident solar irradiance (Es, mw cm^{-2}) at the earth's surface, also known as skylight, may be measured by shadowing a solar radiometer detector. For this study, Es was calculated using the phase functions of atmospheric scatterers as given by Turner et al. (1971)[25].

Therefore, once Ed and Es are known then the total incident solar irradiance at the earth's surface is calculated as:

$$E = Ed + Es. \qquad (7)$$

D. PATH RADIANCE (LP)

Path radiance (Lp, mw cm^{-2} sr^{-1}) is difficult to determine because it cannot be measured directly. It depends on a complex interaction between atmospheric scattering and absorption of incident solar irradiance and reflected solar radiance from background albedo (Turner, 1975)[27] that is scattered into the optical path of the LANDSAT MSS. Thus, several methods have been proposed to infer path radiance indirectly.

Ground-based solar radiometric measurements of diffuse sky irradiance have been used to indirectly derive path radiance using methods given by Gordon et al. (1973)[7], Rogers and Peacock (1973)[21], and O'Neill and Miller (1977)[14]. In addition, Hulstrom (1974)[9] used a plot of L against ground-based measurements of reflectance for various naturally occurring calibration targets on the earth's surface to determine path radiance. Such a plot does not pass through the origin; instead at zero reflectance, Lp = L. The weakness of these methods is that they depend on ground-based solar radiometric measurements that are not readily available.

Ahern et al. (1977)[1] and Chavez (1975)[2] used the radiance of dark targets, such as clear lakes, to determine path radiance. Ahern found that the radiance over a clear lake (Ll), at the top of the atmosphere, is the sum of several terms:

$$Ll = (Lv + Ls + Lg)\ T + Lp \qquad (8)$$

where Lv is the radiance from the water volume, Ls is the radiance from the water surface, and Lg is the radiance from sun glint due to wave action caused by high winds or solar zenith angles less than 30°. From data given by Ahern et al. (1977)[1], Lv = RvE, Ls = 0.006 Es, and Lg = 0. Also, Rv was estimated from Ahern's data using the following empirical equation:

$$Rv = 0.0035 - 0.0036\lambda, \qquad (9)$$

where the wavelength (λ) ranges from 0.4- to 3.0-μm. Thus, path radiance was calculated as:

$$Lp = Ll - RvET - 0.006EsT. \qquad (10)$$

E. REFLECTANCE VARIATION WITH SUN ANGLE

The LANDSAT MSS and ground-based spectroradiometer measured reflectance at the earth's surface at different solar zenith angles for the same plant. Smith et al. (1975)[22] and Duggin (1977)[4], found that LANDSAT reflectance signatures may need to be corrected for plant canopy reflectance variations with sun angle. However, Lemme and Westin (1978)[13] observed that reflectance data collected from about 1015- to 1500-h CDT show minimal effect due to sun angle variation. As a result, we did not attempt to make any sun angle corrections, because the data for both LANDSAT and the ground-based spectroradiometer were collected within this time range.

F. BACKGROUND REFLECTANCE (Rb)

An estimate of the average background reflectance ($\overline{Rb}$) is needed when using the phase function approximations of atmospheric scatterers that relate Lp to t. We used Ahern's et al. (1977)[1] approach, which calculates Rb with the following equation:

$$\overline{Rb} = \frac{\overline{L}\,\pi}{Eo\ \cos\ (\text{solar zenith angle})} \qquad (11)$$

The value for $\overline{L}$ was determined by averaging the LANDSAT DC values from a 512 by 512 pixel matrix for a study area of interest and then using the A and B values in Table 1 to convert to mean radiance ($\overline{L}$).

III. EXPERIMENTAL PROCEDURES

Four prominent rangeland plant communities in south Texas are (Kuchler, 1964; Davis and Spicer, 1965)[11,3]: (i) live oak (Quercus virginiana Mill.), a tree that grows on deep sands in formations ranging from dense, uniform stands to frequent thickets or motts in underbrush; (ii) silverleaf sunflower (Helianthus argophyllus Torr. and Gray), a taprooted annual weed that has white-tomentose plant parts, germinates in April or May, reaches leaf pubescence peak in July, and flowers in late summer or fall; (iii) cenizo (Leucophyllum frutescens (Berland) I. M. Johnst.), a woody shrub that grows as either dense or sparse stands among a wide variety of woody shrubs on shallow soils; and (iv) honey mesquite (Prosopis glandulosa Torr.) that grows as motts or dense stands on a varity of soil types (deep sands, sandy loams, clay loams, or heavy clays).

We used LANDSAT MSS CCT and corresponding color images (1:1,000,000 scale) for a LANDSAT-2 overpass on June 2, 1977 (Scene I.D. 2862-16000). All four of the LANDSAT MSS bands were used, covering the 0.5- to 1.1-μm spectral region. This overpass provided DC data for a 185- by 185-km scene that included sample sites near Sarita, Alice, and Edinburg, Texas for the four plant communities.

We averaged LANDSAT MSS DC data over 417 training pixels (picture elements) collected from the four plant community sample sites and a clear lake. The average of the DC values from the clear lake ($\overline{Ll}$) was used to estimate Lp from equations (8), (9), and (10). The average of the pixels within a 512 by 512 pixel area near Sarita, Texas, was used to estimate $\overline{Rb}$ from equation (11). Then the Lp and $\overline{Rb}$ averages were used with Ahern's method to calculate the T and E which were used with Lp in equation (1) to convert the LANDSAT-2 DC averages for each plant community to plant reflectance at the earth's surface.

The field reflectance spectra were previously collected by Gausman et al. (1977a)[5] for the silverleaf sunflower and by Gausman et al. (1977b)[6] for the live oak, cenizo, and honey mesquite, over the 0.5- to 2.5-μm waveband, during the 1976 growing season with an Exotech Model 20 spectroradiometer (Leamer et al., 1973)[12]. The sensor had a 15-degree field-of-view (0.5 m^2) and was placed 3- to 3.4-m above each of five randomly selected canopies for each plant community sample site.

Using correlation techniques, we analyzed the reflectance data from both LANDSAT and spectroradiometer sensors, at the mid-band wavelength intervals of the LANDSAT MSS (0.55-, 0.65-, 0.75-, and 0.95-μm). Such a correlation will have unit slope and zero intercept if the measured reflectance from both sensors for the same plants were identical. Therefore, we conducted a t-test analysis to test for a significant deviation of the slope from unity and of the intercept from zero.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The value of radiance over the clear lake (L1) for band 4 (Table 2) was high (0.461 mw cm^{-2} sr^{-1}) as compared with Ahern's et al. (1977)[1] average value of 0.329 mw cm^{-2} sr^{-1}. This high value overestimated the path radiance (0.438 mw cm^{-2} sr^{-1}) that was used to determine atmospheric optical depth (t). Thus, for band 4, t = 0.791, which corresponds to a horizontal visible range of only 10 km (Potter and Shelton, 1974)[18]. The horizontal visible range on June 2, 1977 near the rangeland sites was probably more than 23 km. Probably the lake we used as a clear water reflectance standard was more turbid than we originally assumed. Also, the Turner model probably calculates too little path radiance for a given optical depth. The Lp value for band 5 was not overestimated as much as that for band 4. Values for bands 6 and 7 seemed reasonable as compared with Ahern's data.

The solar and atmospheric parameters given in Table 2 were used to convert the LANDSAT-2 digital count data in Table 3 to plant reflectances for the four rangeland plant communities using equation (1). The four plant communities were ranked in descending order by their reflectance values in LANDSAT band 7 so that values for sunflower > live oak > mesquite > cenizo. This ranking agreed with previous reflectance results using ground-based spectroradiometer measurements collected by Gausman et al. (1977b)[6] for the three woody canopies, but it differed from their reported leaf ground cover values, where the ranking was live oak > cenizo > mesquite. The silverleaf sunflower's white-tomentose condition apparently caused its reflectance to be higher than that of the woody plants.

Figure 2 compares the LANDSAT reflectance values (•) from Table 3 with the previously determined ground-based spectroradiometer reflectance measurements (solid lines) for the same plant communities (Gausman et al., 1977a, b)[5,6]. The values seem quite comparable, except that the LANDSAT reflectance values in bands 4 and 5 for cenizo and bands 6 and 7 for live oak were lower than the corresponding ground-based reflectance measurements. Apparently, the undetermined amount of live oak vegetation cover was not very high so that the reflectance in bands 6 and 7 was decreased due to integrating more soil and shadow reflectances in with plant reflectance over a wide ground area (Richardson et al., 1975)[20].

Figure 3 shows the slope and intercept results of correlating the LANDSAT and ground-based spectroradiometer reflectance measurements. The correlation of the reflectance values between the two sensors was highly significant (r^2 = 0.924) and a t-test analyisis showed that the slope (0.994) did not differ significantly from unity nor did the intercept (1.55) differ significantly from zero. Thus, these results indicated that the LANDSAT MSS could be calibrated for solar and atmospheric variations to yield reflectance measurements at the earth's surface that were not significantly different from ground-based spectroradiometric reflectance measurements, even though the lake used as a clear water reflectance standard may have been somewhat turbid.

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Table 1. LANDSAT-1 and -2 calibration constants for converting digital count rates to radiance as measured by the LANDSAT multispectral scanner (MSS) at the top of the earth's atmosphere. (From Potter (1972), Rogers and Peacock (1973), Herzog and Sturm (1975), Otterman and Fraser (1976), and LANDSAT Newsletter #15.)

LANDSAT MSS Sensor		LANDSAT Calibration Constants*				Life-Span of LANDSAT Calibration Constants
		MSS4	MSS5	MSS6	MSS7	
1	A	0.0195	0.0157	0.0138	0.0730	8/25/72 to 1/10/78
	B	0.0	0.0	0.0	0.0	
2	A	0.0157	0.0117	0.0105	0.0637	1/22/75 to 7/15/75
	B	0.10	0.07	0.07	0.14	
2	A	0.0201	0.0134	0.0115	0.0603	7/16/75 to present
	B	0.08	0.06	0.06	0.11	
3	A	0.0170	0.0135	0.0112	0.0615	3/5/78 to 5/31/78
	B	0.04	0.03	0.03	0.03	
3	A	0.0201	0.0139	0.0115	0.0603	6/1/78 to present
	B	0.04	0.03	0.03	0.03	

* The radiance units for A and B are mw cm^{-2} sr^{-1} $count^{-1}$ and mw cm^{-2} sr^{-1}, respectively.

Table 2. Solar and atmospheric variables determined for a June 2, 1977 LANDSAT overpass (scene I. D. 2862-16000) of rangeland communities located in south Texas. Solar zenith angle was 34 degrees.

LANDSAT MSS Bands	Clear Lake Radiance (Ll)	Path Radiance (Lp)	Solar Constant (Eo)*	Diffuse Radiance (Es)	Direct Radiance (Ed)	Atmospheric Transmittance And Optical Depth (T)	(t)	Background Reflectance ($\overline{Rb}$)
	mw $cm^{-2}sr^{-1}$	mw $cm^{-2}sr^{-1}$	mw cm^{-2}	mw cm^{-2}	mw cm^{-2}			
4	0.461	0.438	17.3	7.7	5.5	0.453	0.791	0.133
5	0.274	0.253	15.1	5.8	6.2	0.554	0.590	0.118
6	0.163	0.148	12.4	2.8	7.3	0.751	0.285	0.213
7	0.170	0.155	25.1	3.0	17.7	0.872	0.136	0.242

* From Thekaekara et al. (1969), Rogers and Peacock (1973), and Otterman and Fraser (1976).

Table 3. Digital count (DC) data, radiance at top of atmosphere (L), and reflectance (R) measured by LANDSAT-2 on June 2, 1977 (scene I. D. 2862-16000) for four typical rangeland vegetation communities. Solar zenith angle was 34 degrees.

Rangeland Vegetation Communities	LANDSAT MSS BANDS DC4	DC5	DC6	DC7	L4	L5	L6	L7	R4	R5	R6	R7
					--- mw cm^{-2}	sr^{-1} ---			%	%	%	%
Silverleaf Sunflower	26.2	25.6	67.9	32.8	0.61	0.40	0.84	2.09	9.0	6.9	27.0	33.7
Live Oak	22.0	21.3	56.0	28.3	0.52	0.35	0.70	1.82	4.3	4.6	22.9	29.0
Mesquite	23.8	25.5	51.6	24.7	0.56	0.40	0.65	1.60	6.4	6.9	21.0	25.1
Cenizo	21.1	20.2	47.9	23.1	0.50	0.33	0.61	1.50	3.3	3.6	19.1	23.4

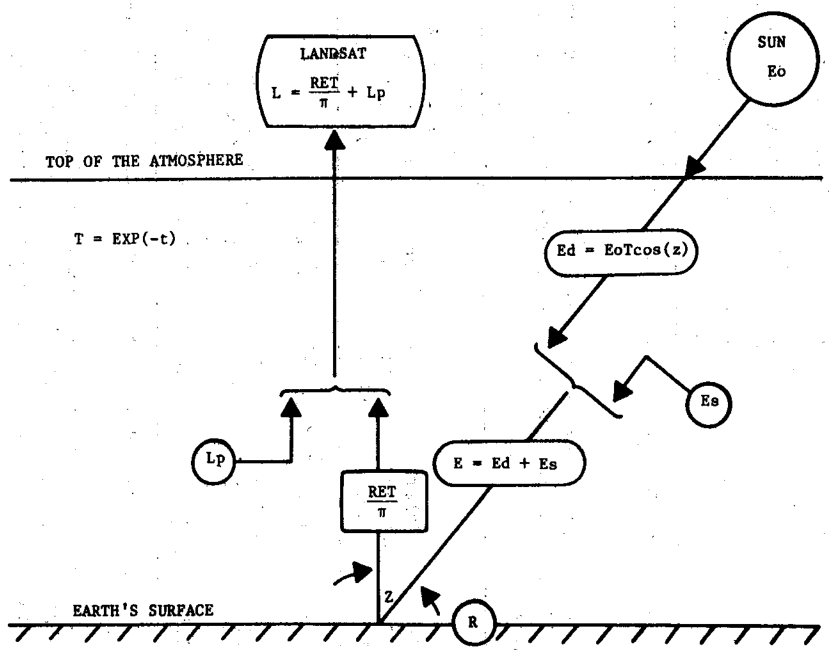

Figure 1. Generalized diagram of the atmospheric problem for converting LANDSAT digital count data to reflectance (R). The solar and atmospheric variables involved were defined previously.

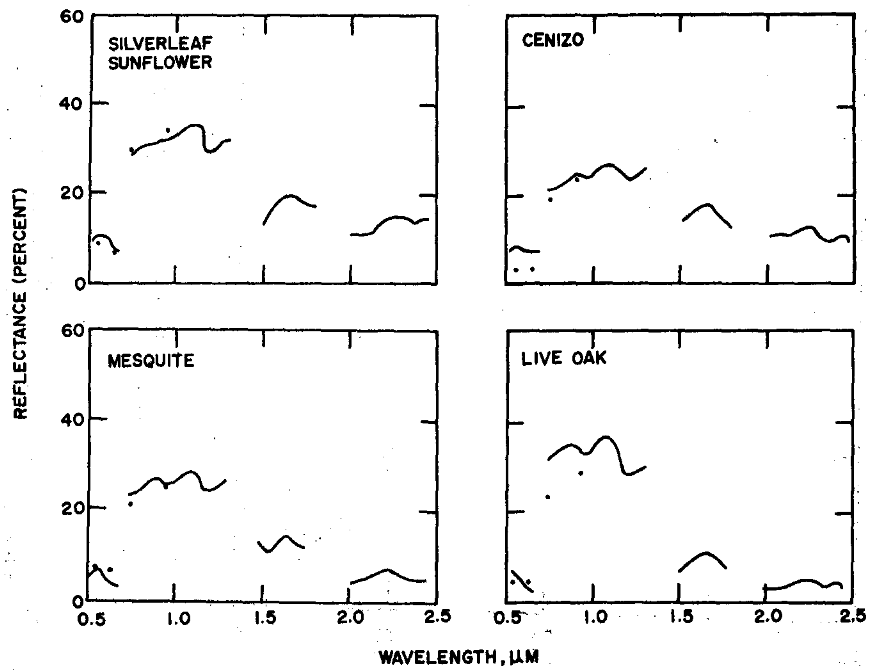

Figure 2. Comparison of ground-based Exotech spectroradiometric (solid line) and LANDSAT (•) reflectance measurements of four south Texas rangeland plants.

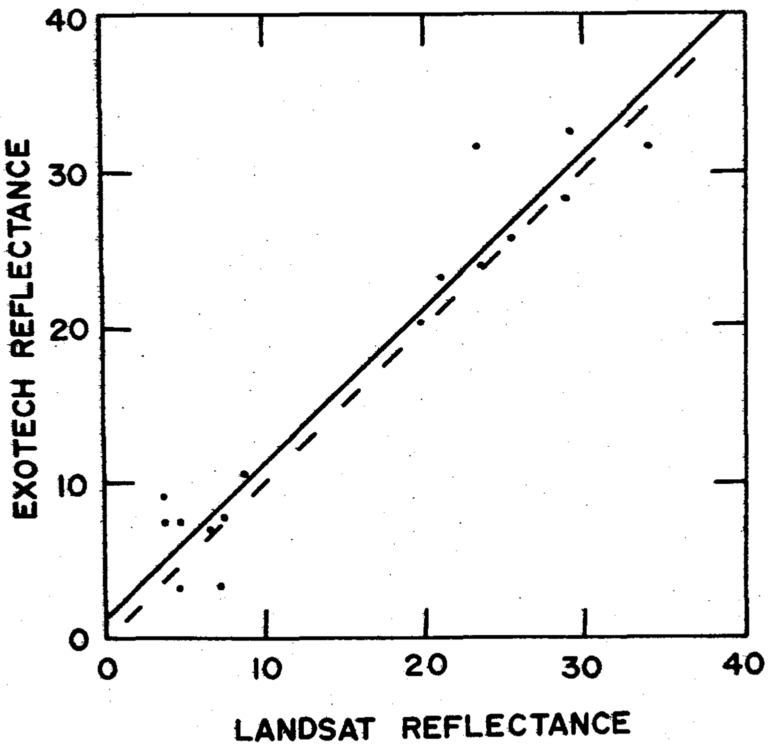

Figure 3. Correlation of ground-based spectroradiometric (EXOTECH) and LANDSAT-2 MSS reflectance measurements at wavelengths 0.55-, 0.65-, 0.75-, and 0.95-μm for four south Texas rangeland plants. The equation of the regression line (solid line) is EXOTECH = 1.55 + 0.994 LANDSAT where r^2 = 0.961. A perfect relation between EXOTECH and LANDSAT measurements is indicated by the dashed line. The standard error of slope and intercept for the regression equation was 0.076 and 3.15, respectively.

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