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Remote Sensing Research

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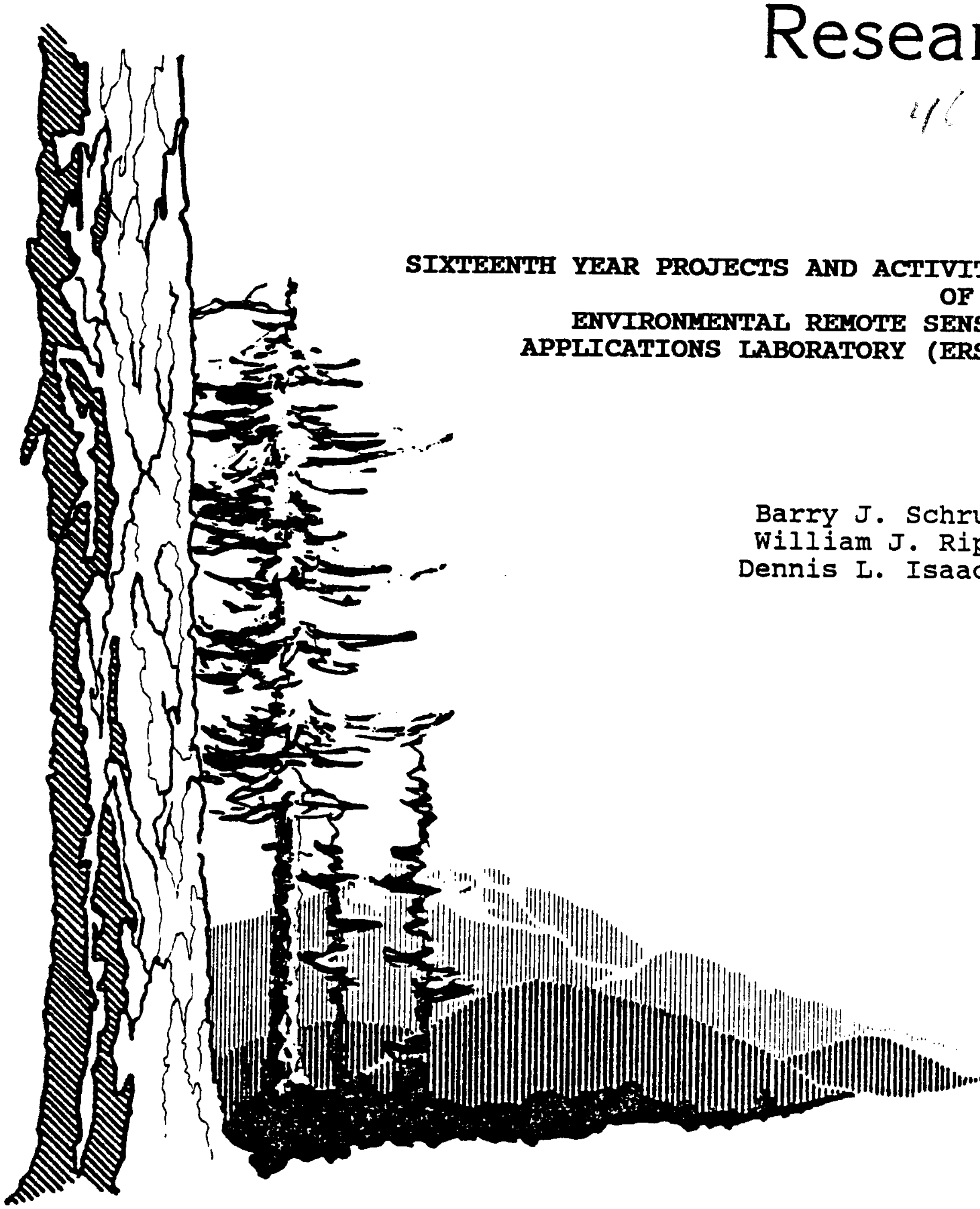

SIXTEENTH YEAR PROJECTS AND ACTIVITIES OF THE ENVIRONMENTAL REMOTE SENSING APPLICATIONS LABORATORY (ERSAL)

by

Barry J. Schrumpf
William J. Ripple
Dennis L. Isaacson

Environmental Remote Sensing
Applications Laboratory – ERSAL

OREGON STATE UNIVERSITY

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RESEARCH IN REMOTE SENSING OF VEGETATION

by

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RESEARCH IN REMOTE SENSING OF VEGETATION

BACKGROUND

The Environmental Remote Sensing Applications Laboratory (ERSAL) at Oregon State University is engaged in a program for the research and development of remote sensing technology. The research topics undertaken by this program were primarily selected to further the understanding of fundamental relationships between electromagnetic energy measured from Earth orbiting satellites and terrestrial features, principally vegetation.

Vegetation is an essential component in the soil formation process and the major factor in protecting and holding soil in place. Vegetation plays key roles in hydrological and nutrient cycles. Indeed, vegetation makes this planet habitable and the condition of vegetation directly determines its capacity to produce those products necessary for sustaining life and for moderating the environment to make it suitable. Awareness of improvement or deterioration in the capacity of vegetation and the trends that those changes may indicate are, therefore, critical detections to make of vegetation condition.

The advent of Earth orbiting satellites established the means for evaluating vegetation condition over extended areas, for monitoring changes in the capacity of vegetation to function and produce, and for evaluating trends in condition as determined by the nature and magnitude of change as a function of time, i.e., improvement or deterioration, and rate of change. These activities require basic knowledge of the energy-matter relationship occurring in vegetation, and measurability with instrumentation on orbiting satellites. A study of those relationships requires consideration of the various portions of the electromagnetic spectrum (shortwave, mid-infrared, thermal, and microwave); characteristics of detector systems (spectral, spatial and temporal resolutions); synergism that may be achieved by merging data from two or more detector systems or multiple dates of data; and vegetational characteristics (decomposition of organic material; species composition; stand structure; canopy structure, geometry and closure; water relationships; responses to stress; diurnal and annual periodic events; etc.).

The vegetation of Oregon is sufficiently diverse as to provide ample opportunity to investigate the relationships suggested above for several vegetation types. Vegetation types are arrayed over climatic extremes, particularly moisture, and over environmental extremes, particularly acidic to basic soils. Not only is the floristic diversity in Oregon representative of the diversity of a much larger area in the western United States and Canada, but the physiognomic diversity of the vegetation of Oregon is also representative of much of the physiognomic diversity worldwide.

THE INFLUENCE OF SOIL ORGANIC MATTER CONTENT AND SOIL PARTICLE SIZE ON SPECTRAL REFLECTANCE

William J. Ripple, Barry J. Schrumpf,
Joseph A. Bernert and Dennis L. Isaacson

INTRODUCTION

Many factors affect the reflective properties of soils; including soil color, organic matter content, moisture, particle size, structure, and surface roughness (Krishnan et al. 1980). Soil organic matter content is important in the agricultural sciences because it is indicative of nitrogen content and form. Large scale remote sensing of agricultural soils has been proposed for the evaluation of fertilizer applications (Schreier and Zheng 1986). The relationship between organic matter content and spectral reflectance of soils has been identified as being inverse; as soil organic matter content increases, the reflectance decreases (Al-Abbas et al. 1971). This inverse relationship is attributed to the changing structural and physical components of the soil, including soil color. Page (1974) defined the relationship between soil organic matter content and visible reflectance as being a negative quadratic for soil organic matter content between 0 and 5 percent. Baumgardner et al. (1970) indicated that soils with organic matter content greater than 2 percent may mask the spectral properties of the soil. Soil particle size affects reflectance and, indirectly, soil moisture and other soil characteristics (Meyers 1983). Bowers and Hanks (1965) identified the relationship between soil particle size and reflectance as being exponential (i.e., reflectance decreases as soil particle size increases). The primary objectives of this research were to experimentally determine 1) the effect of soil particle size on spectral reflectance, and 2) spectral relationships with soil organic matter content.

METHODS

Two experiments were performed in the laboratory with Experiment 1 designed to study the influence of soil particle size on reflectance, and Experiment 2 designed to study the influence of organic matter on reflectance. Spectra for both experiments were collected with a Barringer Ratioing Radiometer, Model Mark II. The five spectral bands used in the project are listed in Table 1.

TABLE 1. Wavelength bands used by the Barringer Ratioing Radiometer, Model Mark II.

Spectral band Midpoint	Half Peak Bandwidth	Spectral Region
550	20	Green
560	79	Green (TM2)
1050	20	Near Infrared
2100	30	Middle Infrared
2215	270	Middle Infrared (TM7)

The spectral band configuration consisted of two broad bands with wavelengths similar to Landsat Thematic Mapper Band 2 (green) and Band 7 (middle infrared), and three narrow bands in the green, near infrared and middle infrared. Previous research has found the green portion of the spectrum to be sensitive to organic matter content (Stoner and Baumgardner 1981).

The soil samples were analyzed for organic matter content prior to all experimentation. The soils examined were from the Semiaho series (a soil with high organic matter content), and Silverswale series (low organic matter). Particle size classes expressed as particle diameters and percent organic matter are presented for both soils in Table 2.

TABLE 2. Six Soil Particle Size Classes (diameter) and Corresponding Percent Organic Matter Content (dry weight basis) for both an Organic Soil (Semiaho) and a Mineral Soil (Silverswale).

	Percent Organic Matter	
Particle Size (mm)	Semiaho Soil	Silverswale Soil
<0.061	41.90	0.16
0.061 to 0.105	48.80	0.32
0.105 to 0.250	53.99	0.16
0.250 to 0.500	53.97	0.27
0.500 to 1.000	51.27	0.32
1.000 to 2.000	51.01	1.03

Spectral data were collected by positioning the radiometer 0.30 meters above and normal to the soil targets. Illumination was provided by a 500-watt Tungsten Halogen lamp (Hubbell Model QL-55) with an illumination elevation of 57^{o}. Radiance was converted to percent reflectance with the use of a barium sulfate reference standard. Experiment 1 involved the collection of spectral data for six particle size classes with two soil types. In Experiment 2, spectra were collected at twelve (12) levels of organic matter content for three soil particle size classes (0.061-0.145mm, 0.25-0.50mm, and 1.00-2.00mm). The various organic matter contents were created by mixing the mineral and organic soils, and ranged from

1 percent to 30 percent organic matter content. The equation used to determine these mixture proportions is:

$$OM = [[MMM/(1-(POM/POO))]-MMM] - [OMM/(1-POO)]$$

where OM is the amount (mass) of organic soil added to the mineral soil; MMM is the mineral mass of the mineral soil; POM is the proportion of organic matter required for the resulting mixture; POO is the proportion of organic matter in the organic soil; and OMM is the organic mass of the mineral soil. A computer program was written in BASIC to compute the required mixture proportions. See Appendix I for a listing of the program.

RESULTS

Experiment 1

The results from Experiment 1 indicated an inverse relationship between spectral reflectance and soil particle size. The reflectance decreased as particle size increased for both the organic and the mineral soils. The rate at which the decrease occurred was defined as a power function, the same relationship as previously defined by Bowers and Hanks (1965). Figures 1 through 5 present the relationships between percent reflectance and mean soil particle size (mm) for five different wavelengths. Changes in small particle sizes impact the reflectance of the soil more profoundly than the larger particle sizes. This can be attributed to surface texture differences and may be related to shadowing effects. Organic soils consistently had lower reflectance than the mineral soils, and similar coefficients existed for the various bands and particle sizes (power coefficients ranged from -0.07 to -0.13 for intrinsically linear regressions; see Table 3).

The results presented here confirm the findings of Bowers and Hanks (1965), that larger particle sizes have "little influence on additional absorption of solar energy".

TABLE 3. Relationships Between Reflectance and Soil Particle Size Using Regression Models with the Power Function.

Spectral Band Midpoint (nm)	Soil Type	Constant	Power	Coefficient of Determination
550	organic	8.96	-0.10	0.94
550	mineral	25.04	-0.10	0.96
560 (TM2)	organic	6.18	-0.07	0.92
560 (TM2)	mineral	26.78	-0.09	0.95
1050	organic	21.01	-0.12	0.97
1050	mineral	31.88	-0.10	0.98
2100	organic	23.20	-0.13	0.97
2100	mineral	32.28	-0.11	0.99
2215 (TM7)	organic	22.43	-0.13	0.97
2215 (TM7)	mineral	32.64	-0.11	0.98

Band ratios were examined as a possible method of reducing the effect of changing particle size. Swain (1978) has noted the objective of band ratios, which can "subtract or divide out the undesirable effects of the atmosphere or variable scene illumination". Satterwhite (1984) has recommended the ratios of near infrared and visible for the discrimination of soils and vegetation. The band ratio of 1050/550nm was effective in removing varying particle size effects on reflectance for both the organic and mineral soils (Figure 6). This reflectance ratio remained relatively constant as the soil particle size changed.

Experiment 2

The results of Experiment 2 indicated an inverse relationship between organic matter content and reflectance. Figures 7 through 11 demonstrate the relationships between percent organic matter and reflectance. Linear equations were defined for all particle sizes and wavelengths, and were highly significant ($p \leq 0.000$). Interpretation of the defined equations must be analyzed cautiously due to the factors of small sample size, and possible nonlinearity in the relationships.

The particle size influence on reflectance was similar to the results of Experiment 1, with the smaller particle size having a higher reflectance than the larger particle classes. The larger particle classes exhibit similar slopes and intercepts, whereas the small particle size (0.061-0.105mm) had a higher overall reflectance and a steeper slope between reflectance and organic matter, indicating organic matter affects the reflectance of fine particle sizes more than that of the larger particle sizes (Table 4). Or, conversely, that the influence on reflectance by incremental changes of organic matter is masked by the shadowing of the larger particles.

The 1050/550nm band ratios appeared to remove most of the reflectance differences associated with changing particle size (Figure 12). The slopes and intercepts for the simple linear regression equations are similar for the three particle sizes using the band ratio (Table 4). With a larger sample size, these differences in the slopes and intercepts for the band ratio equations could be evaluated by an interaction model (Neter et al. 1983). Nonlinearity could also be assessed more accurately with a larger sample size.

TABLE 4. Linear Regression Coefficients Showing the Relationships Between Reflectance and Soil Organic Matter Content for Three Soil Particle Size Classes.

Wavelength (nm)	Soil Particle Size (mm) 0.061 - 0.105 Intercept	Slope	0.25 - 0.50 Intercept	Slope	1.00 - 2.00 Intercept	Slope
550	33.2	-0.60	25.2	-0.41	24.3	-0.42
560 (TM2)	34.1	-0.71	26.4	-0.49	25.6	-0.47
1050	42.2	-0.34	32.7	-0.26	30.2	-0.28
2100	43.9	-0.26	33.9	-0.24	30.2	-0.25
2215 (TM7)	44.2	-0.29	33.9	-0.27	30.1	-0.27
1050/550 ratio	1.20	0.02506	1.24	0.02023	1.20	0.01764

CONCLUSIONS

This exploratory data analysis indicates several relationships that can aid in understanding the influences of soil particle size and organic matter content on spectral reflectance. The relationships are in agreement with previous research. Conclusions from this research are:

> Mineral soils had higher reflectance than corresponding organic soils.

> As soil particle size increased, percent reflectance decreased at an exponential rate.

> As soil organic matter content increased, percent reflectance decreased in a linear manner.

> The ratio of near infrared to green reflectance removed the effects of soil particle size on reflectance.

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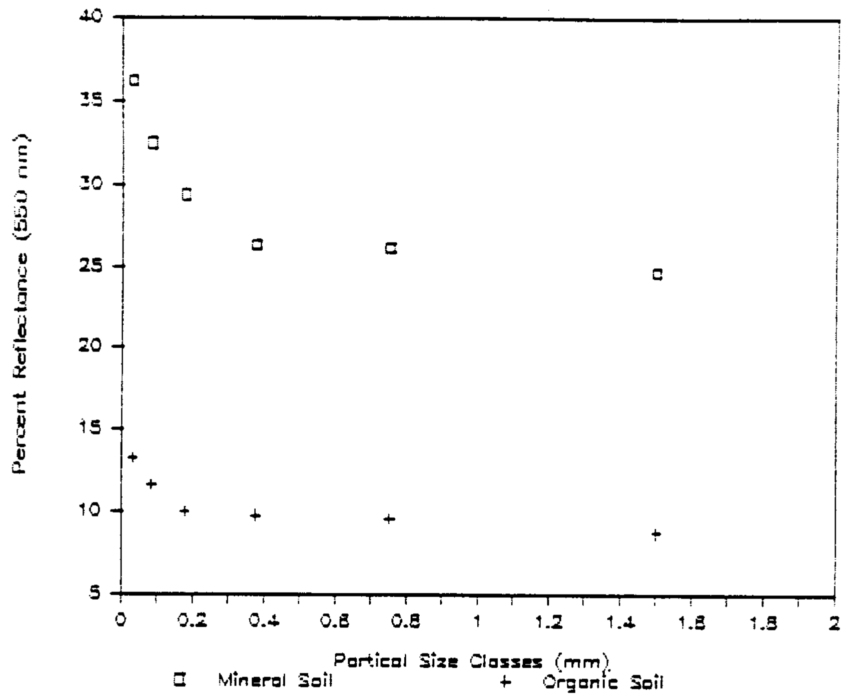

Figure 1. Mean reflectance for six particle size classes (mm) at 550nm.

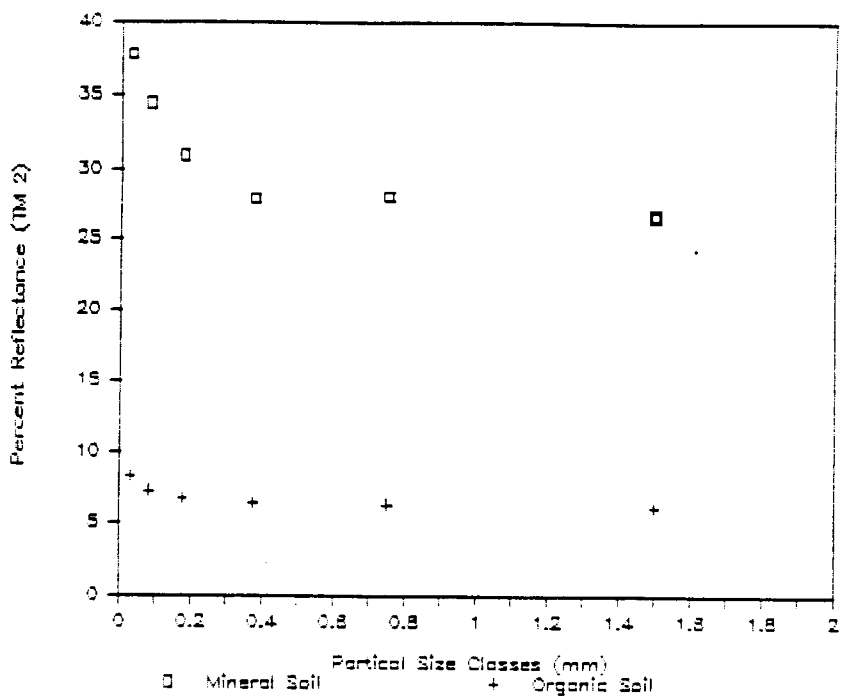

Figure 2. Mean reflectance for six particle size classes (mm) at 560nm (TM2).

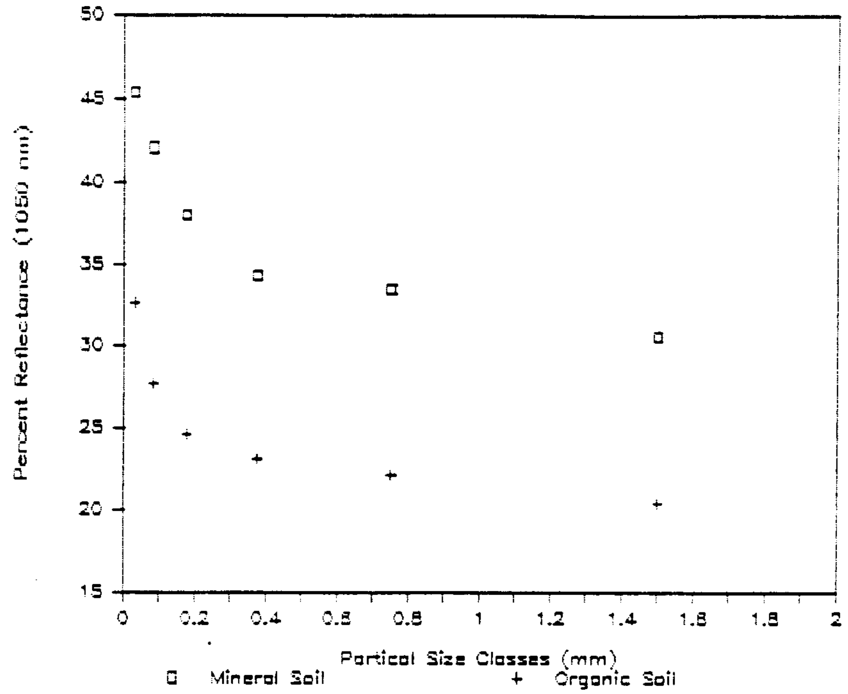

Figure 3. Mean reflectance for six particle size classes (mm) at 1050nm.

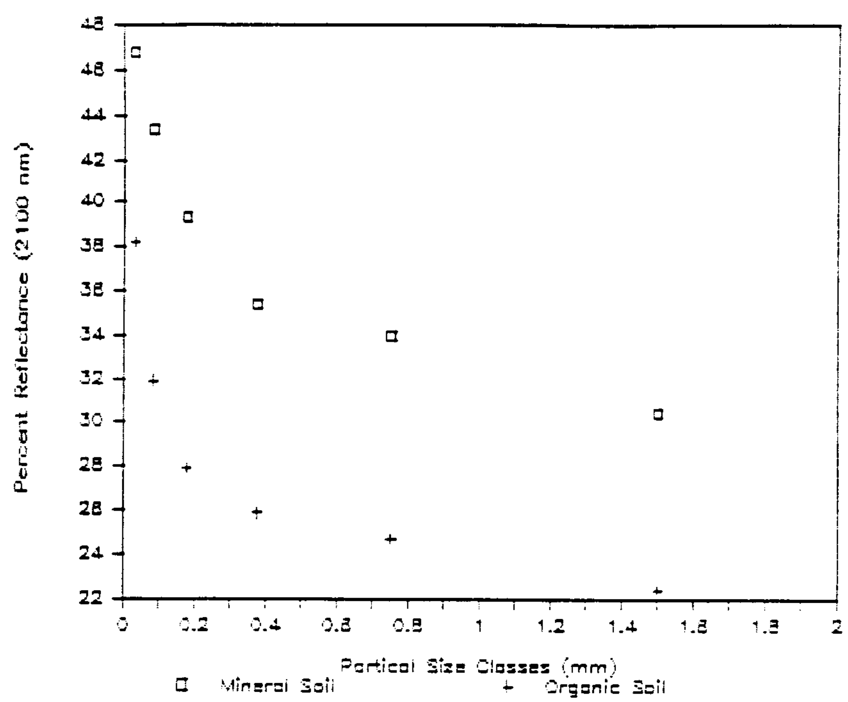

Figure 4. Mean reflectance for six particle size classes (mm) at 2100nm.

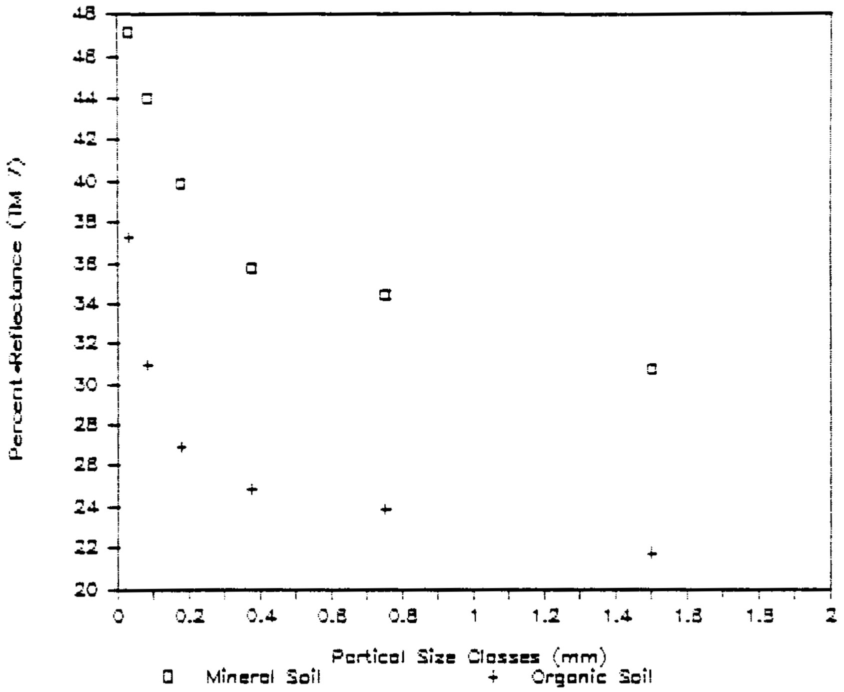

Figure 5. Mean reflectance for six particle size classes (mm) at 2215nm (TM7).

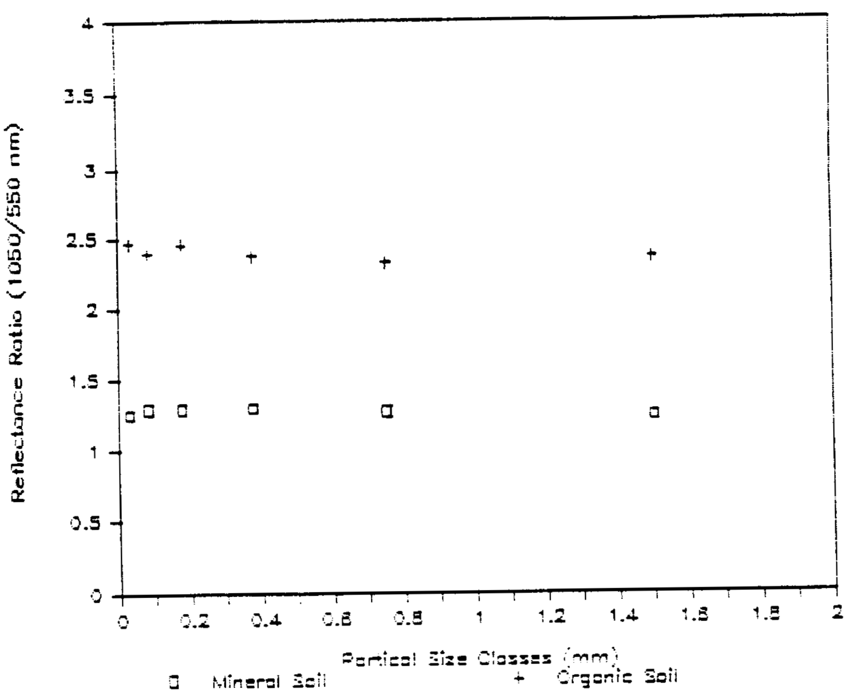

Figure 6. Mean reflectance of the 1050/550nm ratio for six soil particle size classes.

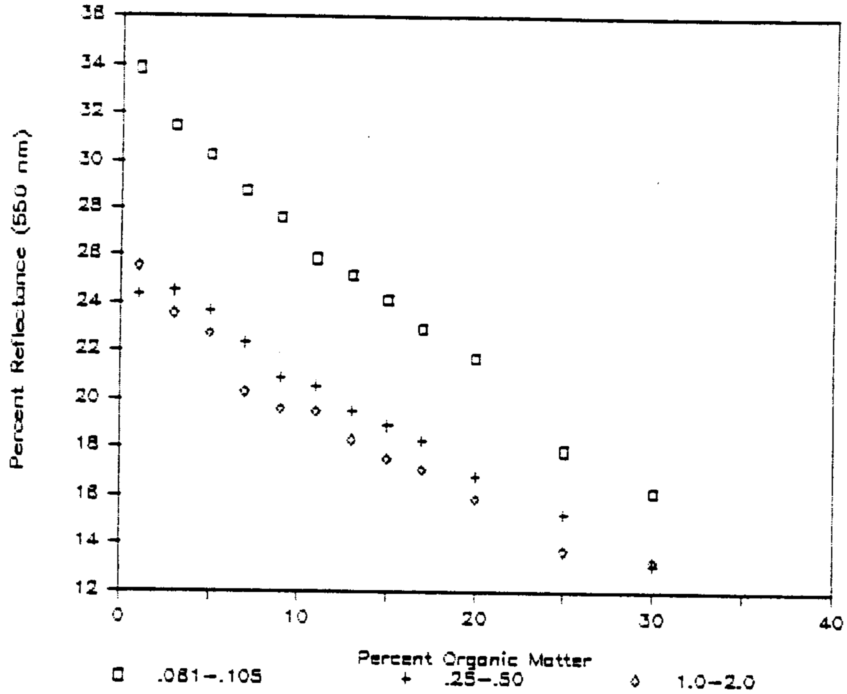

Figure 7. Mean reflectance (550nm) with percent organic matter content for particle sizes 0.061-0.105, 0.25-0.50, and 1.0-2.0mm.

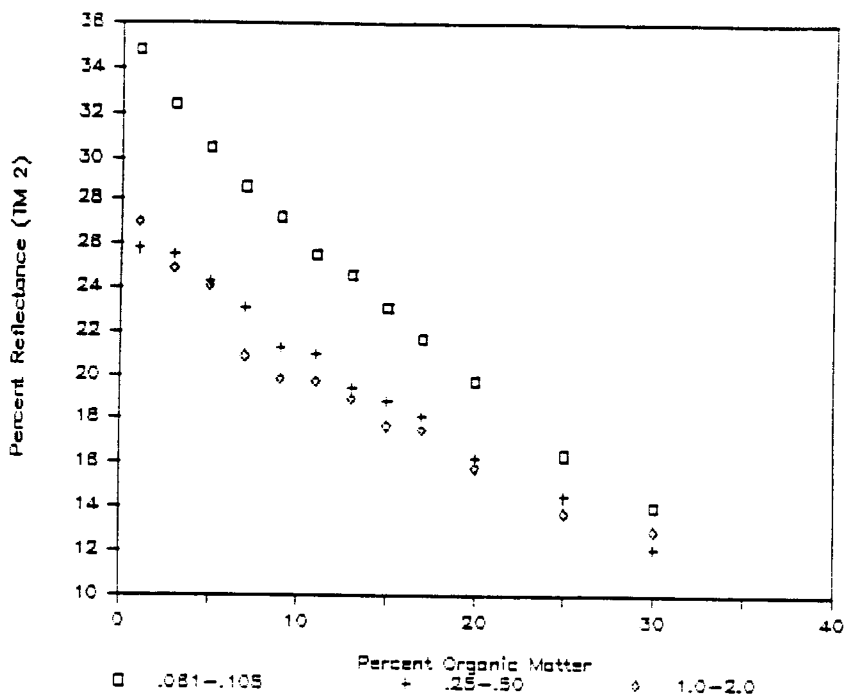

Figure 8. Mean reflectance (560nm, TM2) with percent organic matter content for particle sizes 0.061-0.105, 0.25-0.50, and 1.0-2.0mm.

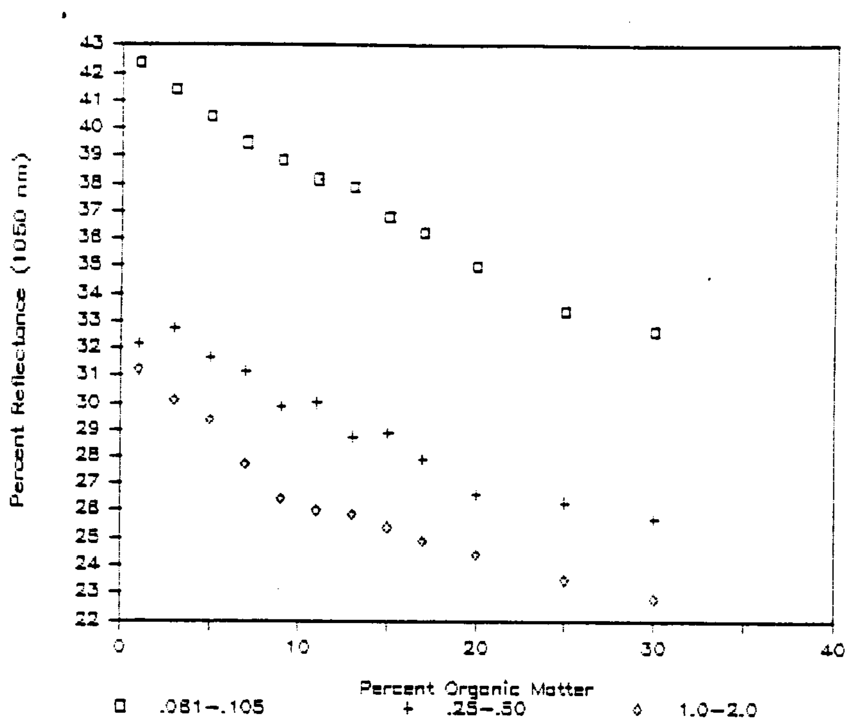

Figure 9. Mean reflectance (1050nm) with percent organic matter content for particle sizes 0.061-0.105, 0.25-0.50, and 1.0-2.0mm.

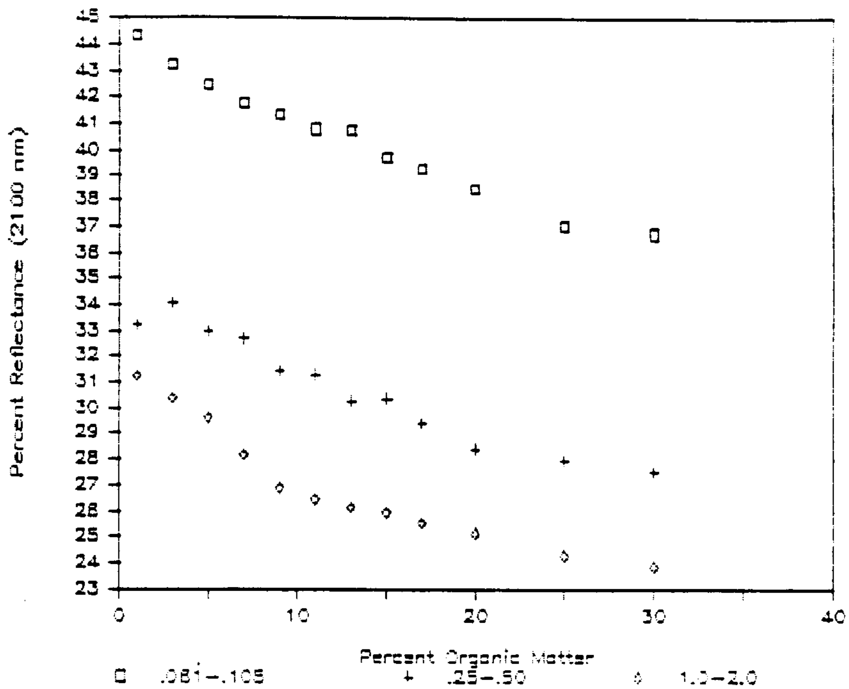

Figure 10. Mean reflectance (2100nm) with percent organic matter content for particle sizes 0.061-0.105, 0.25-0.50, and 1.0-2.0mm.

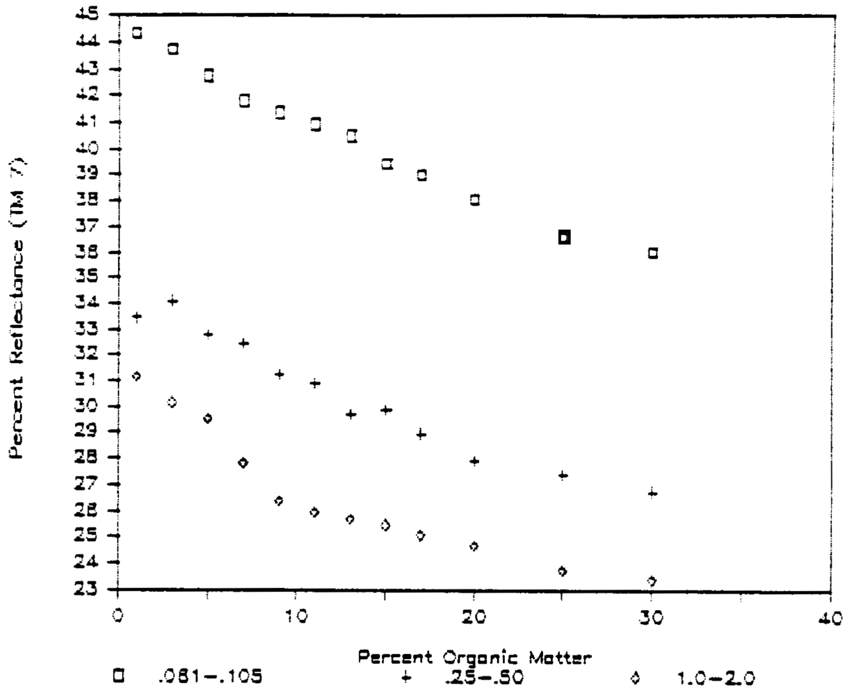

Figure 11. Mean reflectance (2215nm, TM7) with percent organic matter content for particle sizes 0.061-0.105, 0.25-0.50, and 1.0-2.0mm.

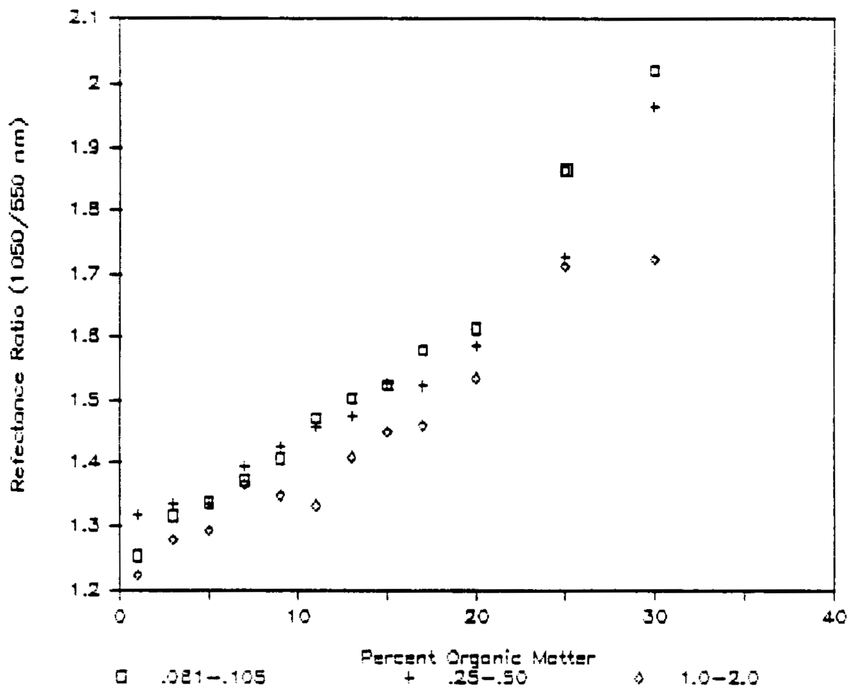

Figure 12. Mean reflectance (1050/550nm ratio) with percent organic matter content for particle sizes 0.061-0.105, 0.25-0.50, and 1.0-2.0mm.

APPENDIX I

```
100 REM ***********************************************************
110 REM *   THIS PROGRAM COMPUTES THE AMOUNT OF ORGANIC SOIL       *
120 REM *   MASS REQUIRED TO MIX WITH A MINERAL SOIL IN ORDER      *
130 REM *   TO OBTAIN A RESULTING SOIL MIXTURE WITH A PRE-         *
140 REM *   DETERMINED PROPORTION OF SOIL ORGANIC MATTER (I.E.     *
150 REM *   1-49 % ORGANIC MATTER CONTENT IN 1% INCREMENTS).       *
160 REM *   THE PROGRAM VARIABLES ARE:                             *
170 REM *     OM  = CUMULATIVE AMOUNT (MASS) OF ORGANIC SOIL       *
180 REM *           ADDED TO MINERAL SOIL                          *
190 REM *     MMM = MINERAL MASS OF SOIL                           *
200 REM *     POM = PROPORTION OF ORGANIC MATTER REQUIRED FOR      *
210 REM *           RESULTING MIXTURE                              *
220 REM *     POO = PROPORTION OFORGANIC MATTER IN ORGANIC SOIL    *
230 REM *     OMM = ORGANIC MASS OF MINERAL SOIL                   *
240 REM *     IOM = INCREMENTAL AMOUNT OF ORGANIC SOIL ADDED TO    *
250 REM *           MINERAL SOIL                                   *
260 REM ***********************************************************
270 DIM OM(100)
280 CLS
290 INPUT "The Mineral mass of mineral soil",MMM
300 INPUT "The percent organic matter of organic soil ",POO
310 INPUT "The organic mass of the mineral soil",OMM
320 FOR I = 1 TO 49
330   POM=I*.01
340   OM(I) =((MMM/(1-(POM/POO)))-MMM)-(OMM/(1-POO))
350   IF I>1 THEN IOM=OM(I)-OM(I-1)
360   PRINT POM,OM(I),IOM
370 IF I=15 OR I=30 OR I=49 THEN INPUT PASS
380 NEXT I
390 GOTO 280
400 END
```

SPECTRAL REFLECTANCE RELATED TO DECOMPOSITIONAL STAGES IN LITTER

by

William J. Ripple, Barry J. Schrumpf and Dennis L. Isaacson

INTRODUCTION

The ability to detect and monitor the processes of decomposition of plant materials from living tissue through to complex organic mineralized elements would be helpful in understanding biogeochemical cycling. This process of decomposition follows a course in which the changes in the chemical composition and the particle size of terrestrial detritus provide the basis for monitoring changes in organic material with remote sensing.

MATERIALS AND METHODS

The experimental approach involved the spectral observation of naturally occurring organic matter in different stages of decomposition. A series of plant materials were collected from western Juniper (Juniperous occidentalis) at the Eastern Oregon Agricultural Research Center Squaw Butte Station in central Oregon.

The spectra for this experiment were collected with a Barringer Ratioing Radiometer, Model Mark II. The spectral band configuration consisted of two broad bands with wavelengths similar to Landsat Thematic Mapper Band 2 (560μm, green) and Band 7 (2215μm, middle infrared); and three narrow bands in the green (540-560μm), the near infrared (1040-1060μm), and the middle infrared (2085-2115μm). The spectra were collected with the radiometer 0.30 meters above and normal to the litter samples. Illumination was provided by a 500-watt tungsten halogen lamp at an elevation angle of 57°. A barium sulfate reference standard was used to convert radiance to percent reflectance. Three replicate spectral readings were obtained from each of the seven litter treatments.

The treatment numbers and sample descriptions were as follows:

Treatment Number	Sample description
1	Dead western Juniper needles (yellow to light brown)
2	Undisturbed litter surface at the ground (yellow, light brown, dark brown, grey needles)
3	Disturbed top 1" including newly fallen needles
4	Disturbed top 1-1/2" without newly fallen needles
5	Disturbed layer 1-1/2" - 4" below ground surface
6	Disturbed layer 4" - 6" below the ground surface
7	Disturbed layer below 6" (mineral soil)

RESULTS AND DISCUSSION

Figures 1 through 5 show how reflectance (y axis) changed with each of the seven litter treatments (x axis). In the green region of the spectrum, mean reflectance decreased from treatments 1 through 4, and increased from treatments 5 through 7. The near infrared band followed a similar pattern but the magnitude of the differences was less than in the green band. In the middle infrared, reflectances increased from treatment 1 through treatment 5, with similar mean reflectance values for treatments 5, 6 and 7. The biophysical reasons for these spectral patterns in the middle infrared are unknown at this time. The spectral changes in the green and near infrared have been caused by initial decreases in brightness with increasing levels of decomposition, followed by increases in brightness with increasing levels of the light mineral soil component.

The results from this pilot study show that spectral differences can be related to the decomposition process of plant materials and soil organic matter levels. Additional studies are needed to determine the biophysical basis for these differences.

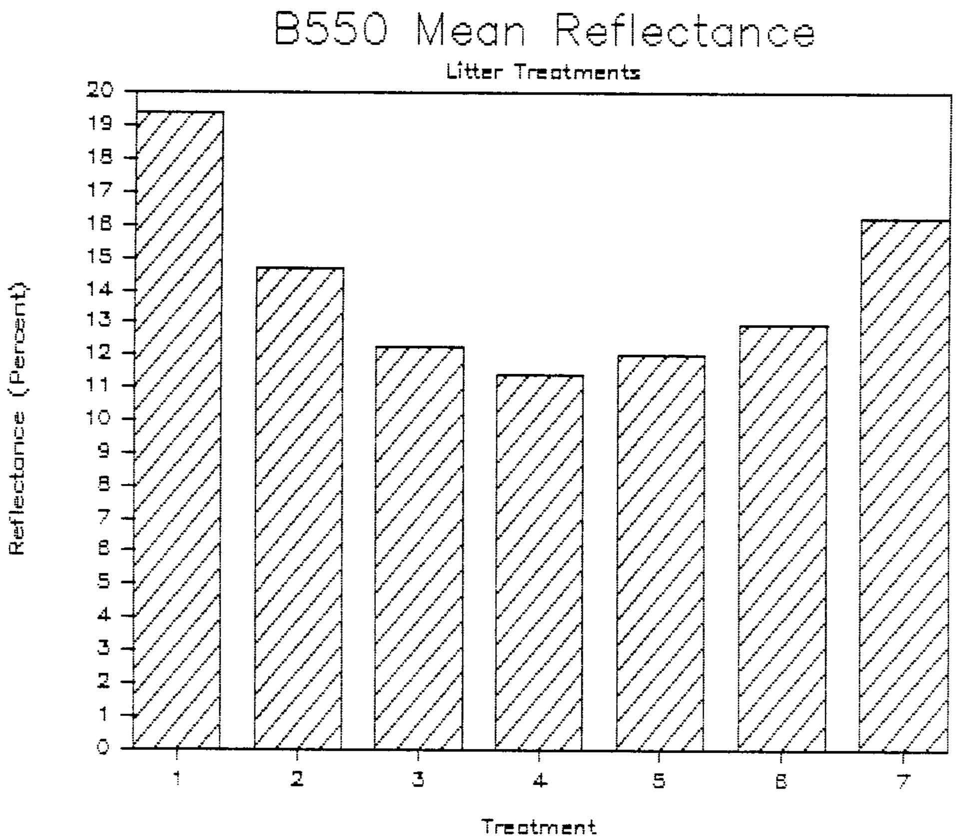

Figure 1. Bar graph showing litter treatments on the x-axis and percent reflectance in the green band (550µm) on the y-axis.

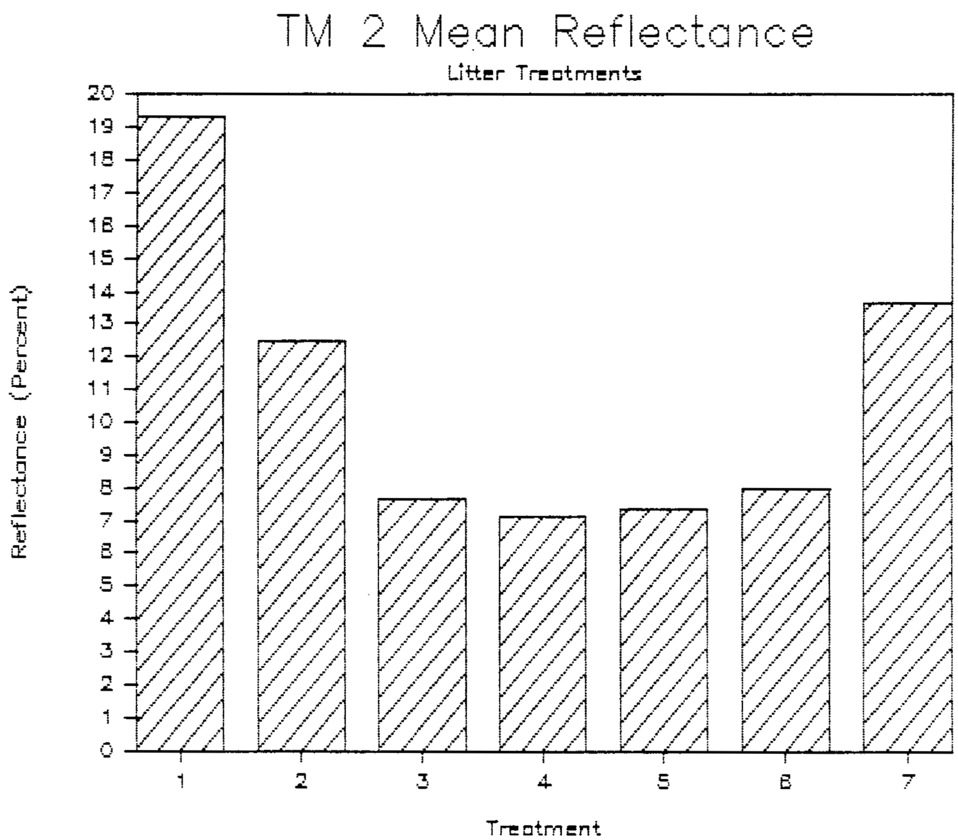

Figure 2. Bar graph showing litter treatments on the x-axis and percent reflectance in the TM2 band (560µm) on the y-axis.

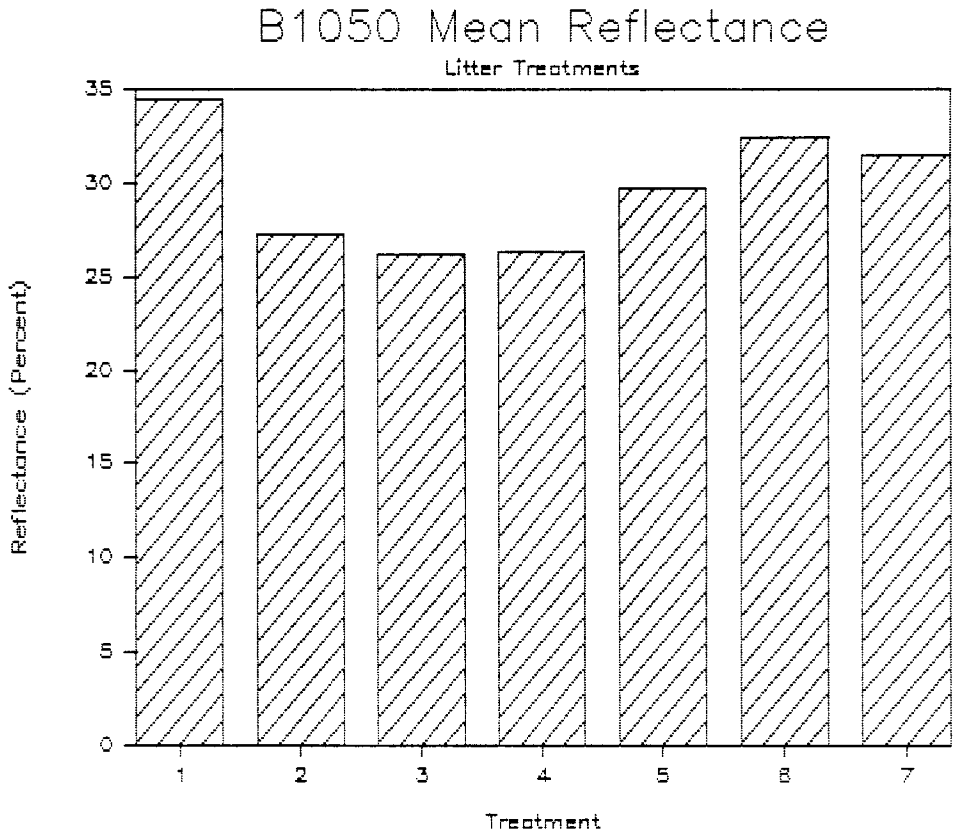

Figure 3. Bar graph showing litter treatments on the x-axis and percent reflectance in the near infrared (1050μm) on the y-axis.

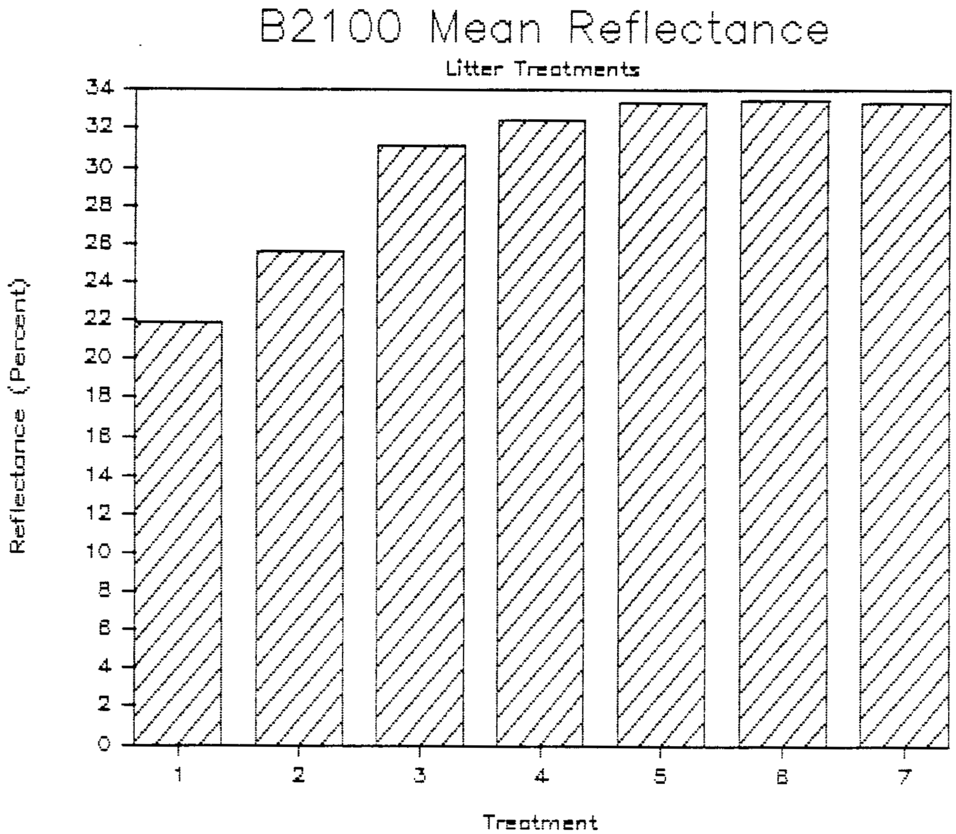

Figure 4. Bar graph showing litter treatments in the x-axis and percent reflectance in the middle infrared (2100μm) on the y-axis.

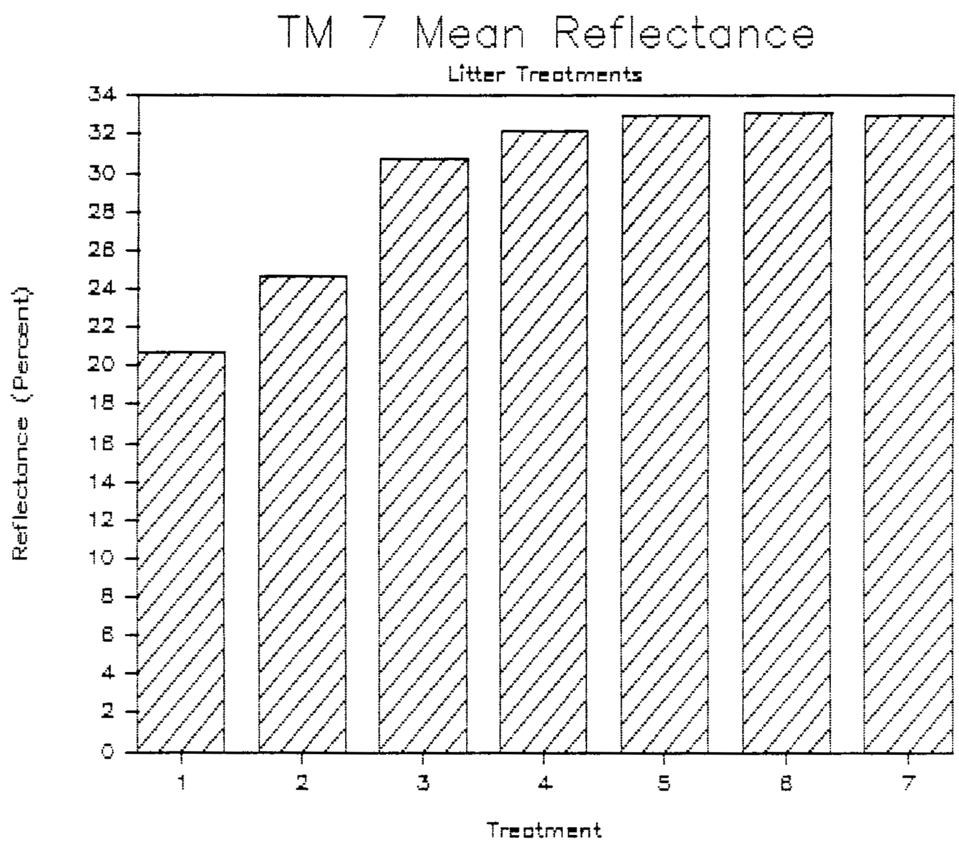

Figure 5. Bar graph showing litter treatment in the x-axis and percent reflectance in the TM7 band (2215µm) on the y-axis.

APPENDIX I

Band	Statist	TMT 1	TMT 2	TMT 3	TMT 4	TMT 5	TMT 6	TMT 7
TM 7	Repl 1	20.44	26.11	29.56	31.03	32.51	32.76	33.00
TM 7	Repl 2	21.92	22.91	31.03	32.27	32.76	33.50	33.00
TM 7	Repl 3	19.95	25.12	31.53	33.25	33.74	33.25	33.00
TM 7	Average	20.77	24.71	30.71	32.18	33.00	33.17	33.00
TM 7	Std Dev	0.70	1.79	0.70	0.82	0.28	0.09	0.00
B1050	Repl 1	33.85	26.96	25.90	25.61	30.07	32.01	31.81
B1050	Repl 2	35.89	26.48	26.38	26.29	29.29	32.69	31.33
B1050	Repl 3	33.66	28.42	26.29	26.96	29.97	32.49	31.23
B1050	Average	34.36	27.29	26.19	26.29	29.78	32.40	31.46
B1050	Std Dev	1.02	0.68	0.04	0.31	0.12	0.08	0.06
TM 2	Repl 1	18.54	11.79	7.55	6.89	7.28	7.95	13.25
TM 2	Repl 2	20.13	12.19	8.21	7.28	7.42	8.08	13.77
TM 2	Repl 3	19.21	13.38	7.28	7.15	7.42	7.95	14.04
TM 2	Average	19.29	12.45	7.68	7.11	7.37	7.99	13.69
TM 2	Std Dev	0.42	0.46	0.15	0.03	0.00	0.00	0.11
B2100	Repl 1	21.4	26.86	30.13	31.22	32.97	33.19	33.41
B2100	Repl 2	23.14	24.02	31.44	32.75	32.97	33.84	33.19
B2100	Repl 3	20.96	25.98	31.66	33.41	34.06	33.41	33.41
B2100	Average	21.83	25.62	31.08	32.46	33.33	33.48	33.33
B2100	Std Dev	0.89	1.41	0.46	0.84	0.26	0.07	0.01
B550	Repl 1	18.18	13.82	11.27	10.91	12.00	12.73	16.00
B550	Repl 2	20.36	14.91	13.09	11.27	12.00	13.45	16.36
B550	Repl 3	19.64	15.27	12.36	12.00	12.00	12.73	16.36
B550	Average	19.39	14.67	12.24	11.39	12.00	12.97	16.24
B550	Std Dev	0.82	0.38	0.56	0.21	0.00	0.12	0.03

Complete data set showing Percent Reflectance by Treatment, Band, and Replication.

SPECTRAL REFLECTANCE OF UNGULATE FORAGE

FROM CLEARCUTS AND OLD-GROWTH FORESTS

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SPECTRAL REFLECTANCE OF UNGULATE FORAGE FROM CLEARCUTS AND OLD-GROWTH FORESTS

BACKGROUND

A preliminary investigation was conducted to examine spectral reflectance relationships to site and forage quality variables. Forage samples from four plant species were obtained from the Hoh River Valley in and near Olympic National Park, Washington by Happe et al (1986). Happe collected four replicate samples of salmonberry (*Rubus spectabilis*), red huckleberry (*Vaccinium parvifolium*), sword fern (*Polystichum munitum*), and vine maple (*Acer circinatum*) from both early seral clearcuts and old-growth forests.

Happe also conducted laboratory analyses to develop the forage quality variables of percent dry matter of field green weight, percent *in vitro* digestibility, neutral detergent fiber (cell wall constituents), acid detergent fiber (cellulose, lignin), and percent lignin.

METHODS

Spectra for the experiment were collected with a Barringer Ratioing Radiometer, Model Mark II. The spectral bands used in the project were green (540-560µm), near infrared (1040-1060µm), and middle infrared (2085-2115µm). The spectra were collected with the radiometer positioned 0.30 meters above and normal to the oven-dried forage samples. Illumination was provided by a 500-

watt tungsten halogen lamp with an illumination elevation angle of approximately 57°. A barium sulfate reference standard was used to convert radiance to percent reflectance.

The statistical analysis of the data had two goals:

1) to determine if there are significant differences in reflectance between the old-growth and the clearcut samples for each of the four species, and
2) to derive predictive models of forage quality, based on reflectance values of forage samples.

For each reflectance variable, means and 95% confidence limits of the means were plotted by species and site. Descriptive statistics of the reflectance variables were computed by species and site. Unpaired t-tests were conducted to test the hypothesis that the mean of the samples from the clearcut site equals the mean of the samples from the old-growth site for each reflectance variable and each species.

Each forage quality variable was regressed on reflectance variables. Multiple stepwise regression was performed to determine the best linear regression model. Criteria to add an independent variable to the model were F-values of 4 or greater; criteria to delete an independent variable from the model were F-values of 3.9 or lower. To check for multicolinearity among the independent (reflectance) variables and for similarity of the response (forage quality) variables, correlation analyses were performed.

PRELIMINARY RESULTS

For all of the reflectance variables, the differences in means between the old-growth site and the clearcut site were highly significant (at the 1% level) for the species vine maple, salmonberry and red huckleberry (Table 1). Percent reflectance measurements from the old-growth forages samples were higher than the measurements from the clearcut samples for these three species. Differences in means were not significant for the sword fern. Caution needs to be exercised in interpreting these results, since the sample size of only four for each t-test was too small for reliable results.

All regression models were highly significant; this means that a multiple linear relationship among dependent and independent variables existed. Residual analysis showed no violations of the regression assumptions. The Coefficient of Determination for the five models were between 0.55 and 0.74 (Table 2). An example of these relationships is shown in Figure 1, with middle infrared reflectance plotted against percent dry matter indicating an inverse relationship (R^2=0.74). Previous results have shown that middle infrared reflectance from fresh green leaves is primarily governed by leaf moisture content (Ripple, 1986; Ripple and Schrumpf, 1987). The biophysical basis for the relationship in this study is unclear, since all samples were oven-dried before reflectance measurements were obtained. Therefore, middle infrared reflectance was influenced by a phenomenon other than water absorption

Surprisingly, the independent variables were not very highly correlated (r=0.00 to 0.71), whereas the dependent variables (neutral detergent fiber, acid detergent fiber, lignin, and digestibility) were extremely highly correlated (r=0.81 to 0.99). It should be noted that the results presented here are from a relatively small database and caution should be exercised in extrapolation of these results and their interpretation to different situations. Additional studies are needed to evaluate the relationships between reflectance and forage samples acquired from a variety of forest seral stages.

REFERENCES

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	Green	Near Infrared	Middle Infrared
vine maple	0.003**	0.008**	0.000**
salmonberry	0.000**	0.000**	0.000**
red huckleberry	0.005**	0.001**	0.000**
sword fern	0.196^{ns}	0.239^{ns}	0.179^{ns}

Table 1. All possible student t-test probabilities of accepting the hypothesis that spectral reflectance between clearcut and old-growth forage samples are equal (two-tailed probability, ** = significant at the .01 probability level; ns = not significant).

Dependent Variable	Independent Variables	F Value	R^2
Percent Dry Matter	Middle infrared	86.4	0.74
Digestibility	Near infrared, Middle infrared, and Green bands	14.5	0.61
Neutral Detergent Fiber	Near infrared and Green bands	24.1	0.62
Acid Detergent Fiber	Middle infrared and Green bands	22.1	0.60
Percent Lignin	Near infrared and Green bands	17.7	0.55

Table 2. Results of multiple stepwise regressions to predict Forage Quality from Reflectance with the Dependent Forage Quality Variables in the left column, the Independent Spectral Bands in the middle column, and the Fisher's F Values and Coefficients of Determination (R^2) on the right.

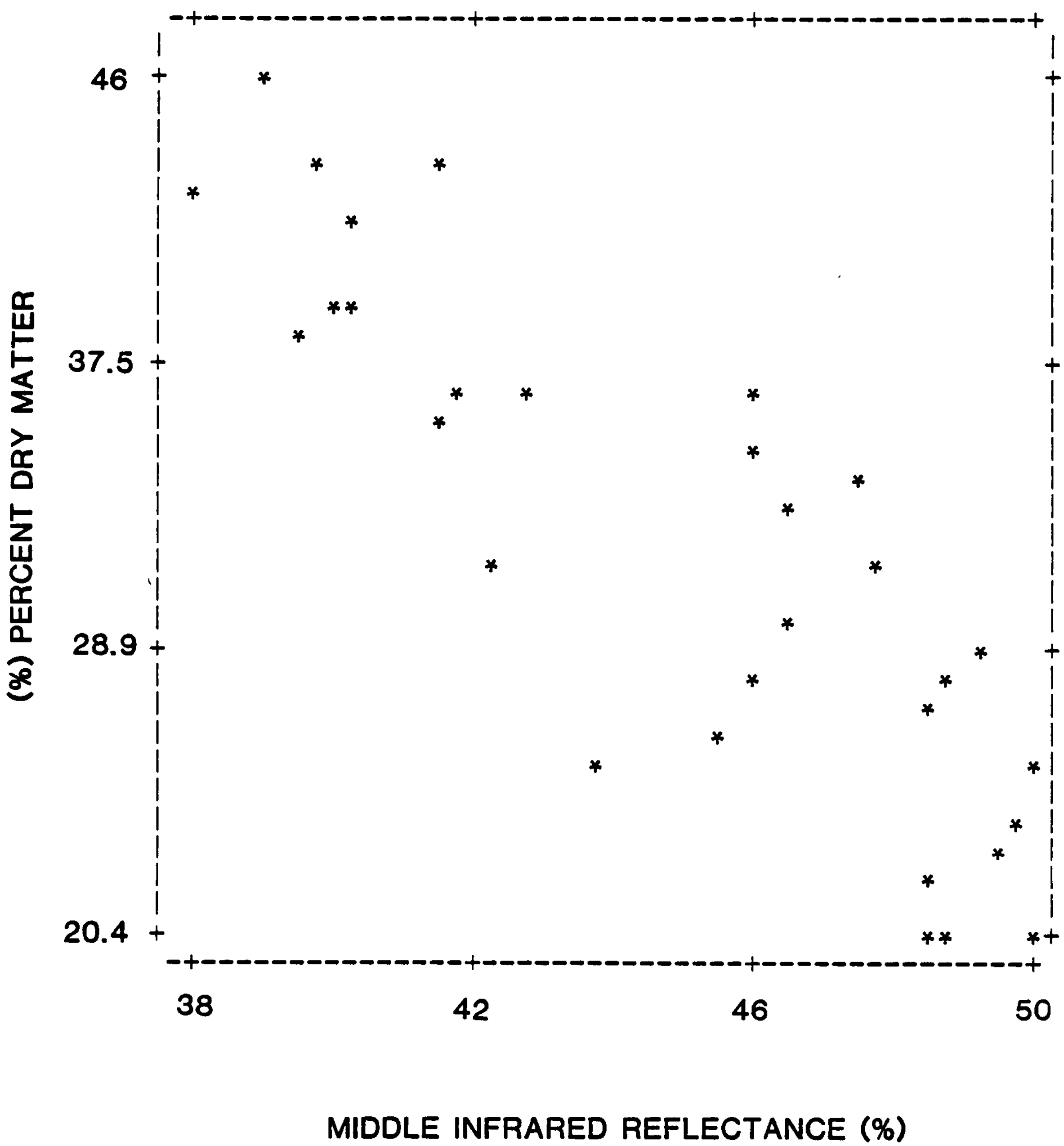

Figure 1. Scatter diagram of Middle Infrared Reflectance and Percent Dry Matter in forage samples from four different plant species.