Reprinted from

Eighth International Symposium

Machine Processing of

Remotely Sensed Data

with special emphasis on

Crop Inventory and Monitoring

July 7-9, 1982

Proceedings

Purdue University
The Laboratory for Applications of Remote Sensing
West Lafayette, Indiana 47907 USA

ASSESSING CROP CONDITION AT THE FIELD LEVEL USING LANDSAT SPECTRAL DATA

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ABSTRACT

A vegetation index (Kauth-Thomas greenness) was used to estimate a stress-no stress condition on corn and soybean fields in AgRISTARS segments. The procedure is an adaptation of the method developed by Thompson and Wehmanen to determine stress levels on the entire segments using Landsat spectral data. The predictions were compared to the Palmer Crop Moisture Index (CMI) and an area was assumed to be stressed when the CMI was less than -1.0. Although additional tests need to be run using years when more severe stress occurs to check the validity of the procedure, in 1978 the procedure predicted 90 and 91 percent of the stress-no stress conditions correctly for corn and soybeans, respectively.

I. INTRODUCTION

Information obtained from Landsat satellite has the potential to assist in assessing crop stress. During the southern corn leaf blight outbreak in 1970 and 1971, MacDonald et al. (1972) used the spectral response of the crop to identify infested corn fields. Although the spectral sensor was flown on an aircraft rather than a satellite, the experiment demonstrated the usefulness of using spectral data to assess the severity of crop stress.

Thomas and Wehmanen (1979) developed a procedure to assess the moisture stress experienced by wheat using Landsat MSS data. It was evaluated over the U.S. Great Plains in 1977 and used operationally to detect droughts in the U.S.S.R. and Australia in 1977. The same authors (1980) later extended this procedure to corn and soybean segments and found good agreement between it and a crop moisture index at the segment level.

The objective of this paper is to investigate the application of the Thompson-Wehmanen Green Index Number (GIN) to estimate crop stress at the field level.

II. EXPERIMENTAL PROCEDURE

Landsat data for 32 segments in the Corn Belt area in 1978 and 30 segments in the Corn Belt and East-Southeast states in 1979 were used to estimate the Green Index Number (GIN) for a sample of corn and soybean fields in the segments. Several spectral acquisitions were available throughout each growing season. In 1978, 693 observations were made on 284 corn fields and 616 observations were made on 274 soybean fields. The corresponding figures for 1979 were 731 observations on 348 corn fields and 983 observations on 449 soybean fields.

A sample of the fields in the segments were observed periodically by USDA personnel as a part of the AgRISTARS program. In addition to observing development stages, notes were made concerning the condition of the crop. These condition reports along with the crop moisture index were used to evaluate the Landsat-derived stress estimates (Palmer, 1968).

Thompson and Wehmanen (1980) calculated the stress index for corn and soybeans by determining the percent of pixels within a field or segment that exceed the bare soil greenness plus a greenness threshold (arbitrarily set equal to 20). Determination of a stress-no stress condition is a function of the stage of crop development. From planting to corn stage 3.5 (Hanway, 1971) and soybean stage R2 (Fehr and Caviness, 1977) the percent of pixels that must have a greenness greater than the above criteria increases linearly from 0 to 30%. From

corn stage 3 and soybean stage R2 to maturity, 30% or more of the pixels must have greenness that exceeds the stress criteria for an area to be non-stressed.

In applying GIN at the field level, two major modifications were made to the procedure. These modifications were elimination of screening the pixels for garbled and nonagricultural pixels, and a different method of calculating the bare soil green line. Elimination of the screening procedure was possible because we worked only with pure pixels, and the pixels were known to be a part of the field of interest and therefore were assumed to be pixels of corn or soybeans only.

Thompson and Wehmanen (1979, 1980) used the ten percent of the "agricultural" pixels with the smallest green numbers to designate the bare soil green line in the segment. For this application, the bare soil green line was determined by calculating the mean greenness of the field using an acquisition prior to June 1. If the first acquisition for the field was after June 1, then the bare soil green line was calculated as Thompson and Wehmanen calculated it. In this case, the mean of the ten percent of the pixels in the field with the lowest greenness was used as the bare soil green line. June 1 is an arbitrary date and was selected because "spectral emergence" had not occurred prior to this date in most segments.

An estimate of the crop development stage is necessary since the stress index is a function of development stage. Two estimates of development stage were available for this purpose. One was the observed development stage from the USDA AgRISTARS segment data. The other was an estimate of development stage calculated from spectral data using the Badhwar and Henderson (1981) temporal profile model.

III. RESULTS AND DISCUSSION

To fully understand the accuracy of the method as applied to the field level, three aspects of the procedure must be examined. These aspects are the effects of calculation of the soil green line, the effects of using a development stage obtained from a spectral estimate, rather than the observed development stage, and finally the accuracy of stress using the field observations and Crop Moisture Index (CMI) as standards.

A. SOIL GREEN LINE CALCULATION

AgRISTARS segment 133 in Whitley County, Indiana, was used as a test segment to evaluate the effects of calculating the soil green line by the method (Method 2) described in Thompson-Wehmanen (1980) and the method (Method 1) described above. Segment 133 was selected because it is included in both the 1978 and 1979 data bases.

Plots of bare soil greenness calculated using Methods 1 and 2 are shown in Figure 1. The data points are connected using a spline fit and as such have no significance. The significant fact is that using Method 2, the bare soil greenness varies throughout the season beginning at a low value early in the season and rising to a greenness ranging from four to eight when the crop begins to cover the soil. This variation may be due to the size of the fields. With Method 2 only one to five pixels are used in estimating bare soil greenness. This small number of pixels may not give an adequate estimate of bare soil greenness.
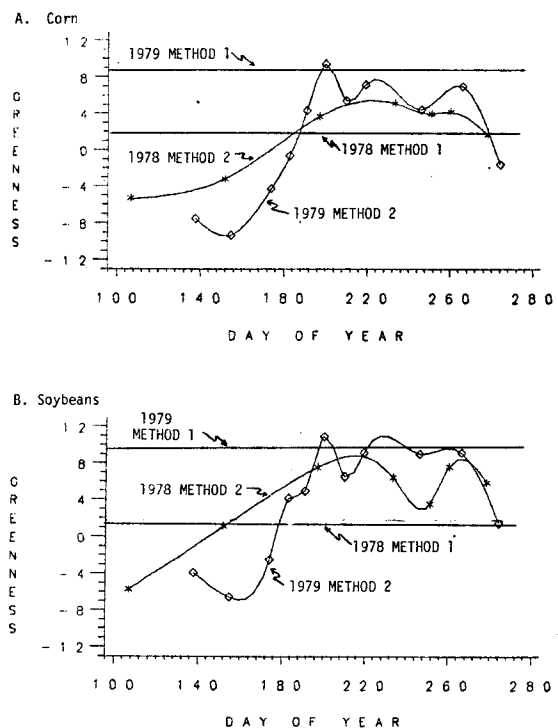

Figure 1. Bare soil greenness calculated using Method 1 and Method 2 for segment 133 in Whitley County, Indiana.

It is interesting to note that early in the season, the mean greenness of the field (Method 1) results in a bare soil greenness equal to one exceeding the bare soil greenness obtained from using the 10 percent of pixels with the lowest green number in each field (Method 2). The larger early season bare soil greenness using Method 1 is due to using all the pixels in the field rather than the small number used in Method 2.

The data plots also indicate a variation of bare soil greenness from year to year. This variation could be due to the fact that different fields were used within the same segment between the years, or because of different soil moisture conditions. It is not appropriate to make major conclusions relative to this variation but it does warrant further consideration with a larger data set.

The two methods of calculating bare soil greenness do not result in a significantly different stress index. Tables 1 and 2 show the contingency tables used to evaluate the difference between the two methods. The x^2 statistic was tested using a two tail test with an α of 95% and 5% and 1 degree of freedom.

The conclusion from this data would be that both methods of calculating bare soil greenness are the same when calculating a stress-nostress index. If the stress index were a multilevel stress index (i.e. no stress, moderate stress, moderately severe stress, severe stress) the method of calculating the bare soil greenness might become more important.

B. DEVELOPMENT STAGE CALCULATION

The result of using spectrally derived development stages is compared to using the observed development stage in Table 3 for corn and in Table 4 for soybeans. Using a two tailed x^2 test with 1 degree of freedom and an α of 95% and 5% reveals that only corn in 1979 gives the same stress result for both methods of estimating development stage. The corn results in 1978 and soybeans in both years result in a different stress index when spectral data is used to estimate the development stage.

The results lead to the conclusion that the use of this spectral estimate of development stage in GIN is not accurate enough to estimate stress conditions. Therefore, a more accurate model to depict development stage from spectral data is needed. In the interim an observed development stage should be used with the GIN model.

Table 1. Contingency tables showing effect of two methods of calculating bare soil greenness on stress calculation in 1978 for corn.

A. 1979

	No Stress	Stress	Total
Method 1	23 (21.5)	17 (18.5)	40
Method 2	20 (21.5)	20 (18.5)	40
Total	43	37	80

$$x^2 = 0.45$$

B. 1979 Corn

	No Stress	Stress	Total
Method 1	13 (17.0)	25 (21.0)	38
Method 2	21 (17.0)	17 (21.0)	38
Total	34	42	76

$$x^2 = 3.40$$

C. COMPARISON TO CROP MOISTURE INDEX (CMI)

Two comparisons to the crop moisture index were made using the 1978 crop data. One considered a stress to be present when the CMI was less than 0.0, the other when the CMI was less than -1.0. The first case is a very slight stress condition, while the second would result in a deteriorating crop condition. In the second case, some droughty fields would begin to show signs of stress.

A comparison of the predicted results to the observed CMI is presented in Table 5. In making the comparison between stress predicted at the field level to a stress indicated by the CMI, it was assumed that if the CMI for the crop reporting district indicated a stress on the day of the spectral acquisition, than all the fields in the segment were considered stressed. The data in Table 5 includes all acquisitions for the Indiana,

Illinois, and Iowa segments. The stress index showed a much higher degree of accuracy (90% vs. 60%) when a stress was assumed to occur when the CMI was less than -1.0. However, when this assumption was made, only the Northwest Crop Reporting District (CRD) in Indiana had an observed stress condition, and this occurred in late August. On this date, only two corn fields and one soybean field were predicted to have a stress.

The high percent of correct predictions is encouraging. However, it is difficult to make any conclusions based on this set of data because no prolonged moisture stresses occured in 1978. In addition, the CMI is based on a very large area, and the soil and moisture variations are removed from the index. Thus droughty fields may show a stress spectrally where the CMI would not indicate the stress. The reverse is also true, a field may not show a stress where the CMI indicates a stress. This is the case in the Northwest

Table 2. Contingency tables showing effect of two methods of calculating bare soil greenness on stress calculation for soybeans.

A. 1978

	No Stress	Stress	Total
Method 1	13 (11)	9 (11)	22
Method 2	9 (11)	13 (11)	22
Total	22	22	44

$$\chi^2 = 1.45$$

B. 1979

	No Stress	Stress	Total
Method 1	12 (15.0)	36 (33)	48
Method 2	18 (15.0)	30 (33)	48
Total	30	66	96

$$\chi^2 = 1.75$$

Table 3. Results of using spectrally derived development stage versus observed development stage to predict a stress-no stress condition using GIN for corn.

A. 1978

Development Stage	No Stress	Stress	Total
Spectrally	665 (640)	28 (53)	693
Observed	615 (640)	78 (53)	693
Total	1280	106	1386

$$\chi^2 = 13.746$$

B. 1979

Development Stage	No Stress	Stress	Total
Spectrally	513 (516)	218 (215)	731
Observed	519 (516)	212 (215)	731
Total	1032	430	1462

$$\chi^2 = 0.118$$

CRD of Indiana. Both segments are located in prime agricultural areas, with deep, clayey, poorly-drained soils while the majority of the district is composed of old sandy lake shores. The large area of sandy soils in this district masks the smaller areas with good soil moisture characteristics. Therefore, it is not unreasonable for a small number of the fields to show a stress spectrally while the majority of the fields do not in this test. It is encouraging that the only day that the fields in this district show a stress is when the CMI indicates a stress (CMI -1.0).

Comparing the results of the stress calculations to the CMI is an incomplete test of the procedure. By definition, stress was occuring anytime the greenness of less than 30 percent of the pixels had a greenness less than 20 plus the bare soil greenness. However, this definition of stress could include because of excessively wet conditions, disease,

nutrient stresses and poor stands in addition to a low moisture stress. For example, excessively wet conditions for short periods in Indiana, Illinois, and Iowa could result in drowning of crops in many fields with poorly drained conditions. If a major portion of any field were experiencing this problem, the spectral data would indicate a stress, while the CMI would show adequate soil moisture conditions and no stress. Likewise, the CMI gives no indication of disease or nutrient stresses. Unfortunately, the periodic observations in 1978 do not give adequate information to check for these other stresses.

Table 4. Results of using spectrally derived development stage versus observed development stage to predict a stress-no stress condition using GIN for soybeans.

A. 1978

Development Stage	No Stress	Stress	Total
Spectrally	513 (531)	103 (85)	616
Observed	549 (531)	67 (85)	616
Total	1062	170	1232

$$\chi^2 = 8.232$$

B. 1979

Development Stage	No Stress	Stress	Total
Spectrally	820 (754)	163 (230)	983
Observed	687 (754)	296 (230)	983
Total	1507	459	1966

$$\chi^2 = 9.00$$

Table 5. Results of comparing spectral stress index with CMI.

	Crop	
	Corn	Soybeans
Stress: CMI = 0		
No. Predictions	471	419
No. Correct	290	262
Percent Correct	61.6	60.1
Stress: CMI = -1.0		
No. Predictions	471	419
No. Correct	426	383
Percent Correct	90.4	91.4

D. COMPARISON OF SPECTRAL STRESS WITH PERIODIC OBSERVATION

In making the comparisons of spectral stress with the periodic observations, a segment was found that had adequate notes describing field conditions. A judgement was then made as to whether the field should be classified as stressed or non-stressed for each day a spectral stress estimate was available. A field was classified as stressed if the observer described the field as poor or having a thin stand.

The results for segment 133 in Whitley County, Indiana, are shown in Table 6 as a contingency table. The χ^2 test indicates that there is a difference between the observed stress and the predicted stress. The χ^2 statistic was tested with an $\alpha = 5\%$ with 1 degree of freedom.

Firm conclusions cannot be drawn from these results because of the small sample size and because the fields did not exhibit moisture stress during 1979. Also, it is difficult to observe field problems due to the causes mentioned above from ground level. These observations at ground level are possible only by an extensive walking of the fields and this was not practical in making the periodic observations. Therefore some stresses may actually be present but not noted. Additional tests need to be made using other years when moisture and other environmental stresses were experienced.

Table 6. Comparison between spectrally predicted and observed stress.

A. CORN

	Stress	No Stress	Total
Predicted	25 (15.5)	13 (22.5)	38
Actual	6 (15.5)	32 (22.5)	38
Total	31	45	76

$$x^2 = 19.667$$

B. SOYBEAN

	Stress	No Stress	Total
Predicted	46 (25.0)	12 (33.0)	58
Actual	4 (25.0)	54 (33.0)	58
Total	50	66	116

$$x^2 = 62.007$$

IV. SUMMARY

The Thompson-Wehmanen GIN procedure has been applied to Landsat spectral data at the field level. Although no firm conclusions can be drawn at this time due to the limited ground data bases, the procedure does not seem to be overly sensitive to the method of calculating bare soil greenness. It is, however, sensitive to errors in estimating development stages and therefore, accurate development stages should be used to calculate the stress index if the data are available.

Before any major conclusions can be made concerning the validity of applying the procedure to a field level, tests should be run using Landsat spectral data collected during a year when soil moisture was limiting. Such a year would be 1980. We intend to conduct these studies to more completely evaluate the procedure and its applicability to the field level.

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