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Detection of Saline Soils with Skylab Multispectral Scanner Data

Measuring the contrast of digital data between vegetated and bare soil areas may provide a better method for detecting saline soil levels than using MSS digital data from vegetated or bare soil areas individually.

ABSTRACT: *The feasibility of detecting and delineating eight areas of low, medium and high salinity levels in Cameron County, Texas, was tested by using SKYLAB S192 multispectral scanner (MSS) data. Scan lines of MSS digital data corresponding to each of the 13 S192 MSS bands were selected from bare and from adjacent naturally vegetated soil in each saline area.*

The S192 MSS digital data from fallow cropland could not be related to salinity levels except for MSS band 9 (1.09- to 1.19-μm). However, the S192 MSS digital differences between vegetated- and bare-soil areas (contrast) correlated significantly with salinity levels for six contiguous S192 bands ranging from 0.69- to 1.7-μm. The highest correlations (r = -0.946 and -0.963, respectively) were for bands 7 (0.78- to 0.88-μm) and 10 (1.2- to 1.3-μm). The results indicate that the reflective infrared wavelengths are superior to the visible wavelengths for soil salinity detection and that soil salinity may not be readily estimatable when using bare-soil information alone. The predictive procedures used may lead to a useful saline-soil detection and delineation scheme, but more testing is warranted.

INTRODUCTION

PRENTICE[6] DEMONSTRATED that airborne thermal and spectral data could be used to detect and delineate conditions indicative of salinity and of rising water tables. He used thermal contouring to map distributions of surface soil moisture, and spectral data to identify various stages of salt-stressed vegetation and wet soils.

Colwell[4] reported that high-flight photography and LANDSAT-1 (formerly ERTS-1) satellite imagery, particularly band 5, were useful and accurate in detecting and delineating the areal extent of saline deposits, difficult to measure from field surveys, and additional resolution from SKYLAB color photography made possible a mapping accuracy approaching that obtained by using high altitude 1:120,000 scale photography.

Anderson[1] used LANDSAT-1 and SKYLAB imagery to show that vegetation species can be used to indicate the salinity of three classes of wetlands. Reeves[7] classified vegetation species into improved pastures, useable rangeland, and unproductive salt marsh areas by using LANDSAT-1 data, and concluded that such classifications could be used to estimate animal-carrying capacity or forage production.

This paper presents studies on the feasibility of detecting and delineating saline soils in Cameron County, Texas, with SKYLAB S192 multispectral scanner (MSS) data collected from bare and vegetated saline soil areas.

Materials and Methods

Soil Procedures

The soil types in the Cameron County saline study site were sandy clay loam, clay loam, fine sandy loam, clay, silty clay, and silty clay loam. These soils were sampled, oven-dried, and passed through a 2-mm sieve. Their particle-size distribution was determined by using the Bouyoucos[3] method, and their salinity levels were determined by making electrical conductivity readings (ECe) on saturated soil extracts[8].

Because of poor correlation between conductivity readings and particle-size distribution, which determines soil type, we divided the test site arbitrarily into areas (eight areas from A through H) of low, medium, and high salinity levels based on ECe readings. Areas A to E ran north to south along Paredes Road, and areas F to G ran west to east along Farm Road 510 (Figure 1).

A completely objective approach for testing the extendibility of the relationship between ECe and satellite data to other areas would have included a second independent set of saline soil sites for verification[2]. However, it was felt that if this study should indi-

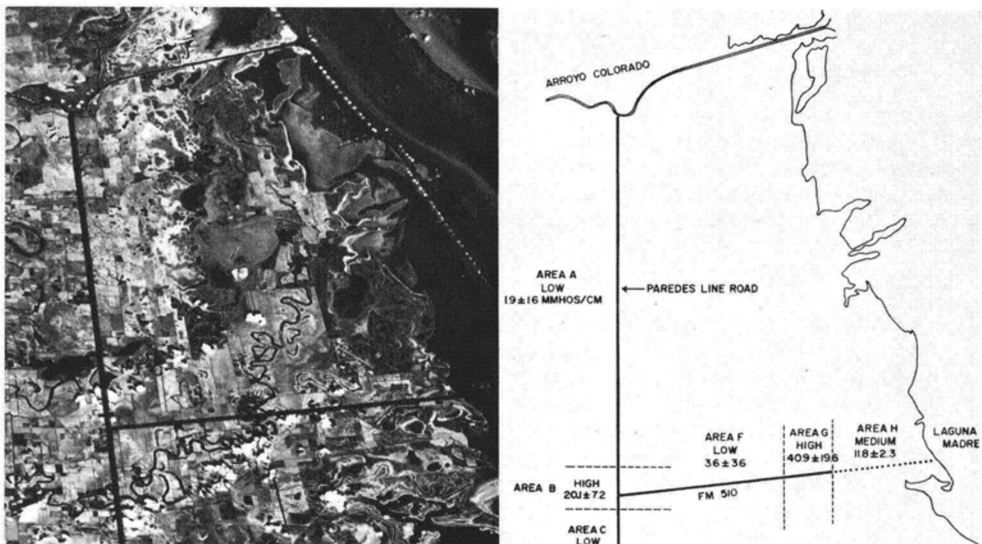

FIG. 1. Saline-soil study site in Cameron County showing location of electrical conductivity measurements (mmhos/cm) for eight saline-soil areas. The study site is located on Paredes Road and Farm Road 510 and was used for relating soil salinity measurements to the black-and-white imagery (EK-3414) from the S190B Earth Terrain Camera (shown), as well as to color film (SO-242) and S192 multispectral scanner data.

cate the feasibility of saline soil mapping using satellite data, by producing significant relationships, then verification would come as another study using independent saline soil sites from other areas. Production of relationships that are not significant would mean such study is unnecessary.

MULTISPECTRAL SCANNER DIGITAL DATA

Computer compatible digital tapes (CCT) of the SKYLAB S192 13-band multispectral scanner (MSS) were obtained for the December 5, 1973, overpass of the saline soil areas in Cameron County. The SKYLAB S192 MSS covers the 0.41- to 12.5-μm spectral region as shown:

Band number	Spectral region (μm)	Band number	Spectral region (μm)
1	0.41 – 0.46	8	0.98 – 1.08
2	0.46 – 0.51	9	1.09 – 1.19
3	0.52 – 0.55	10	1.2 – 1.3
4	0.56 – 0.61	11	1.55 – 1.75
5	0.62 – 0.67	12	2.1 – 2.35
6	0.69 – 0.76	13	10.2 – 12.5
7	0.78 – 0.88		

Each of the 13 bands of S192 MSS data was studied, using a cathode ray tube image display, to visually determine the band showing the best contrast between bare and vegetated soil within the study site. Threshold values were determined for distinguishing among cloud shadows, water, bare soil, vegetation, and cloud categories by using the band giving the best contrast between bare and vegetated soil. These threshold values permitted studies of salinity effects on bare-soil and vegetation categories separately and also permitted editing CCT digital values in all 13 bands due to cloud shadows, water, and clouds. The rationale was that the reflectance contrast between bare and vegetated soil (i.e., S192 MSS digital value difference or ratio between bare and vegetated soil) should better indicate salinity effects than bare or vegetated soil individually.

Electrical conductivity readings are more representative of bare-soil areas than vegetated-soil areas, because most soil samples taken for ECe determination were from bare-soil areas. But we felt that vegetated areas nearest to the soil sample locations might better indicate salinity effects than the bare-soil areas, since the native vegetation population density would be affected by soil salinity.

A line printer gray map was used to locate the various saline areas in the study site. Each cloud-free saline soil area (Figure 1) was divided into seven blocks located sequentially along the Paredes Road and Farm Road 510. Since site "E" was under clouds, the mean digital value for all 13 bands of the S192 MSS for seven areas (7 cloud-free saline areas × 7 blocks/saline area = 49 blocks) was calculated separately for bare- and vegetated-soil categories.

Linear correlation analysis was determined by relating soil salinity levels (ECe) to the differences and ratios between bare and vegetated soil S192 MSS digital means for all 13 MSS bands. Correlation analyses were also determined individually for bare and vegetated soil for comparison with correlations of bare- and vegetated-soil differences and ratios.

Results and Discussion

MULTISPECTRAL SCANNER RESULTS

SKYLAB S192 MSS band 7 (0.78 – 0.88 μm) was chosen, from visual interpretation of S192 MSS data displayed on a cathode ray tube, as having the best contrast between bare and vegetated soil. The S192 MSS digital count (DC) threshold values of cloud shadows (10-to-20 DC range), water (4-to-20 DC range), bare soil (21-to-39 DC range), vegetation (40-to-72 DC range), and cloud (73-to-181 DC range) was determined from inspection of the digital values of samples of these categories selected from S192 MSS CCT.

The S192 mean digital data for the 13-band S192 MSS is given in Table 1 for vegetated-and bare-soil areas. For area "E" the mean digital data is missing because this area was under clouds. Electrical conductivity readings are listed in this table for reference to the corresponding digital data in each of the 13 bands of the S192 MSS. These data were used for linear correlation analysis between ECe readings and DC values.

Linear correlation analysis showed a significant relation between ECe measurements and S192 MSS digital means (See Table 2), using saline areas A, B, C, D, F, G, and H (N = 7). Only band 9 yielded a statistically significant correlation coefficient (r = 0.670) using S192 MSS data from bare-soil areas. Bands 6, 7, 10, and 12 yielded statistically significant correlation coefficients using vegetation S192 MSS data (r = -0.597, -0.656, -0.548, and -0.567, respectively). Neither the difference nor the ratio of vegetation to bare soil produced large correlation

TABLE 1. MEAN DIGITAL DATA FOR THE SKYLAB S192 13-BAND MULTISPECTRAL SCANNER (MSS) AND ELECTRICAL CONDUCTIVITY (ECe) READINGS FOR EIGHT SALINE-SOIL SITES STUDIED IN CAMERON COUNTY. DIGITAL DATA WERE COLLECTED FOR VEGETATED- AND BARE-SOIL AREAS WITHIN EACH SITE ON DECEMBER 5, 1975. THESE DATA WERE USED FOR CORRELATION ANALYSIS RELATING DIGITAL INFORMATION, FOR EACH S192 BAND, TO ECe READINGS IN MMHOS/CM.

MSS	MSS and ECe data from vegetated-soil sites								MSS and ECe data from bare-soil sites							
band number	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H
1	48	51	57	52	—	50	47	49	48	47	51	50	—	47	47	49
2	85	94	98	86	—	88	84	86	83	85	81	80	—	83	85	89
3	47	50	51	49	—	45	45	48	43	45	42	43	—	43	44	48
4	27	34	33	31	—	27	25	27	24	29	25	25	—	24	23	27
5	33	37	42	37	—	31	30	34	30	31	33	33	—	29	29	31
6	60	57	60	59	—	53	52	55	44	46	43	44	—	41	41	51
7	49	47	48	48	—	48	44	44	29	31	30	31	—	30	20	37
8	60	65	61	59	—	58	56	53	38	46	39	39	—	39	38	49
9	63	60	63	61	—	68	63	55	43	44	42	43	—	42	51	52
10	64	62	63	58	—	61	58	56	44	45	42	40	—	42	43	53
11	51	51	52	44	—	47	43	42	44	42	40	35	—	39	42	43
12	37	39	43	33	—	36	31	31	40	35	36	30	—	34	38	36
13	130	137	133	128	—	141	131	130	133	135	134	130	—	135	136	134
Electrical conductivity readings	1.9	20.1	1.6	13.9	1.3	3.6	40.9	11.8	1.9	20.1	1.6	13.9	1.3	3.6	40.9	11.8

coefficients. Even though some of these coefficients were significant, they were too small to be conclusive. We found that saline area H (Figure 2) was different from the other areas so it was deleted from the analyses. Area H was probably at a lower elevation than the other areas, and its salinity readings may have been influenced by tidal floodings.

By using saline areas A, B, C, D, F, and G ($N = 6$), we found that all correlations relating saline effects with S192 MSS data were improved (See Table 2). Two of 13 S192 MSS bands correlated significantly with the salinity of bare-soil areas ($r = 0.588$ and 0.936 for band 2 and 9, respectively) while the digital data from 5 of the 13 MSS bands correlated significantly for vegetated areas (r = -0.623, -0.929, -0.760, -0.626, and -0.649 for bands 6, 7, 10, 11, and 12, respectively). Thus, vegetated areas seemed better indicators of salinity effects than bare-soil areas. The negative correlation coefficients showed that as salinity increased, reflectance from vegetated areas decreased, because salinity stunted vegetal growth or reduced plant density or both. This inverse relationship between salinity and reflectance from vegetation was first observed by Thomas[9] who measured film densities of saline and nonsaline cotton fields on aerial photographs.

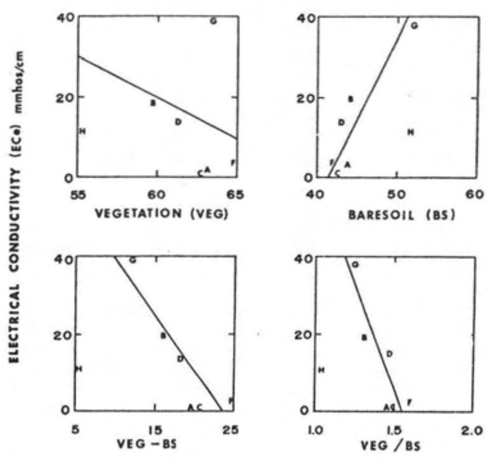

FIG. 2. Relationship between electrical conductivity in mmhos/cm and various combinations of S192 digital counts (band 9; 1.09-1.19 μm) for vegetation (VEG) and bare soil (BS) only, and the digital count difference (VEG-BS) and ratio (VEG/BS) for seven saline-soil study areas (A, B, C, D, F, G, and H) in Cameron County (December 5, 1973). Area H deviated significantly from a linear relationship and so was deleted from the analysis. Area E was not used because it was under clouds. Thus, the regression lines are for six study areas only (A, B, C, D, F, and G). Simple correlation coefficients for VEG, BS, VEG-BS, and VEG/BS, were -0.258, 0.936**, -0.876**, and -0.905** respectively.

TABLE 2. SIMPLE LINEAR CORRELATION ANALYSIS RELATING SOIL SALINITY LEVELS (ELECTRICAL CONDUCTIVITY READINGS) TO EACH OF BARE SOIL (BS), VEGETATION (VEG), VEG-BS, AND VEG/BS S192 MSS DIGITAL DATA. DATA WERE COLLECTED FROM PAREDES ROAD AND FARM ROAD 510 ON THE DECEMBER 5, 1973 SKYLAB OVERPASS FROM SEVEN SALINE-SOIL AREAS.

S192 MSS	Salinity areas A, B, C, D, F, G, and H correlated with (N = 7):				Salinity areas A, B, C, D, F, and G correlated with (N = 6):			
band number	Bare soil (BS)	Vegetation (VEG)	VEG-BS	VEG/BS	Bare soil (BS)	Vegetation (VEG)	VEG-BS	VEG/BS
	Correlation coefficients							
1	−0.437	−0.448	−0.307	−0.294	−0.438	−0.481	−0.389	−0.376
2	0.327	−0.355	−0.428	−0.434	0.588*	−0.375	−0.527	−0.530
3	0.153	−0.357	−0.362	−0.370	0.430	−0.358	−0.456	−0.462
4	0.055	−0.250	−0.367	−0.396	0.078	−0.272	−0.505	−0.543
5	−0.357	−0.435	−0.463	−0.475	−0.354	−0.445	−0.492	−0.507
6	−0.110	−0.597*	−0.340	−0.312	−0.136	−0.623*	−0.739*	−0.727**
7	0.000	−0.656**	−0.293	−0.275	0.162	−0.929**	−0.946**	−0.865**
8	0.062	−0.259	−0.198	−0.213	0.159	−0.393	−0.862**	−0.688*
9	0.670**	−0.116	−0.455	−0.525	0.936**	−0.258	−0.876**	−0.905**
10	0.029	−0.548*	−0.277	−0.278	0.184	−0.760**	−0.963**	−0.869**
11	0.064	−0.504	−0.499	−0.479	0.083	−0.626*	−0.722**	−0.680*
12	0.050	−0.567*	−0.513	−0.503	0.051	−0.649*	−0.569	−0.566
13	0.420	−0.157	−0.374	−0.368	0.424	−0.180	−0.423	−0.416

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

The two highest correlation coefficients found by using the reflectance difference between vegetation and bare soil were those for bands 7 and 10 (r = -0.946 and -0.968, respectively). These bands are in the infrared region (0.78-to-1.3μm). Since 6 of 13 S192 MSS bands (6 to 11) were significant, these correlation coefficients showed that S192 MSS data differences between vegetated and bare soil better indicated saline effects than did MSS data for either bare- or vegetated-soil areas individually. Studies involving LANDSAT-1 and 24-channel MSS aircraft data produced significant correlations between ECe data and bare-and vegetated-soil digital data in the reflective infrared region (0.72 to 1.17 μm)[10].

SALINE SOIL DETECTION AND DELINEATION

The statistically significant linear regression equation shown in Figure 2, relating the digital count difference between vegetated and bare soil to ECe measurements, has a standard error of estimate (Sy·x) about the regression line of ±8.2 mmhos/cm. This standard error of estimate is large compared with salt tolerance criteria of crop plants, measured as the yield of a crop on saline soil relative to its yield on nonsaline soil under otherwise similar growing conditions, developed by the United States Salinity Laboratory staff that indicate a 50 per cent reduction in yield for an increase in ECe of 0-to-6 mmhos/cm or 0-to-10 mmhos/cm depending on the species of crops[8].

LANDSAT-1 digital data[10], for these saline soil sites, generally yielded smaller standard errors of estimate (Sy·x = ±4.2 mmhos/cm for MSS band 7; 0.8-1.1 μm) than the SKYLAB standard error of estimate; but even these standard errors are large considering the salt tolerance criteria of crop yield. A larger number of vegetated and nonvegetated sites and a multispectral approach, rather than the single-channel approach used in this study, may reduce the standard error of estimate.

Data for this study were obtained in the winter when the cropland was fallow. Natural soil spectral variation was superimposed on the spectral differences associated with soil salinity; of particular importance in this study were the many meanders of the Rio Grande that crossed the study area with resultant frequent changes in soil type.

As indicated above, plants are sensitive indicators of soil salinity. Had the study been conducted during the crop season, advantage could have been taken of crop vegetation density and vigor differences associated with soil salinity in order to detect differences smaller than was possible in this study using the spectral differences between the fallow cropland and adjacent native vegetation.

Conclusions

Of the 13 SKYLAB S192 MSS bands used to test for distinguishing among soil salinity levels in Cameron County, Texas, only S192 band 9 (1.09-to-1.19μm) digital data correlated significantly with the salinity of fallow cropland; thus, soil salinity was not readily detectable by using bare-soil information alone. However, the difference between S192 digital counts from bare soil and adjacent naturally vegetated areas, that is the spectral contrast between vegetated and bare soil, was correlated significantly with soil salinity for six contiguous S192 bands ranging in wavelength from 0.69 to 1.75 μm.

These data, as well as LANDSAT-1 and 24-channel MSS aircraft data also tested, indicate that the reflective infrared wavelengths are superior to the visible wavelengths for soil salinity detection.

The procedures used in this study may lead to a useful saline soil detection and delineation scheme (by estimating the soil salinity for each MSS pixel from the regression equations developed), but they need further testing. Natural soil color variations superimposed on the salinity variations need to be dealt with. Multiple regression analyses using multiple bands also merit study in order to improve saline soil detection compared with the simple correlation analysis using single bands conducted in this study.

Acknowledgment

This study was supported in part by the National Aeronautics and Space Administration under Contract No. T-4105B.

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