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REDUCING LANDSAT DATA TO PARAMETERS WITH PHYSICAL SIGNIFICANCE AND SIGNATURE EXTENSION--A VIEW OF LANDSAT CAPABILITIES

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ABSTRACT

The premise of this paper is that LANDSAT is capable of sensing only a few physical parameters; all computer processing and recognition schemes for LANDSAT data can be successful only to the extent that the desired classifications correlate with, or are designated by, these physical parameters. When this is not the case, automatic recognition results can become highly circumstantial and often hopelessly ambiguous. Although some limited differentiation of plant species can be done by computer processing, most often separation of vegetation types is less dependent on species differences than on differences caused by topography or content of vigorous vegetation. Much of the contrast provided in LANDSAT data is provided by differences in vegetation cover.

Although dominant, vegetation is not the only physical parameter that can be detected with LANDSAT; a ratio of MSS Channel 5 to MSS Channel 4 (R5,4), two visible channels, separates materials by color hue. Additional information is attained by the addition of MSS channels 5 and 4 to approximate brightness, permitting separation of materials by color value. Other spectral combinations may provide correlations with these physical parameters or new ones.

An iron absorption in the infrared can also be recognized in LANDSAT data when iron content is present in sufficient percentages. Although by color, limonite-rich soils are distinctive as bright yellow, they are not unique in the aoorementioned R5,4. However, the yellow color imparted to these soils is the result of well disseminated, fine-grained limonite (hydrous ferric oxide) in relatively large quantities. A fairly strong iron absorption is present in the infrared band MSS Channel 7, for these soils, although the wideband configuration of LANDSAT is not optimal for its enhancement and the effects of vegetation often obscure it.

Other such physical relationships are probably available in the spectral configuration of the LANDSAT multispectral scanner and other coming scanners. It is important to isolate and document them so that enhancement, categorical analysis, and image interpretation can better be based upon criteria with physical significance, providing spatial and temporal extension.

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1. INTRODUCTION

The view of LANDSAT capabilities presented here and the major premise set forth in the abstract are the distillates of a collection of LANDSAT studies in mineral exploration and land cover classes with which author has been involved. Two data sets available from two of these studies will be drawn upon for illustrative material. The first is a set of laboratory spectra corrected to LANDSAT response, quantitative color determinations, and measurements of iron content for twenty samples of regosols from the Wind River Basin, Wyoming, which were gathered during a study of alteration products associated with roll-type uranium deposits (Salmon and Pillars, 1975). These samples will be used where laboratory measurements are indicated and color designations have been accurately annotated by Munsell standard, as well as by a general color description. The second data set is comprised of field spectra measurements made by personnel of The U.S. Bureau of Land Management on perennial and ephemeral rangeland vegetation types and some soils. These spectra are representative of the natural materials to the extent that it was possible to fill the field of view of the RPMI* spectrometer with a specific plant or soil in the natural environment; soil color designations are only field descriptions and are not standardized (Bentley, et al., 1977).

The Munsell color system is a widely accepted system of color standardization in use in the United States, especially by geologists and soil scientists. The system is based on a color sphere in which the vertical axis represents color value, the radial axes represent color chroma, and the circumference represents color hue. Notation of Munsell color includes, by convention, the color hue, represented by a number and a letter abbreviation, followed by a number representing color value, a slash(/), and a number representing color chroma, or intensity. An informal color designation of color is sometimes called upon in this paper for ready separation of important visual color differences which are not easily recognized by Munsell designation; most importantly, both tan and yellow samples of regosols in the first data set fall into the 10YR Munsell hue. These have been distinguished with appropriate single letter notation when necessary.

In the discussion of vegetation cover we will follow Maxwell (unpublished report) in assuming a high correlation among biomass, chlorophyll, and leaf water. Recognizing the distinct spectral differences between dead vegetation and green vegetation, when considered in general categories these two will be referred to as "dry" and "green". "Green", a single parameter by definition including leaf water, chlorophyll and biomass, will imply wet-green-biomass.

2. COLOR HUE

Hue is the attribute of color that permits it to be classed as red, yellow, green, blue or an intermediate between any contiguous pair of these. A progression of Munsell hues plotted against LANDSAT response-weighted reflectances for bands 4 and 5 for twenty regosols showed that MSS Band 4 provides better color separation than Band 5, although it is not optimal (Figure 1). Notice that in this figure a progression from YR (yellow-red) to GY (green-yellow) to Y (yellow) colors results.

Spectral ratio values using bands 5 and 4 were calculated from the same data and plotted against full Munsell designation in the order of increasing ratio value (Figure 2). Unlike the single band plots, GY samples are at the end of the progression, which continues from Y to YR. The ratio values not only correlate better than single channels with Munsell hue, but show discontinuities between hue designations. These quantitative differences may be important indicators of LANDSAT MSS capability to separate soil types and to detect surface deposits important for oil and mineral exploration. Ferric oxides in the form of hematite with well-disseminated particles imparting reddish colors to soils and alteration minerals can be enhanced with this single ratio. However, as indicated in Table 1, Munsell hue 10YR contains samples of general description of both tan and yellow, an important distinction to make in geology. Data points in the 10YR range (and one other yellow sample) are annotated in Figure 2 by "Y",indicating a yellow sample, or by "T", indicating a tan sample. The R5,4 did not separate these two colors, their difference being obvious visually. Spectra collected over the whole visible region show definite, promising differences among colors of interest. The nonoptimal LANDSAT configuration does not, however, make optimal use of these differences.

LANDSAT data collected over the Wind River Basin, Wyoming, was used to test how well these laboratory results correspond to actual data. Singatures were extracted from areas known to be well exposed and covered with materials of similar hue to some of the regosol samples which had been measured. Signatures consisted of multiple pixel element samples, the values of which were collected and ratios formed to give R5,4 values, their means and ranges (Figure 3). The anticipated relationship with color hue is borne out, although the ranges of individual sample values often overlap in R5,4 value. This result gives some indication of the realistic capability of this LANDSAT spectral ratio to separate and recognize materials by color hue under limited vegetation cover conditions.

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*Bendix Aerospace Systems Division Radiant Power Measuring Instrument

LANDSAT MSS Channel 7, an infrared band, was examined for evidence of possible geochemical information, for there are well known iron absorptions in this spectral region (Rowan, 1972). Spectra and iron content of eighteen of the twenty regosols are shown in Figure 4 with notation of the LANDSAT MSS Channels 6 and 7 superimposed. Yellow samples, which in this case are highest in iron content (and ferric oxide content), are seen to have a strong absorption band in MSS Channel 7. A plot showing R5,4 vs. R6,7 (Figure 5) indicates that using this additional chemical information, separation of yellow and tan on iron content is allowed. The additional separation of colors of interest which would be allowed in a two dimensional system is valid for only those cases where these physical and chemical properties can be expected to retain this relationship.

3. COLOR VALUE

The property of lightness is called color value. Lightness is presumably the result of high reflectance across most of the visible spectrum producing a maximum value in reflected energy when totalled across these wavelengths. No optimization study was conducted here to show that the combination of channels used was the best available for predicting color value; weighting of these channels or some other combination may actually improve color value determinations. However, the simple combination of MSS Band 4 and MSS Band 5 by addition should give an indication of the material returning the highest energy and at least indicate a possibility to recognize this physical property. Figure 6 shows the value of the twenty samples listed in Table 1 plotted against the sum of their MSS Band 4 and MSS Band 5 response-weighted reflectances. General color descriptions are annotated for additional consideration.

Although descriptions of colors were not standardized for the data set made up of field measurements of plants and soils, color relationships of both hue and value for these samples seen in Figure 7 seem to agree with the relationships found for the more precisely determined colors of the soil samples (Figure 2 and 6). In considering these results, allowances must be made for nonoptimal field conditions and possible inconsistencies in color descriptions, but the overall relationships are still strongly indicated. This data set is included to allow the additional consideration of dry and green vegetative material for a more general comparison.

4. INFLUENCE OF VEGETATION

Both color hue and value are important for differentiating among non-vegetative targets because they are indicative of soil characteristics and LANDSAT is spectrally sensitive to these physical parameters. The interplay among rock and soil spectra, natural variation, instrument response, atmospheric conditions, and the influence of superimposed vegetation makes actual recognition and mapping of these characteristics a nontrivial exercise. Discussion of capabilities of LANDSAT to recognize geologic materials without consideration of these factors, particularly vegetation conditions, provides only an estimate of the best results, possible only in ideal data and environments. Much of the terrain in which these materials are to be mapped has at least sparse, partially green, vegetation cover. Increasing percentages of green vegetation would result in so diminishing the distinctive spectral characteristics of the limonitic soils shown in Figure 4 that their LANDSAT spectral uniqueness would be eliminated quickly. Where substantial vegetation interefers with spectral recognition of non-vegetative targets, a method of correcting for vegetation cover must be used simultaneously with spectral parameters which are sensitive to differences in geologic materials.

The LANDSAT multispectral scanner is, by design, sensitive to variations in cover by functioning green biomass. Indeed, we have stated that much of the spectral contrast available in LANDSAT data is provided by extremes in vegetative cover and that without these, many automatic recognition procedures could not make the differentiations which appear possible. A ratio of infrared to red is often drafted for enhancement of vegetation cover differences because it is relatively insensitive to background variation and very sensitive to wet-green-biomass. Figure 8 shows the relationship of R7,5 measurements of rangeland vegetation and soils. Note that most of the useful dynamic range of R7,5 is the result of differences in the spectra of green vegetation--and likewise differences in their spectral contribution in LANDSAT data due to variation in ground cover--with little meaningful separation among rocks and soils.

R7,5 and other single ratios may not be optimal for recognizing vegetation, either for correcting for its interference with geologic targets or for land cover type mapping. Optimal combinations of MSS bands or highbred spectral parameters may, for any particular environment or time of year, be found by a number of linear and polynomial optimization methods. A relatively simple combination of ratios we have tried uses the vegetation information available in the R7,5 ratio with color information supplied in R5,4. While R7,5 is the highest for high vegetation cover, it can also be high for common iron oxides. However, R5,4 will always be at a minimum for things which appear green and high for red ferric iron oxides. Dividing R7,5 by R5,4, one would expect vigorous plant material which is high in the numerator and low in the denominator to become even more separated to the high end of the values. This ratio of ratios allows the range for green plants in soils ranging in color from red to white to expand slightly from that available in a single ratio.

Most importantly, the influence of vegetation is treated in these methods as a continuous, unique variable. Other such physical parameters which may be possible to isolate using LANDSAT data, particularly with the additional information allowed by registration of multiple-date data sets, are percent grass, grass/shrubs within vegetation, etc. It is the significance of those physical parameters which can be isolated in some spectral dimension in LANDSAT data to the definition of plant communities or crop types that will determine the success of recognition in the spectral signature approach. The physical basis for spectral differences among targets is sometimes not analyzed. As a result, the vegetative or soil characteristics which are most influential in the spectral signature do not necessarily become apparent. Whether a plant community is recognizable in a particular data set because of differences in soil, plant species, or vegetation cover is not evident when employing automatic recognition. This can be a drawback, since the ability to recognize these same plant communities in another data set or in another area is contingent on which of these factors contributes most to its uniqueness.

Although the author is unaware of any quantitative studies which have documented the range of percent vegetation cover over which the R7,5 or other spectral parameters for predicting vegetation cover are sensitive, much qualtative data indicates that accuracy falls off well above those percentages important for mapping vegetation in tasks such as desertification mapping, ephemeral rangeland condition and rangeland trend, and perhaps even some crop identification. In a recent study in ephemeral rangeland in Arizona, we found that the open growth characteristics of desert trees and shrubs and the low percentages of ground cover by live plant material created a diffuse target highly influenced by the background soil and rock. Figure 9 shows the ranges of LANDSAT single channel values for thirteen targets extracted from separate plant community sites in an area west of Phoenix, Arizona, for May, 1975. Little separation is available in any of the data for these plant communities, which range from 3 to 24 percent vegetation cover.

Difficulties in recognizing the expected influence of vegetation in arid regions of sparse cover have precedence in the literature. In his reply to Jackson and Idso (1975), Otteman reports an observed low reflectance in MSS Band 7 in an area of appreciable vegetation cover in the Western Negev and refers to it as "the Negev infrared reflectance paradox". The apparent explanation for the anomalous reflectance of the area was that even with 25 to 35 percent ground cover, it was the intertitial soil that effectively controlled the reflectances. In the Negev the intertices showed dark-gray plant litter and stablized soil. In contrast, intertitial soil reflectances were high in the adjoining Sinai, where unstablized soil with a high albedo was well exposed under a mere 10 percent vegetation cover. This observation would seem to be in agreement with the work of Baldridge, et al. (1975) in the widely different environment of the State of Ohio. In land use inventory categories designated for the mapping of land use in Ohio, the most dense industrial and commercial areas classed as "urban" were grouped into a vegetation cover class of 0 to 35 percent vegetation cover.

5. RECOGNITION OF PLANT SPECIES

Certainly some influences of plant species' reflectance properties are present in LANDSAT data. The important question is which, if any, can be distinguished spectrally from differences in vegetation cover. When species differentiation is inferred from information which actually depends on vegetation cover differences, the latter should be specified precisely as the distinguishing physical parameter. Not only is it less misleading, but optimal processing functions can then be adjusted systematically for differences in growing season, climate, background, etc..

In the study of perennial rangeland in Montana, two of the plant communities defined during fieldwork were upland grass, a mixture of grasses, sedges, and bushes with 46 percent ground cover, and bluestem hillside, with 47 percent ground cover chiefly made up of Andropgon scoparius, or "little bluestem". In a single channel of LANDSAT data (MSS Channel 5) these two plant communities differed, most likely because of their correlation with prominent topographic differences. A ratio R7,5 of the same area showed no difference between the two plant communities, although considerable variation in vegetation cover within the upland grass plant community became evident.

Two other plant communities with very different vegetation characteristics, a wet meadow with 75 percent vegetation cover and a pine-bunchgrass community with 59 percent cover (where it occurred on north facing slopes) were equally dark in MSS Channel 5. Pine-bunchgrass stands on other exposures looked similar to upland grass plant communities also present. The unique reflectance properties of pine needles and leaves of other evergreens provide a strong influence which can possibly be used in species identification. However, it and other species determination must be represented in a spectral dimension independent of vegetation cover influences for operational mapping potential.

6. CONCLUSION

The consequences of this view of LANDSAT capabilities are of major importance to operational procedures being designed by The U.S. Bureau of Land Management in their newly assigned task of keeping a current inventory of the natural resources of public lands. Species differences is crucial information for estimating conditions for grazing. The recognition of plant communities in natural environments is somewhat more difficult than in agricultural areas where, for a field of a certain size, a discrete, homogeniety of target can be assumed. In rangeland and forested environments, there can be a continuous blend of species, their phenologies can differ according to weather conditions, and apparent cover can change differentially due to specific canopy characteristics. The separation of vegetation characteristics due to differences in the cumulative wet-green-biomass present and those that are truly indicative of species' spectral differences can lead to a better understanding of LANDSAT capability to map vegetative types in both natural environments and agricultural areas. In addition, specific attention to the physical conditions which bound LANDSAT capabilities may prevent planning of future mapping and recognition efforts when spectral resolution may not be sufficient, such as plant community mapping in areas with less than 25 percent vegetation cover.

The implications of this view are equally important to land use studies which require classification in greater detail than Level I land use. Separation of even Level I with LANDSAT multispectral processing is highly dependent on vigorous vegetation extremes to provide contrast, as well as to characterize classes such as "old residential" or "park areas". Spectral processing actually recognizes land cover rather than land use. Land cover characteristics can very with climate, city layout, and residential development. Spectral recognition will vary with these local land use practices. Where vegetation cover is not significantly different among land use classes, or where contrast due to extremes in vegetation is not available, the accuracy of land use mapping will be seriously degraded.

Geologic applications must be performed for specific tasks and in those environments where physical characteristics also fall within the spectral and spatial capabilities of LANDSAT data. For mineral exploration, target deposits must first fit the basic criteria of possible spectral distinction and sufficiently large surficial expression. Then it must be determined that compositional differences which are important to discovery of the deposit have spectral characteristics strong enough for detection above noise and vegetation present in the data. This may require restatement of specific questions such as "Can LANDSAT help discover new deposits of uranium?" to "Under what conditions can LANDSAT help discover new deposits of uranium?" Details of vegetation conditions and the color of oxidization products associated with the uranium deposits are inextricable from the answer to be given; it is the germaine physical parameters which define a successful application of LANDSAT multispectral data to earth resource investigations.

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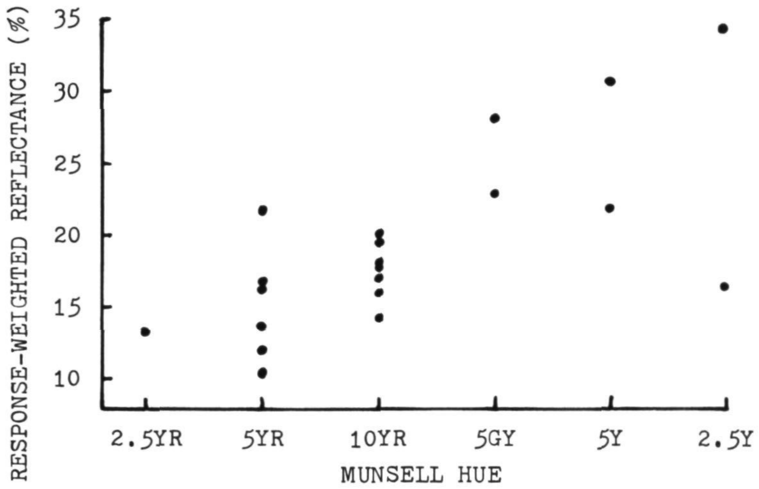
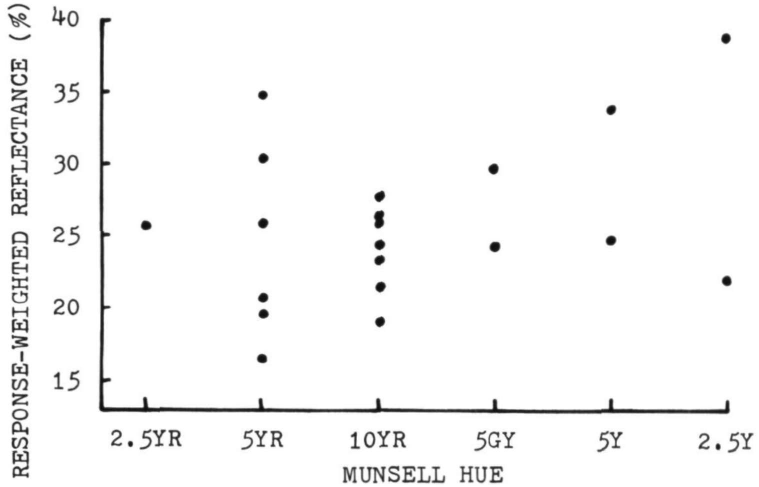
MUNSELL COLOR	GENERAL COLOR AND ABBREVIATIONS	
5 YR 5.5 / 8	Dark Orange; (Nugget ss)	(Or)
5 YR 7 / 8	Light Orange; (Nugget ss)	(Or)
2.5 YR 4.5 / 6	Bright Red; (Chugwater Fm.)	(R)
5 YR 4 / 6	Dark Red-Brown	(R)
5 YR 4 / 4	Bright Red	(R)
5 YR 5 / 6	Pale Red	(R)
5 YR 5 / 4	Pale Red	(R)
10 YR 5 / 6	Yellow	(Y)
10 YR 6 / 5.5	Yellow	(Y)
10 YR 4 / 6	Yellow	(Y)
10 YR 5 / 5	Yellow	(Y)
2.5 Y 6 / 6	Yellow	(Y)
10 YR 5 / 3.5	Tan	(T)
10 YR 5 / 3	Tan	(T)
10 YR 6 / 3	Tan	(T)
2.5 Y 8 / 2	White to Pale Orange	(W)
5 Y 6 / 4	Yellow-Green	(YG)
5 Y 6 / 2	Pale Yellow-Green	(YG)
5 GY 7 / 2	Blue-Green	(G)
5 GY 6 / 2	Green	(G)

TABLE I. COLOR DESIGNATIONS OF REGOSOLS FROM THE WIND RIVER BASIN, WYOMING.



(a) Band 4 (Green)



(b) Band 5 (Red)

FIGURE 1. LANDSAT RESPONSE-WEIGHTED REFLECTANCES FOR MSS BANDS 4 AND 5 VS. MUNSELL HUE FOR 20 REGOSOLS IN THE WIND RIVER BASIN, WYOMING.

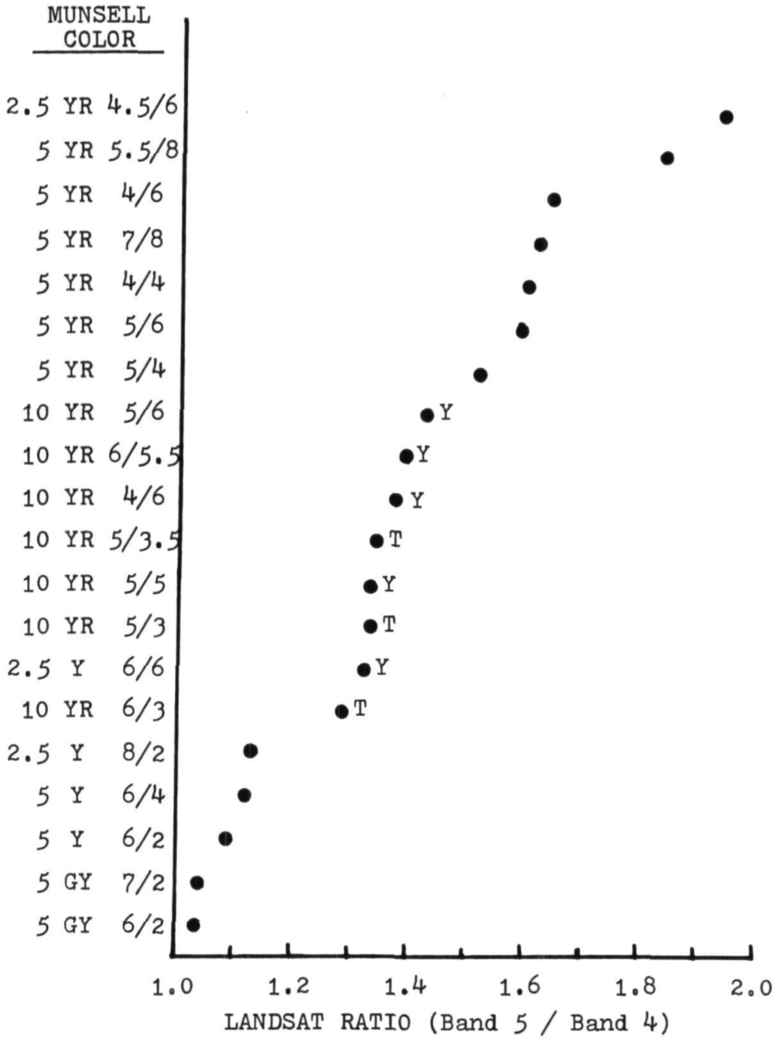


FIGURE 2. MUNSELL COLOR VS. INCREASING LANDSAT R5,4 VALUE FOR 20 REGOSOLS IN THE WIND RIVER BASIN, WYOMING

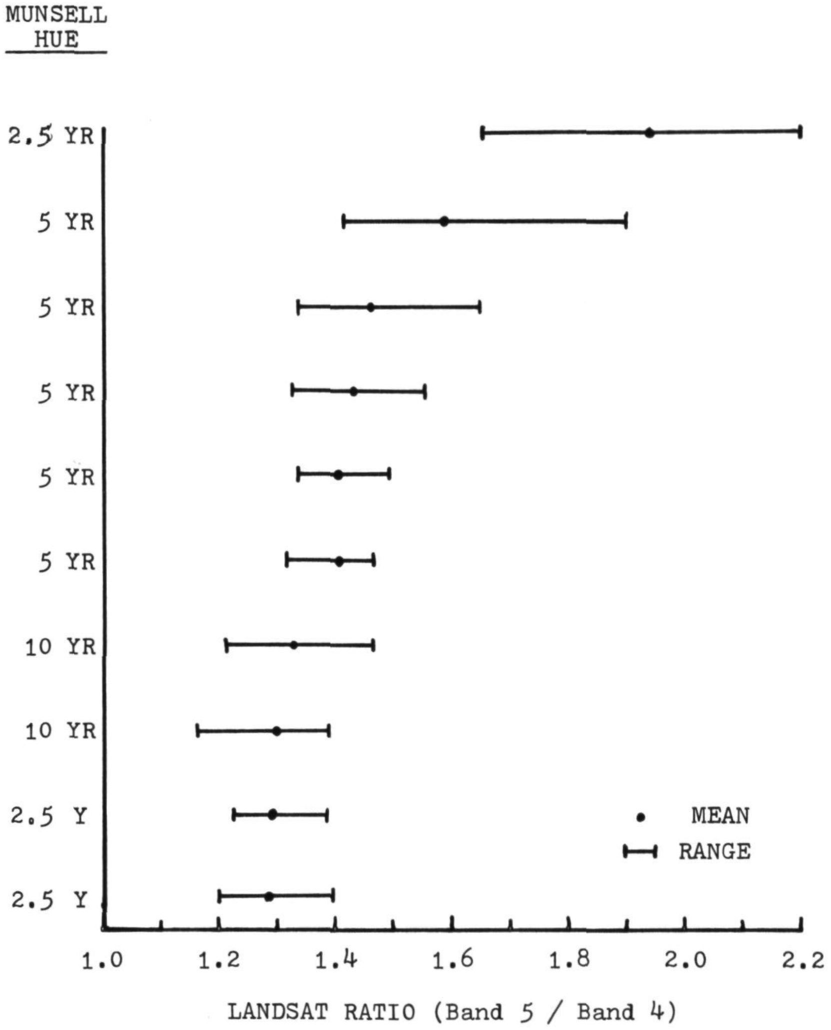
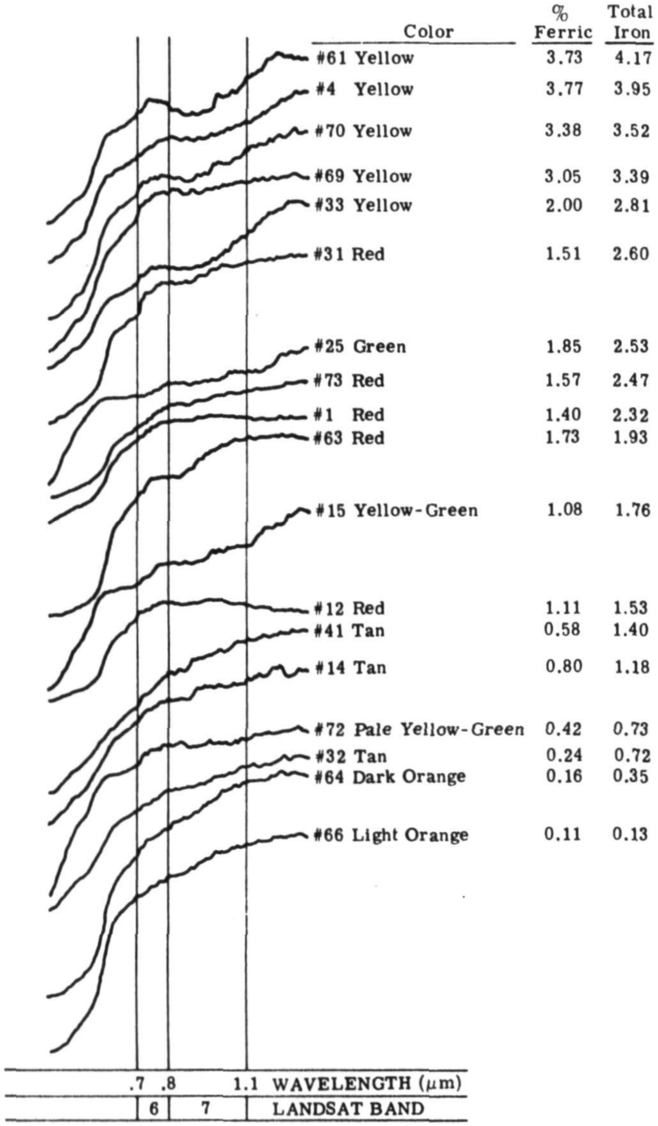


FIGURE 3. MUNSELL HUE VS. LANDSAT R5,4 SIGNATURES CALCULATED FROM DIGITAL VALUES OF LANDSAT DATA COLLECTED OVER THE WIND RIVER BASIN, WYOMING, AUGUST, 1972.



Color	% Ferric	Total Iron
#61 Yellow	3.73	4.17
#4 Yellow	3.77	3.95
#70 Yellow	3.38	3.52
#69 Yellow	3.05	3.39
#33 Yellow	2.00	2.81
#31 Red	1.51	2.60
#25 Green	1.85	2.53
#73 Red	1.57	2.47
#1 Red	1.40	2.32
#63 Red	1.73	1.93
#15 Yellow-Green	1.08	1.76
#12 Red	1.11	1.53
#41 Tan	0.58	1.40
#14 Tan	0.80	1.18
#72 Pale Yellow-Green	0.42	0.73
#32 Tan	0.24	0.72
#64 Dark Orange	0.16	0.35
#66 Light Orange	0.11	0.13

FIGURE 4. INFRARED SPECTRAL FEATURES IN ORDER OF DECREASING TOTAL IRON CONTENT (and general color).

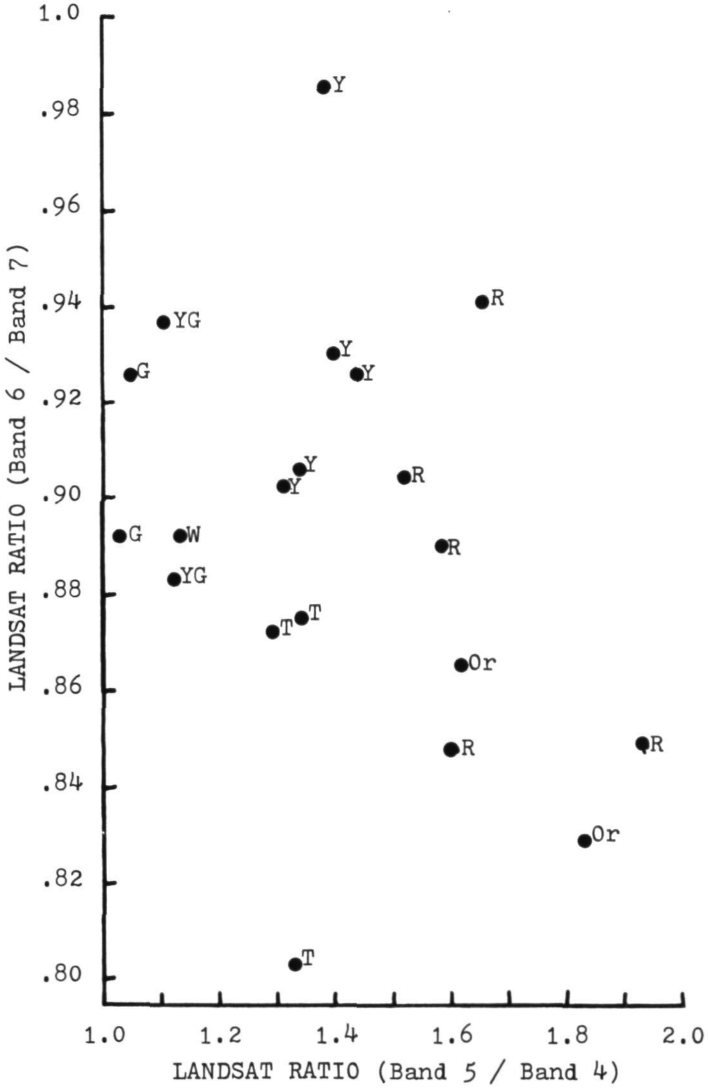


FIGURE 5. LANDSAT R6,7 VS. LANDSAT R5,4 FOR 20 REGOSOLS IN THE WIND RIVER BASIN, WYOMING.

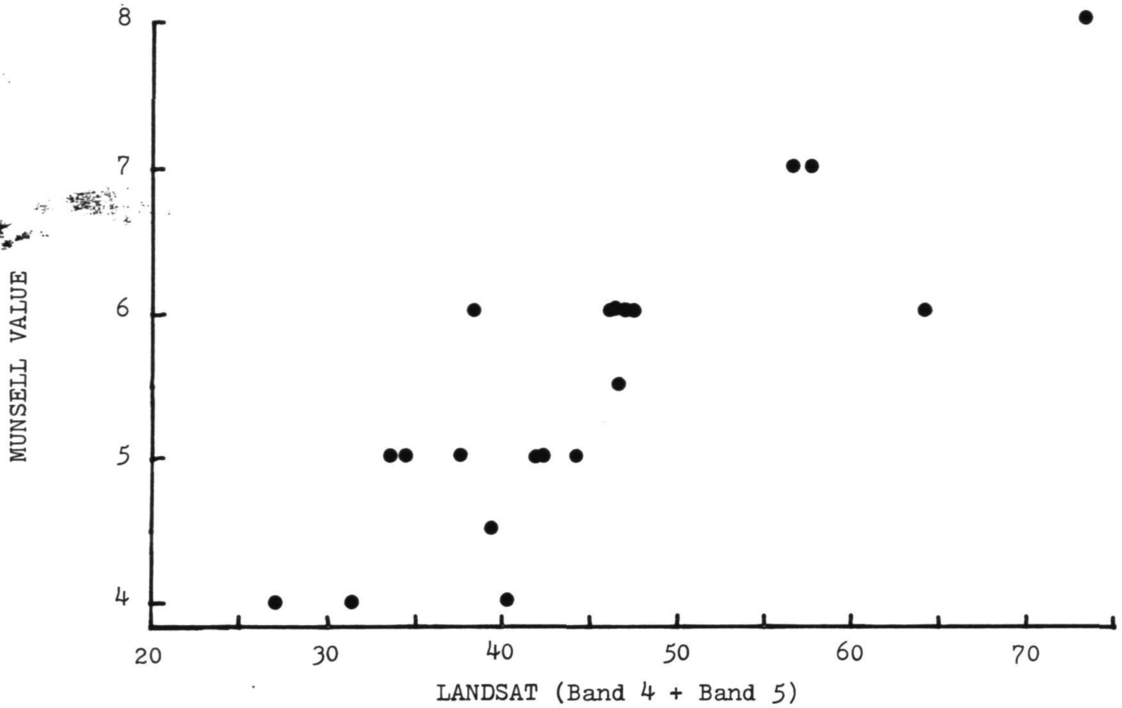


FIGURE 6. MUNSELL VALUE VS. LANDSAT (Band 4 + Band 5) CALCULATED FROM RESPONSE-WEIGHTED REFLECTANCES FOR 20 REGOSOLS IN THE WIND RIVER BASIN, WYOMING.

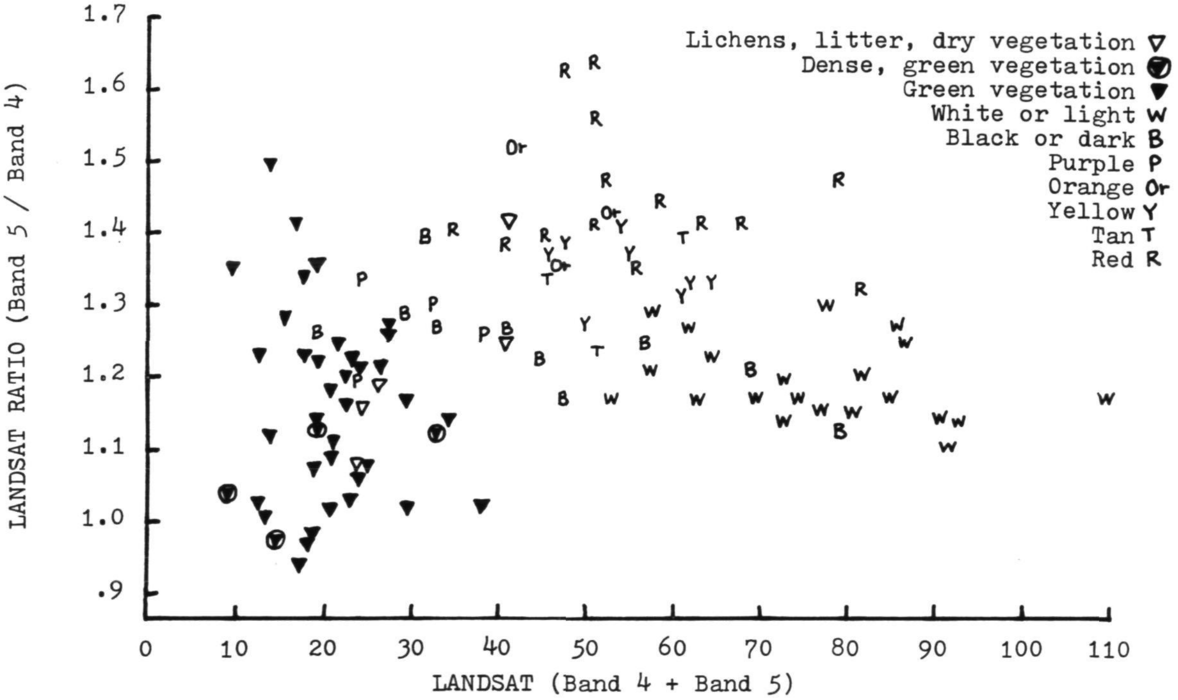


FIGURE 7. LANDSAT R5,4 VS. LANDSAT (Band 4 + Band 5) CALCULATED FROM FIELD SPECTRA OF RANGELAND PLANTS AND SOILS IN EASTERN MONTANA.

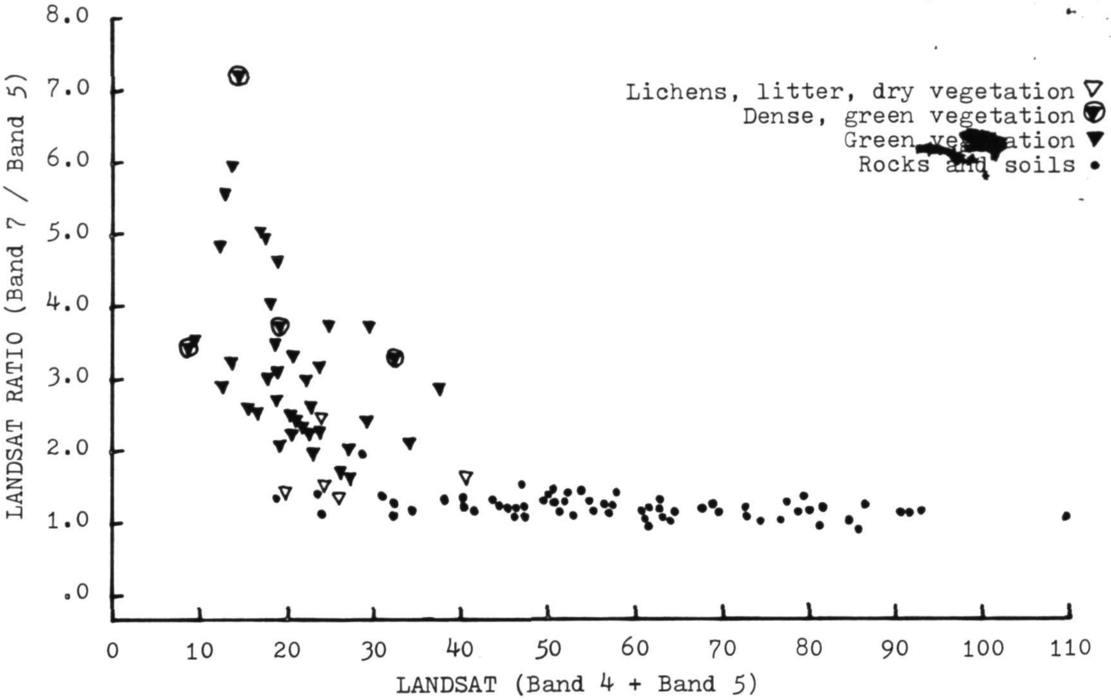


FIGURE 8. LANDSAT R7,5 VS. LANDSAT (Band 4 + Band 5) CALCULATED FROM FIELD SPECTRA OF RANGELAND PLANTS AND SOILS IN EASTERN MONTANA.

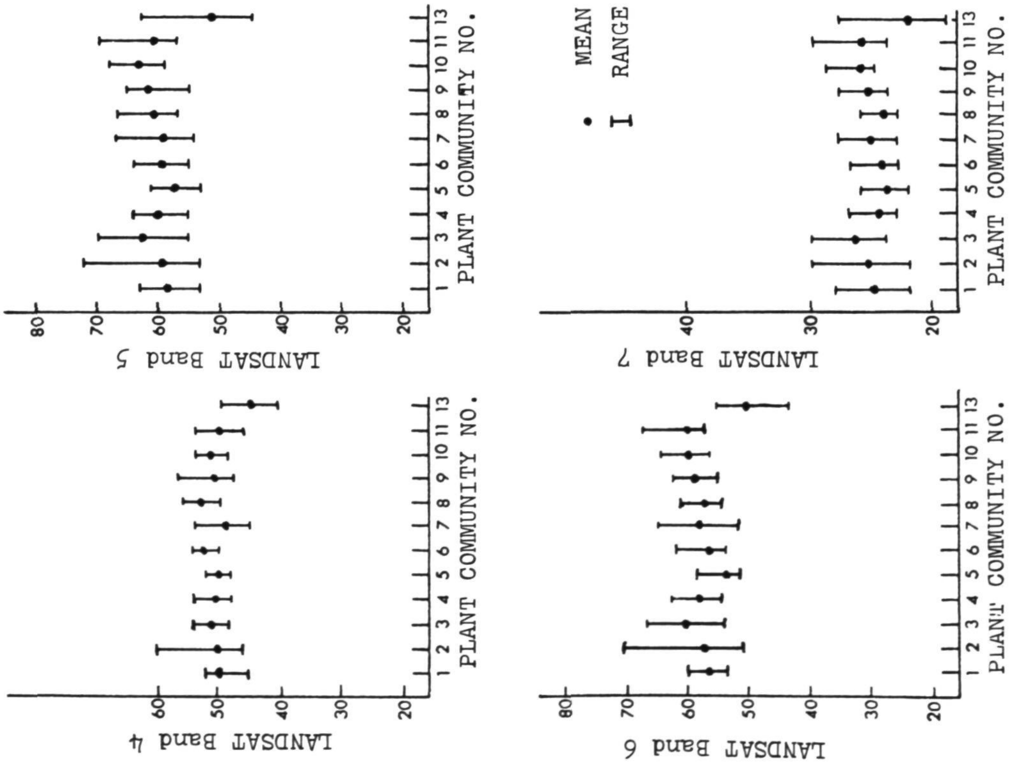


FIGURE 9. PLANT COMMUNITY SIGNATURES EXTRACTED FROM LANDSAT DATA FOR EPHEMERAL RANGELAND IN ARIZONA WITH 3 TO 24 PERCENT VEGETATION COVER, MAY, 1975.