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SPECTRAL REFLECTANCE OF SURFACE SOILS - RELATIONSHIPS WITH SOME SOIL PROPERTIES

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ABSTRACT

Using a published atlas of reflectance curves and physicochemical properties of soils, a statistical analysis was carried out. Reflectance bands which correspond to five of the wavebands used by NASA's Thematic Mapper were examined for relationships to specific soil properties. The properties considered in this study include: Sand Content, Silt Content, Clay Content, Organic Matter Content, Cation Exchange Capacity, Iron Oxide Content and Moisture Content. Regression of these seven properties on the mean values of five TM bands produced results that indicate that the predictability of the properties can be increased by stratifying the data. The data was stratified by parent material, taxonomic order, temperature zone, moisture zone and climate (combined temperature and moisture). The best results were obtained when the sample was examined by climatic classes. The middle Infra-red bands, 5 and 7, as well as the visible bands, 2 and 3, are significant in the model. The near Infra-red band, band 4, is almost as useful and should be included in any studies. General linear modeling procedures examined relationships of the seven properties with certain wavebands in the stratified samples. These results reinforced the hypothesis that the TM bands can be utilized to predict certain soil properties. Some relationships between curve shape and soil properties were also investigated and produced positive results.

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INTRODUCTION

Spectral reflectance of soil is influenced by the physical and chemical properties of that soil. Some of these physiochemical properties are more influential than others. These properties can be measured in the laboratory using standard tests. Recent works [Stoner and Baumgardner, 1980], [Crouse, et al., 1983], [Kiesewetter, 1982], have suggested relationships of several properties to the spectral signature of the respective soils, particularly in certain wavebands. The objective of these studies has been to utilize the Landsat Satellite data in identifying and classifying soils of the earth. Stoner (1979) measured the spectral reflectance of 485 soils of the United States along with physical, chemcial and engineering properties of those soils. The result of that investigation has been published as the "Atlas of Soil Reflectance Properties," [Stoner, et al., 1979]. This data was used by Kiesewetter (1982) and Crouse, et al. (1983), to statistically establish relationships between the soil properties and reflectance at certain wavelengths. Crouse has selected six wavebands which correspond to those of the Thematic Mapper (TM) aboard NASA's Landsat 4 Satellite. That study suggested that four, and possibly 5, of the six TM wavebands may be important in the identification of certain properties. Figure shows a typical soil presentation from Stoner's work. The properties which showed the best results in regression studies were, in order of their relevance, as follow: Organic Carbon Content, Water Content, Clay Content, Cation Exchange Capacity (C.E.C.), Calcium, Magnesium, Fine Sand, Base Saturation, Sand Content, Extractable Acidity, and Iron Oxide Content. In addition. ten other properties were included in the original regression analysis but were later dropped from consideration because they showed little potential of being predicted from TM data. These properties include: Potassium, Medium

Sand Content, .pa Coarse Sand Content, Silt Content, Aluminum,, Coarse Silt, Fine silt, Very Coarse Silt, Sodium, and Very Fine Sand.

This current work looks at several properties and five of the six TM wavebands which are in the range of spectral reflectance measured by Stoner (1979) and attempts to stratify the soils on the basis of Climate, Taxonomy and Parent Material. The objective of this investigation is to determine which soil properties show an ability to be predicted from T.M., spectral measurements, knowing some information about the temperature and moisture zones (climate) and the underlying parent material. This information could conceivably be available for an unknown soil from sources such as a geographic atlas or geologic maps and reports.

THEORY

The physical and chemical properties of the soil, in combination, produce the spectral reflectance. Some of these properties exert more influence than others. Previous work, (Stoner and Baumgardner, 1980) suggests that moisture content, organic matter, iron oxide content, texture, cation exchange capacity are more influential than other properties. Kiesewetter (1982) demonstrated that strong negative correlations exist when organic matter, iron oxide, and moisture content are compared with reflectance values. As the percentage of each of these increases the reflectance decreases. The strongest negative correlation seems to be with moisture content. Crouse et. al., (1983) have found, through regression analysis, that eleven properties seem to be dominant in determining reflectance.

Since reflectance is dependent upon the physical and chemical makeup of the soil, it is logical to try to ascertain how these properties are acquired. Parent material should be a place to begin since the soil will inherit certain characteristics from this source material. We know, however, that soils from similar parent materials can vary greatly in physical and chemical composition so other factors must be in play at the same time. Climate (temperature and moisture) is a contributing factor since temperature and moisture influence biological and chemical processes at work in a soil. Parent material is significant in determining the soil texture and chemical composition. Parent material may be residual (weathered from underlying rock or sediments) or it may be transported by means of wind, water or ice and deposited on the bedrock. Other factors at work in the formation of soils are topography, living organisms and time. Time is an important factor since it changes the characteristics of weathered material from those which are inherited from the parent material to those which are acquired in the aging process. The presence of organisms, both plant and animal, is a strong contributor to the overall reflectance of the soil.

Another consideration was to examine the taxonomic order of the soil. This is done, primarily, to investigate the possibility that soils classified in a particular order will have similar reflective characteristics. Taxonomic order, as defined by the USDA in 1972, is a classification system based on properties of soils as found in the field. Earlier classification systems were based on soil genesis rather then field properties. Utilizing the information developed by Stoner et. al. (1979), which includes reflectance of various soil samples from around the continental United States as well as numerous physical and chemical properties, a statistical analysis was carried out to determine which properties affect which wavebands. The chosen wavebands for this study were those which match the bands of the Thematic Mapper. The thematic mapper operates on six narrow bands: Band 1 (0.45-0.52µm), Band 2 (0.52-0.60µm), Band 3 (0.63-0.69µm), Band 4 (0.76-0.90µm), Band 5 (1.55-1.75µm), Band 7 (2.08-2.35µm), and a broad thermal band (10.4-12.5µm). Since the laboratory reflectance values cover only the wavelengths 0.4 to 2.4µm, this study does not consider the thermal band.

The work of Crouse, et. al. (1983) has shown that bands 5 and 7, which are in the middle Infra-red portion of the spectrum, are significant in the study of soils using satellite information. The near Infra-red band, Band 4, also shows promise for these studies. The two visible bands, Band 2 and Band 3, will sometimes provide additional information. Band 1 does not appear to be useful for these purposes, because the laboratory data is sketchy in these wavelengths. For that reason Band 1 was not considered in the present study.

The statistical work in this study was carried out using the Statistical Analysis System package developed by SAS Institute, Cary, North Carolina. The procedure R-SQUARE was used to carry out the initial regression work. The GLM procedure was used to regress each soil property on the five TM bands and gave F values to indicate the significance of each TM band in the model.

RESULTS

Utilization of the published (Stoner, et. al., 1979) values limited this study to the following properties: Sand, Silt, Clay, Organic Matter, Cation Exchange Capacity, Iron Oxide content and Moisture content. By regressing these properties on the mean value of each of the five TM bands chosen for this study (Bands 2, 3, 4, 5, and 7) it was determined that prediction of certain properties was possible just by knowing these five wavebands. The results of this regression study, on the 467 soils in the data set, are presented in Table 1. The R-SQUARE values can be read as percentages of the various properties which can be accounted for by the five wavebands. For instance, from Table 1 we can say that we can account for 44.4% of the organic matter in the soil by knowing the reflectance values of the five bands.

The next step in the study was to stratify the total sample by Prent Material, Temperature Zone, Moisture Zone, Taxonomic Order and Climate (comined temperature and moisture). The results of those regressions are shown in Table 7 under the appropriate column headings. The values shown on Table 7 are mean values of the various classes within each group. Parent material was broken down into the following classes: Igneous Residuum, Sedimentary Residuum, Eolian (air transported) origin, Unconsolidated Terrigenous Deposits (alluvial and lacustrine), Marine Deposits, and Glacial origins. Table 2 shows the various R-SQUARE values for these classes. The soils were then reclassified by temperature zones and analyzed. The results of that stratification and regression are shown in Table 3. Other classifications based on Moisture Zone, Taxonomic Order and Climate are tabulated in Tables 4, 5, and 6 respectively. The summary shown in Table 7 indicates that prediction values increase with stratification. Looking at the values in Table 7 it is apparent that a stratification based on Climate (temperature and moisture) would be beneficial. It is also intuitively apparent that these two factors are the only ones of which we could have prior knowledge for an unknown earth area. It would be easier to assign a climatic parameter to an unmapped area than to use Parent Material or Taxonomic Order, since these parameters imply a prior study of the soil. In simpler terms, if we knew these parameters we would no longer have an unmapped area. A known Taxonomic Order for a soil on the earth could, however, be used to verify or "fine tune" our TM data. We can assign a climatic parameter to an unknown earth area without any prior knowledge of the soil type.

The next phase of the study involved regressing the soil properties on the five TM wavebands in order to determine which bands are significant in predicting the soil properties. Table 8 shows the results of this procedure for the entire sample population of 467 soils. A high F value and a low (less than 0.0050) PR > F value indicates significance. It can be seen from Table 8 that bands 2 and 7 are significant in predicting six of the seven properties. Band 3 is significant for five properties while Band 5 and Bands 4 are significant to a lesser degree. The F value tests how well the model as a whole accounts for the dependent variable's behavior. The value labeled "PR > F" is the significance probability - if this value is small it indicates significance.

Again, the soil sample population was stratified and the results of the regression analyses were tabulated. Tables 9 and 10 show the values for each property in relation to the five TM bands, when stratified by temperature (Table 9) and moisture (Table 10). These results show only the greatest F values, where the significance probability is less than .0050 for the various properties on the five wavebands. Table 11 shows the results of combining temperature zones and moisture zones for a stratification based on climate. The importance of certain wavebadnds to the model are obvious from a perusal of Table 11. Based on all stratifications, it can be seen that Band 2, Band 7 and Band 3 are most significant in the prediction of soil properties. Bands 4 and 5 are slightly less important overall; but they should be considered in all models.

A preliminary approach to prediction of certain properties was attempted based on correlations which were evident when the angle of the tangent to the rising limb of the reflection curve was compared with the soil properties. This angle was designated "Angle X" and is referred to as such in this paper. The unstratified data indicated that correlations exist in Sand Content, Clay Content, Organic Matter, Cation Exchange Capacity and Moisture Content. When the data is stratified by climate, strong correlations were found for C.E.C., Organic Matter, Clay Content, Sand Content and Iron Oxide Content for certain temperature and moisture combinations.

Similar correlations were observed when looking at the declination angle of the tangent to the curve at the higher wavelengths of the data. This angle was designated "Angle Y" for this study. Correlations in the unstratified sample were strongest in Organic Matter, C.E.C., and Moisture

TABLE 1

R-SQUARE VALUES

OBTAINED BY REGRESSING SOIL PROPERTIES ON THE FIVE T.M. BANDS

ALL SAMPLES (467) NON STRATIFIED

PROPERTY	R-SQUARE
SAND	.182
SILT	.049
CLAY	.362
ORGANIC MATTER	.444
CATION EXCHANGE CAPACITY	.340
IRON OXIDE	.119
MOISTURE CONTENT.	.347

TABLE 2

R-SQUARE VALUES - REGRESSING SOIL PROPERTIES
ON FIVE T.M. BANDS.
STRATIFIED BY PARENT MATERIAL.

	IGNEOUS RESIDUUM	SEDIMENTARY RESIDUUM	EOLIAN ORIGIN	UNCONSOL. TERRIG. SED.	MARINE DEPOSITS	GLACIAL ORIGINS
SAND	.683	.399	.187	.226	.345	.197
SILT	.564	.274	.121	.074	.187	.052
CLAY	.715	.640	.484	.425	.525	.310
ORG. MATTER	.569	.430	.498	.526	.460	.651
C.E.C.	.742	.682	.504	.284	.490	.574
Fe_2O_3	.711	.176	.124	.198	.304	.303
MOISTURE	.582	.654	.336	.376	.309	.462

TABLE 3

R-SQUARE VALUES

MAST = MEAN ANNUAL SOIL TEMPERATURE

FRIGID ZONE (MAST < 8°C)

SAND	.255
SILT	.068
CLAY	.341
ORG.M	.378
CEC	.542
Fe_2O_3	.339
MOISTURE	.443

MESIC ZONE (8°C ≤ MAST < 15°C)

SAND	.143
SILT	.067
CLAY	.405
ORG.M.	.468
C.E.C.	.370
Fe_2O_3	.140
MOISTURE	.270

THERMIC ZONE (15°C ≤ MAST < 22°C)

SAND	.212
SILT	.071
CLAY	.432
ORG.M.	.363
C.E.C.	.268
Fe_2O_3	.146
MOISTURE	.365

HYPERTHERMIC ZONE (22°C ≤ MAST)

SAND	.656
SILT	.602
CLAY	.644
ORG.M.	.583
CEC	.652
Fe_2O_3	.331
MOISTURE	.560

TABLE 4

R-SQUARE VALUES - REGRESSING SOIL PROPERTIES ON FIVE T. M. BANDS

STRATIFIED BY MOISTURE ZONE

-60 to -40 = MOISTURE INDEX (STONER & BAUMGARDNER)

PROPERTIES.	ARID -60 to -40	SEMI-ARID -40 to -20	SUB-HUMID -20 to 20	HUMID 20 to 100	PERHUMID 100 AND +
SAND	.508	.304	.368	.182	.944
SILT	.184	.187	.147	.113	.226
CLAY	.670	.415	.537	.222	.886
ORGANIC MATTER	.606	.416	.548	.442	.805
C.E.C.	.389	.415	.560	.426	.752
Fe_2O_3	.343	.409	.076	.289	.735
MOISTURE	.626	.251	.604	.281	.842

TABLE 5

R-SQUARE VALUES - REGRESSING SOIL PROPERTIES ON FIVE T.M. BANDS STRATIFIED BY TAXONOMIC ORDER

PROPERTIES.	ALFISOLS	ENTISOLS	INCEPTISOLS	VERTISOLS	MOLLISOLS	SPODOSOLS	ARIDISOLS	ULTISOLS
SAND	.175	.232	.126	.825	.250	.488	.363	.190
SILT	.120	.160	.121	.985	.088	.467	.296	.164
CLAY	.287	.366	.166	.938	.431	.398	.311	.394
O.M.	.474	.393	.733	.981	.497	.623	.514	.429
CEC	.442	.234	.319	.945	.481	.598	.262	.490
Fe_2O_3	.348	.114	.386	.999	.082	.770	.480	.416
MOIST	.221	.255	.460	.869	.403	.539	.285	.172

TABLE 6

R-SQUARE VALUES - REGRESSING SOIL PROPERTIES ON FIVE T.M. BANDS - STRATIFIED BY CLIMATE

CLIMATE CLASS	SAND	SILT	CLAY	ORG. MATTER	CEC.	Fe_2O_3	MOISTURE
FRIGID-SEMIARID	.489	.513	.502	.413	.317	.332	.469
FRIGID-SUBHUMID	.429	.337	.424	.605	.750	.231	.588
FRIGID-HUMID	.622	.296	.666	.664	.599	.516	.613
MESIC-ARID	.488	.207	.833	.702	.770	.305	.704
MESIC-SEMIARID	.493	.276	.494	.441	.565	.309	.420
MESIC-SUBHUMID	.489	.369	.595	.687	.555	.412	.408
MESIC-HUMID	.362	.349	.346	.457	.540	.095	.149
MESIC-PERHUMID	.944	.226	.886	.805	.752	.795	.842
THERMIC-ARID	.634	.665	.471	.592	.341	.659	.587
THERMIC-SEMIARID	.623	.583	.704	.722	.610	.841	.587
THERMIC-SUBHUMID	.626	.419	.662	.402	.629	.282	.748
THERMIC-HUMID	.148	.076	.393	.174	.395	.375	.205
HYPERTHERMIC-SEMIARID	.925	.866	.936	.814	.883	.269	.950
HYPERTHERMIC HUMID	.791	.542	.623	.676	.593	0.000	.445

TABLE 7

R-SQUARE VALUES FOR TOTAL SAMPLE AND FOR VARIOUS STRATIFICATIONS

PROP.	TOTAL SAMPLE	PARENT MATERIAL	TEMP. ZONE	TAXONOMIC ORDER	MOIST. ZONE	CLIMATE (TEMP & MOIST)
SAND	.182	.3395	.3165	.3240	.4612	.5716
SILT	.049	.2120	.2020	.3001	.1714	.4089
CLAY	.362	.5222	.4555	.4114	.5460	.6096
ORG. MATTER	.444	.5223	.4480	.5805	.5634	.5824
C.E.C.	.340	.5460	.4580	.4715	.5064	.5928
Fe_2O_3	.119	.3027	.2390	.4500	.3704	.4124
MOISTURE	.347	.4532	.4095	.3971	.5208	.5511

TABLE 8

F
PR>F } FROM REGRESSIONS OF SOIL PROPERTIES ON T.M. BANDS

TOTAL SAMPLE POPULATION - NON STRATIFIED

SOIL PROP.	T.M. BANDS				
	2	3	4	5	7
SAND	21.17 0.0001	5.05 0.0251	2.79 0.0953	3.01 0.0833	70.54 0.0001
SILT	4.87 0.0279	1.69 0.1969	0.18 0.6696	8.58 0.0036	8.36 0.0040
CLAY	39.42 0.0001	7.96 0.0050	23.33 0.0001	3.02 0.0830	188.10 0.0001
ORG. MATTER	303.22 0.0001	69.50 0.0001	0.28 0.5956	5.69 0.0174	0.15 0.7024
C.E.C.	54.98 0.0001	9.41 0.0023	52.68 0.0001	2.35 0.1256	117.70 0.0001
Fe_2O_3	9.23 0.0025	13.80 0.0002	0.37 0.5456	27.79 0.0001	10.79 0.0011
MOISTURE	108.24 0.0001	14.56 0.0002	7.77 0.0055	22.69 0.0001	92.03 0.0001

TABLE 9

F VALUES WHERE PROBABILITY SIGNIFICANCE (PR>F) IS
LESS THAN .0050

SAMPLE STRATIFIED BY TEMPERATURE ZONE

SOIL PROP.	T.M. BANDS 2	3	4	5	7	TEMP. ZONE
SAND					23.73	FRIGID
					27.30	MESIC
	13.46				10.89	THERMIC
	14.06				19.87	HY-THER
SILT						F
						M
						T
		12.86			12.25	H
CLAY		9.66			29.97	F
		14.70	18.80	26.71	71.80	M
	28.46		9.12		56.51	T
	11.47				22.17	H
ORG. MATTER	44.82					F
	170.04					M
	32.42	40.57				T
	10.23	16.10				H
C.E.C.	54.63				37.80	F
	23.20	12.89	27.78		52.39	M
			17.73		24.95	T
	12.25				22.36	H
Fe_2O_3		21.72			8.43	F
		10.34				M
	8.40					T
						H
MOISTURE	24.78			9.12	35.66	F
	29.85				34.83	M
	19.43	13.28			34.77	T
	14.49					H

TABLE 10

F VALUES - WHERE PROBABILITY SIGNIFICANCE (PR>F) IS LESS THAN .0050

SAMPLE STRATIFIED BY MOISTURE ZONE

	T.M. BANDS					
SOIL PROP.	2	3	4	5	7	MOISTURE ZONE
SAND	28.80	14.29		11.95		ARID
		9.80	9.63		15.68	SEMIARID
	13.40	12.76		14.83	26.88	SUBHUMID
		14.04			20.66	HUMID
			23.94		38.11	PERHUMID
SILT	8.61					A
						S
				12.96		SH
					11.80	H
						P
CLAY	36.56	17.12		37.81	23.60	A
					47.23	S
	21.76	24.51	8.32		79.51	SH
		21.63			20.92	H
						P
ORG. MATTER	68.44	15.51				A
	9.13	42.53				S
	115.92	15.35	9.00			SH
	106.39			19.16		H
	20.23					P
C.E.C.	10.30			10.52	12.04	A
		10.63			32.57	S
	52.73	25.77	16.77		51.32	SH
	100.27				15.03	H
						P
Fe_2O_3	15.55					A
		13.94	18.10	24.80		S
						SH
		35.72			20.58	H
						P
MOISTURE	57.94	13.15		12.48	14.92	A
					21.83	S
	65.98	24.29	15.00	24.09	50.95	SH
	22.00			27.00	16.49	H
					23.61	P

TABLE 11

ALL STRATIFICATIONS PR>F IS LESS THAN .0050

SIGNIFICANCE OF VARIOUS BANDS TO PROPERTIES.

P= PARENT MATERIAL (8) C = CLIMATE CLASS (14)
T= TEMPERATURE ZONE (4)
M= MOISTURE ZONE (5) SUBSCRIPT= NO. TIMES BAND IS SIGNIFICANT

	T.M. BANDS				
	2	3	4	5	7
SAND	P_1 T_2 M_2 C_5 10	P_3 M_4 C_2 9	P_2 M_1 C_1 4	M_2 C_2 4	P_2 T_4 M_4 C_4 14
SILT	T_1 M_1 C_4 6	P_1 1		M_1 C_1 2	T_1 M_1 C_1 3
CLAY	P_2 T_2 M_2 C_5 11	P_6 T_2 M_3 C_2 13	P_1 T_1 M_1 C_1 4	P_2 T_1 M_1 C_2 6	P_4 T_4 M_4 C_4 16
ORGANIC MATTER	P_6 T_3 M_5 C_8 22	P_3 T_2 M_3 C_1 9	P_1 M_1 2	M_1 C_2 3	
C.E.C.	P_4 T_3 M_3 C_7 17	P_3 T_1 M_2 C_2 8	P_3 T_2 M_1 C_3 9	M_2 C_1 3	P_5 T_4 M_4 C_6 19
Fe_2O_3	P_2 T_1 M_1 C_2 6	P_1 T_2 M_2 C_2 7	M_1 C_1 2	P_2 M_1 C_1 4	P_1 T_1 M_1 3
MOISTURE	P_5 T_4 M_3 C_7 19	P_4 T_1 M_2 C_3 10	P_1 M_1 C_1 3	P_1 M_3 C_2 6	P_3 T_3 M_4 C_4 14

TYPICAL SOIL ENTRY IN ATLAS (T.M BANDS ADDED FOR THIS STUDY)

DRUMMER(IL)

Typic Haplaquoll
fine-silty, mixed, mesic
humid zone
thick loess over outwash and drift
Champaign Co.

——	- - - -
Ap horizon	Ap horizon
A slope	A slope
poorly drained	poorly drained
silty clay loam	silty clay loam
13%S 56%Si 32%C	8%S 60%Si 32%C
10YR 2/1 (moist)	10YR 2/1 (moist)
10YR 3/2 (dry)	10YR 3/2 (dry)
5.61% O.M.	6.09% O.M.
40.3 meq/100g CEC	41.7 meq/100g CEC
0.76% Fe_2O_3	0.92% Fe_2O_3

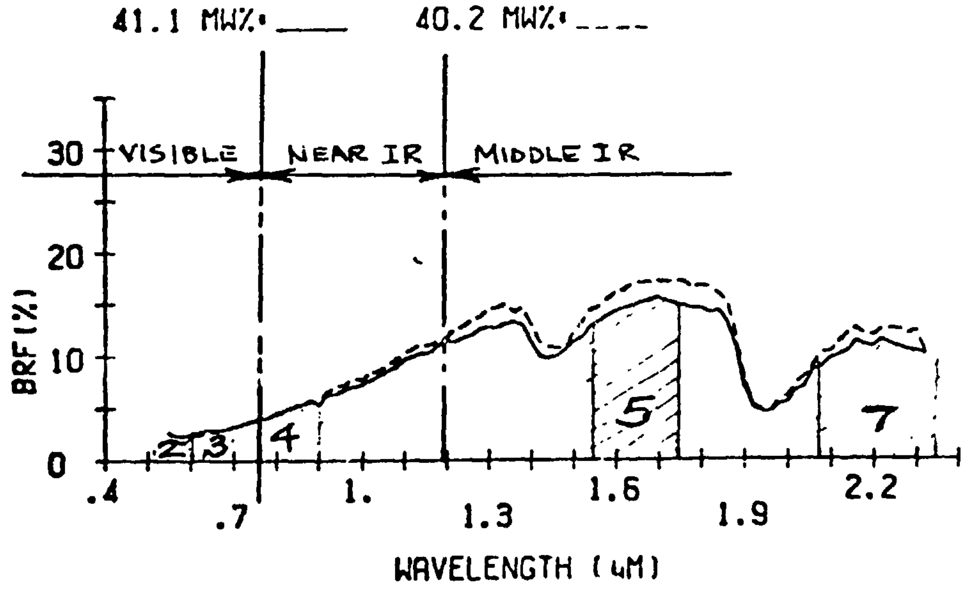
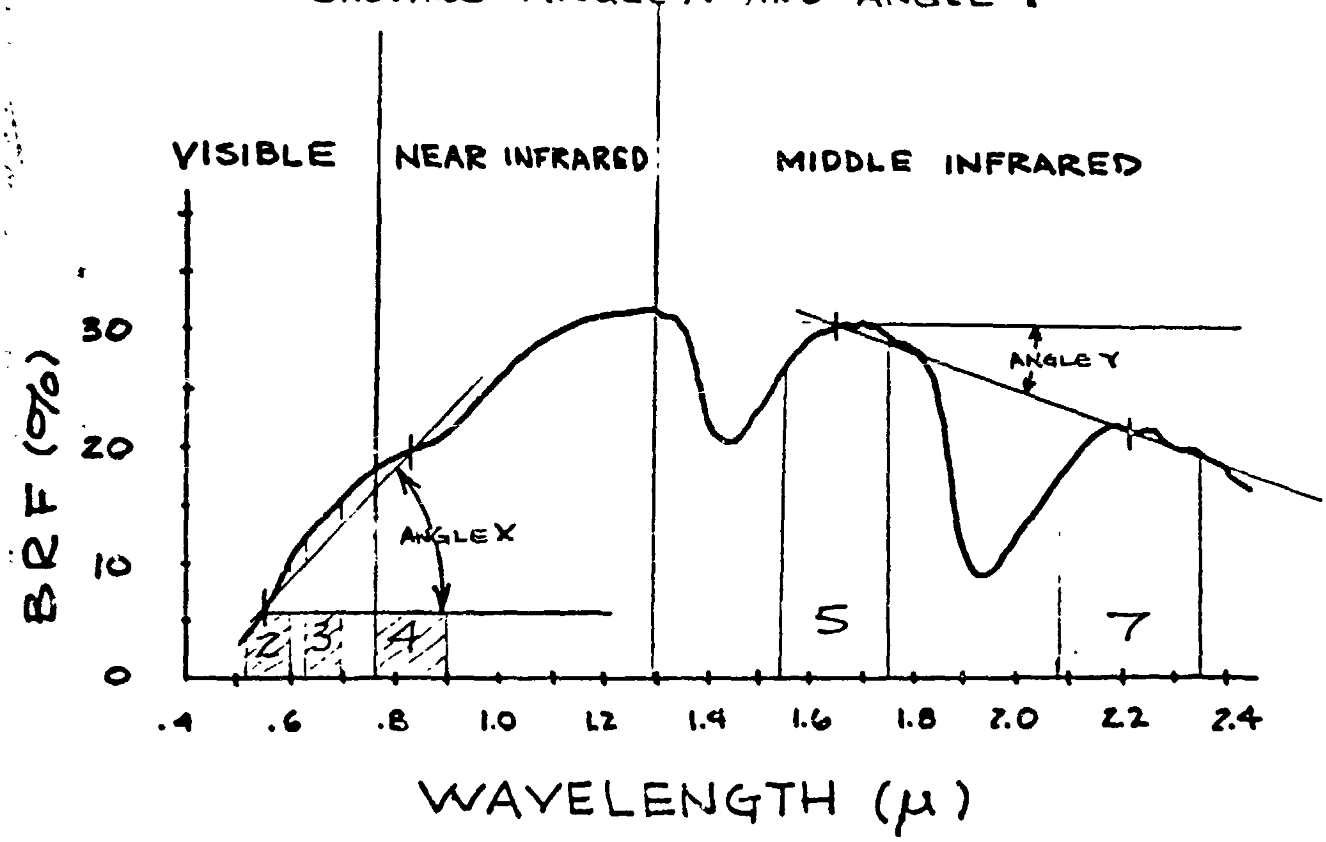


Figure 1

PLOT OF BRF(%) VS. WAVELENGTH (μ)
SHOWING ANGLE X AND ANGLE Y



CORRELATIONS

	PROPERTIES	CLIMATE CLASS
ANGLE X:	ORG. M, C.E.C.	FRIGID-SUBHUMID
	ORG. M,	FRIGID-ARID
	ORG. M, CLAY, C.E.C.	MESIC SUBHUMID
	ORG. M, SILT.	MESIC HUMID
	FE,	THERMIC-SEMIARID
	ORG. M., SAND, CLAY, CEC., M.W.	THERMIC-SUBHUMID
ANGLE Y:	ORG. M., C.E.C., M.W.	FRIGID-SUBHUMID
	ORG. M.	FRIGID-HUMID
	ORG. M., M.W.	MESIC-ARID
	ORG. M.	MESIC SUBHUMID
	FE	THERMIC ARID
	FE	THERMIC SEMIARID
	M.W.	THERMIC SUBHUMID

Figure 2

Content. The correlations were all negative-indicating that lower quantities of these properties produce a steeper angle of descent at the trailing end of the reflectance curve. When the data is stratified by climate, the correlations are strongest in certain climate classes for the three soil properties mentioned as well as a very strong relationship of iron oxide in the Thermic-Arid and Thermic-Semiarid sample set. Figure 2 shows these relationships in a summarized format.

CONCLUSIONS

The results of this work will aid in the utilization of TM data for soils investigations. We can define the wavebands which will supply the most significant data regarding soil properties. The study has indicated that bands 2 and 7 are very significant in the study of soil properties and their influence on TM responses. Band 2 is in the visible spectrum, while Band 7 is one of the middle IR bands. Bands 3 and 5 are somewhat less significant overall but become more important when stratification by climate is undertaken. Band 4, the near IR band, is individually important to some of the properties. Bands 2 and 4 were used to determine "Angle X', the slope of the tangent to the ascending limb of the reflectance curve. Bands 5 and 7 were used to obtain "Angle Y", the slope of the tangent to the trailing end of the curve.

Sand Content appears to be associated with responses in the visible range (Bands 2 and 3) and in the middle IR bands (Bands 5 and 7). In both cases a high sand content produces a strong reflectance response.

Silt content has shown consistantly poor potential for prediction. Only when stratified by climate does Band 2 come into play in several classes to produce positive correlations.

Clay content appears to be related negatively to responses in Bands 7, 2, and 3.

Organic Matter Content, under various stratifications, figures dominantly in the Band 2 and Band 3 responses. These are negative correlations indicating that high organic content tends to depress the responses in the visible bands. This reduced response in the visible area produces a flattened curve. This was used by Stoner (1981) to classify the curves by shape.

Cation Exchange Capacity shows excellent results in Bands 2 and 7, while several stratification classes show strong responses in Bands 3 and 4. These responses all show negative correlations, indicating that an inverse relationship exists between C.E.C. and waveband response.

Iron Oxide Content showed somewhat erratic results in the studied wavebands. This was not totally unexpected since Stoner pointed out iron absorption wavelengths in his study which lie outside the bands covered by the TM; however, two climatic zones (Thermic-Arid and Thermic-Semiarid), showed strong negative correlations of Iron Oxide content with the Y Angle.

Moisture Content produced strong negative correlations with Bands 2 and 7 with somewhat lesser results in Bands 3 and 5. Again, the negative correlations indicate that increasing moisture content tends to depress responses in these wavebands.

Clay content may be one key to the response prediction problem. Higher clay contents in soils tend to be associated with higher organic matter, increased Cation Exchange Capacity and increased moisture contents. The amount of clay present is not nearly as important as the type of clay minerals present. Soil scientists are quite aware of the role that climate plays in clay formation. All other things being equal, an increase in temperature and precipitation causes an increase and enhancement of the weathering reaction. High average temperatures tend to foster rapid weathering and clay formation. A minimum degree of weathering is produced by climates that are: warm and dry, cold and dry, or cold and moist. This is borne out in the climate-stratified sample population when the mean clay contents are examined for the various climate classes - the frigid dry, frigid moist and thermic dry classes all show reduced clay contents. This indicates that it may be practical to develop a model which takes into account the climatic zone of an unknown earth area and then makes an assumption of clay content before checking the various wavebands for reflectance responses.

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