

THE USE OF LANDSAT DIGITAL DATA TO DETECT AND MONITOR  
VEGETATION WATER DEFICIENCIES

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ABSTRACT

In the Large Area Crop Inventory Experiment a technique was devised using a vector transformation of Landsat digital data to indicate when vegetation is undergoing moisture stress. A relation was established between the remote-sensing-based criterion (the Green Index Number) and a ground-based criterion (Crop Moisture Index).

1. INTRODUCTION

Meteorological indexes which provide methods of computing the extent and severity of general drought have been developed. The most common of these are the Palmer and Foley drought indexes [1]. The Palmer drought index is the more involved and the most satisfactory solution to the problem of combining precipitation and temperature data and producing a predictor variable [2]. During periods when a major drought is developing and spreading, it provides a means for routinely assessing the areal distribution of the various degrees of drought severity [3].

Palmer used a two-layer soil moisture model for estimating soil moisture deficiency on a month-by-month basis [4]. These monthly variations are adequate for the study of drought; however, they do not reveal the shorter periods of soil moisture fluctuations which are important during strategic phases of plant growth. The earlier drought study was modified by Palmer to calculate a weekly index of soil moisture related to crop water requirements [3]. This index uses the same two-layer models to compute a weekly hydrological balance. It is published in the United States as the Crop Moisture Index (CMI). Although the CMI provides an indication of current plant-water relationships, it requires climatological analysis of a long record in order to derive the constants which define the moisture characteristics of the climate in the area of interest. This paper describes a procedure using criteria based on remote sensing to detect and monitor crop moisture deficiencies without analyzing a long record of climatological data.

2. METHODS

The procedure described in this paper was devised in an attempt to quantify the subjective judgment of the analyst-interpretor in deciding that a region is or is not drought affected. The data used are Landsat multispectral scanner (MSS) values for Large Area Crop Inventory Experiment (LACIE [5]) sample segments throughout South Dakota, which were acquired during the 1975 and 1976 crop years (fig. 1),

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and the CMI values reported weekly during these crop years by the U.S. Department of Agriculture (USDA) for each crop reporting district (CRD). Using the ideas presented by Kauth and Thomas [6], we devised a summary number, the Green Index Number (GIN), which was computed for each acquisition of each segment. Each segment was classified twice as drought affected or normal - first using only the GIN (remote-sensing-based criterion) and second using only the CMI (ground-based criterion). The results of these two classifications then were compared (table 1), and a contingency table of the GIN and CMI classifications (table 2) was prepared.

The GIN is defined as follows: First, the data in the segment acquisition are summarized by clustering using the Iterative Self-Organizing Clustering System (ISOCLS) algorithm [7] as implemented on the Earth Resources Interactive Processing System (ERIPS [8]) on the special purpose processor. (This parallel processor clusters a segment in approximately 30 seconds.) The clustering procedure summarizes the segment in 20 or fewer cluster means in the four Landsat channels. The count of pixels belonging to each cluster is also calculated. Each mean vector  $x^i$  is then transformed by

$$y^i = Ax^i + b' \quad (1)$$

where

$$y^i = \begin{bmatrix} y_1^i \\ y_2^i \\ y_3^i \\ y_4^i \end{bmatrix} = \text{a vector representing the Landsat-1 version of the Kauth-Thomas transformation of } x^i \text{ [6]; the subscript number indicates the Landsat channel, and the superscript is the cluster number.}$$

$$A = \begin{bmatrix} 0.4326 & 0.6325 & 0.5857 & 0.2641 \\ -0.2897 & -0.5620 & 0.5995 & 0.4907 \\ -0.8242 & 0.5329 & -0.0502 & 0.1850 \\ 0.2229 & 0.0125 & -0.5431 & 0.8094 \end{bmatrix}$$

$$b' = (0.45, -1.50, 10.61, 2.22)$$

Each vector is inspected automatically, and any vector having values unreasonable for agricultural data is discarded using the following procedure.

A cluster  $y^i$  is accepted as good only if

$$\left. \begin{aligned} 30 &\leq y_1^i \leq 110 \\ -10 &\leq y_2^i \\ -10 &\leq y_3^i \\ -10 &\leq y_4^i \leq 10 \end{aligned} \right\} \quad (2)$$

The greenness level  $m$  of the soil line then is estimated by the minimum second channel value  $y_2^i$  for acceptable clusters. That is,

$$m = \text{M I N} \left( y_2^i \right)_{i \text{ is good}} \quad (3)$$

Then the green number  $g^i$  is computed for each cluster by

$$g^i = y_2^i - m \quad (4)$$

The value of  $g^1$  should be a good measure of the green vegetation present on the picture elements (pixels) in cluster 1. Experience with spectral plots in the brightness-greenness plane and the corresponding imagery led to the following assumptions.

- $g^1 = 0$  indicates bare soil
- $g^1 = 5$  indicates a trace of vegetation
- $g^1 = 15$  indicates good cover of vegetation

Operating on these assumptions, we chose the level 15 and defined GIN to be the percentage of pixels in the entire image within clusters having green numbers greater than 15. This value was considered somewhat unstable for consecutive-day data where, for example, a cluster would slip from 15.1 one day to 14.9 the next day; therefore, cubic weighting was added to smooth this calculation in the following manner.

Let a cluster have green number  $g^1$  and contain  $n$  pixels. Define the weighting factor  $w$  by

$$\left. \begin{aligned} w &= 0 & \text{if } g^1 < 11 \\ w &= 1 & \text{if } g^1 > 17 \\ \text{Otherwise,} & & w = \frac{1}{2} + \left[ \frac{g^1 - 14}{4} \right] \left[ 1 - \frac{(g^1 - 14)^2}{27} \right] \end{aligned} \right\} \quad (5)$$

The cluster is counted as having  $w \times n$  pixels with green numbers greater than 15. This curve makes a smooth transition from full counting to not counting as the green number decreases.

The GIN then is an estimate of the percentage of pixels in a Landsat scene having green numbers high enough ( $\geq 15$ ) to indicate full cover of green vegetation. It is computed using only Landsat data. A sample spectral plot of green numbers versus brightness [6] is given in figure 2.

Having defined this segment summary number, the results had to be analyzed. For the test set used, it was impossible to make (1) year-to-year comparisons because of sparse Landsat acquisitions and important weather differences between 1975 and 1976, (2) area-to-area comparisons because of differing wheat proportions and haze effects, and (3) a direct comparison of GIN's and CMI's because the GIN contains crop stage effects not taken into account in calculating the CMI. This comparison also is confused by nonwheat crops with different crop calendars from those of wheat.

Therefore, the preferred technique for this analysis was a comparison of classifications. The plot of GIN versus time for a normal, predominantly wheat segment should follow a curve such as  $a$  in figure 3. If an observed point for a segment fell into the shaded region, the segment was classified as drought affected. The bounds for the shaded region were defined empirically as shown in figure 3, with  $t$  defined as the approximate spring emergence date in days. For different areas or years, the shaded area can be moved from side to side to match the greenup curve. The initial point in South Dakota was usually near day 110 ( $t = 110$ ). This classification was compared to a classification based on the CMI for CRD's, wherein a CRD was classified as drought affected if the CMI fell below -0.5 for 2 consecutive weeks. Both classifications were restricted to similar time frames. Classification was performed only for data between April 1 and July 10.

### 3. DATA AND RESULTS

The data used in this study consisted of all LACIE segments in South Dakota which had at least 5 percent wheat as measured by the LACIE Classification and Mensuration Subsystem (CAMS [9]) in the 1976 growing season. This definition yields 17 segments with 34 possible classifications. Of the 34, 12 had either

insufficient data during the growing season or data were inaccessible for other reasons. The final data set contained 22 segment years<sup>1</sup> for 13 LACIE segments (fig. 1, table 1). The contingency table (table 2), which applies the two classification methods to the 22 good segment years, shows that the classifications based on the CMI and GIN are related. It was concluded that the GIN is detecting moisture through crop responses.

An inspection of the five disagreements on the classification results (table 1) disclosed that on two segments the GIN algorithm was confused by a lake. Three of the segments were on the edge of their CRD's, and the CMI classifications may not reflect the actual conditions in these segments. One segment was located on the eastern edge of the CRD where heavy rains occurred at the weather station located in the Black Hills in the western part of the CRD, causing a possible incorrect condition to be reflected by the CMI.

Examples of the segment classification procedure are shown in figures 4 and 5. The GIN indicates that 1975 was normal for the entire crop season for segment J (fig. 4). In 1976, the GIN indicated that by May 24 there was moisture stress in segment J. This indicates that the GIN detected vegetation moisture stress at the same time as the CMI. Segment L (fig. 5) experienced drought as indicated by both the GIN and the CMI during the 1975 crop year. In 1976, the GIN indicated moisture stress on May 26, which was confirmed by the CMI.

#### 4. DISCUSSION

The results reported cover a first attempt at measuring drought conditions using Landsat data. Preliminary checks indicate that this procedure works in the U.S. Great Plains. More recently, we have developed a program using raw image data and avoiding the clustering procedure, enabling the generation of GIN's with any threshold. This new procedure will be utilized in continuing investigations.

#### 5. CONCLUSIONS

A technique was developed using Landsat digital data from 9-by-11 kilometer sample segments, which indicates when agricultural vegetation is undergoing moisture stress. A relation between this technique, which utilizes remote sensing, and a ground-based criterion (the CMI) has been shown. Indications are that this procedure may be capable of detecting crop moisture deficiencies in areas of the world where ground information is not available or reliable.

#### 6. REFERENCES

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<sup>1</sup>A segment year is defined as an observation of 1 segment for 1 year.

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TABLE 1. RESULTS OF GIN AND CMI CLASSIFICATIONS

Segment	1975		1976	
	GIN	CMI	GIN	CMI
A	W	W	-	D
B	-	W	W	D
C	W	W	D	D
D	W	W	D	D
E	W	W	D	D
F	W	W	W	D
G	W	W	W	D
H	W	W	D	W
I	W	W	-	W
J	W	W	D	D
K	W	W	D	D
L	D	D	D	D
M	-	D	W	D

[ D = Drought conditions  
 W = Normal conditions  
 - = No data ]

TABLE 2. CONTINGENCY TABLE OF GIN AND CMI CLASSIFICATION METHODS

		CMI		
		Normal	Dry	
GIN	Normal	10	4	14
	Dry	1	7	8
		11	11	22

$\chi^2 = 7.07$  with 1 degree of freedom.  
 $\hat{p} = 0.0082$  = level of significance.

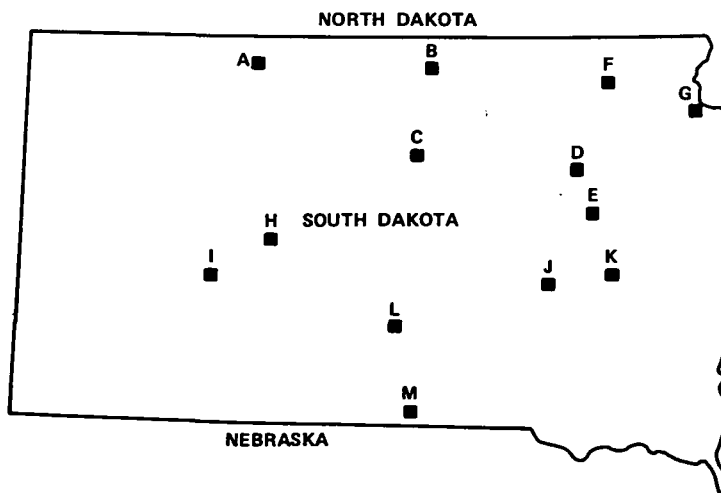


FIGURE 1. SEGMENT LOCATIONS. Map of South Dakota showing locations of LACIE 9-by-11 kilometer sample segments.

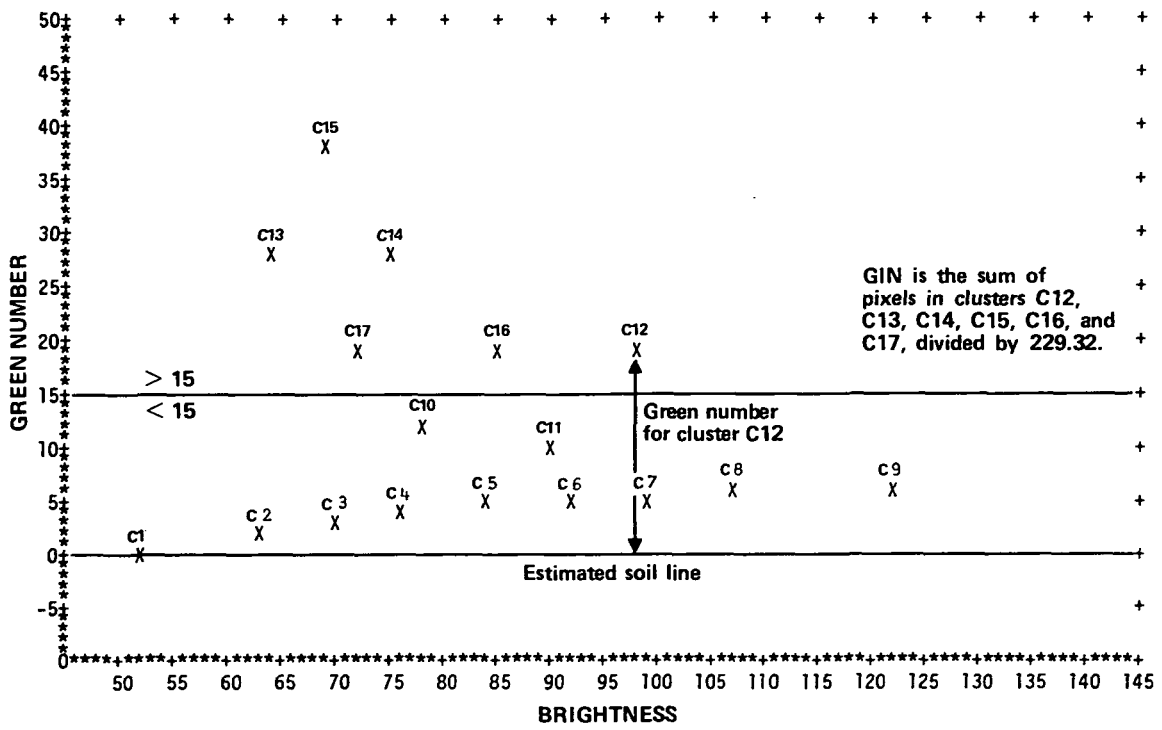


FIGURE 2. SPECTRAL PLOT. Sample spectral plot of cluster statistics.

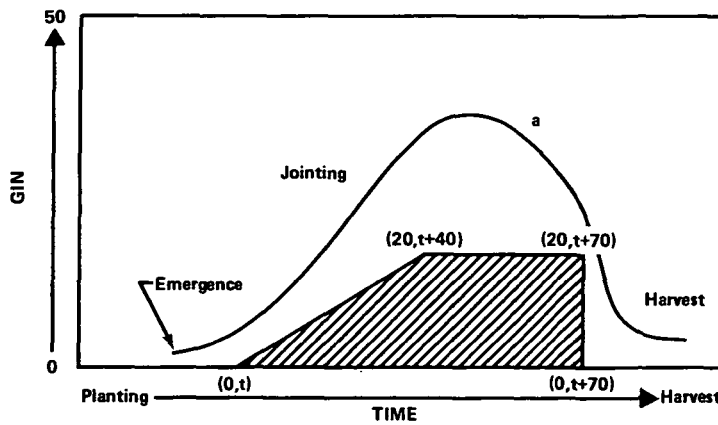


FIGURE 3. PLOT. GIN versus time for a normal, predominantly wheat segment.

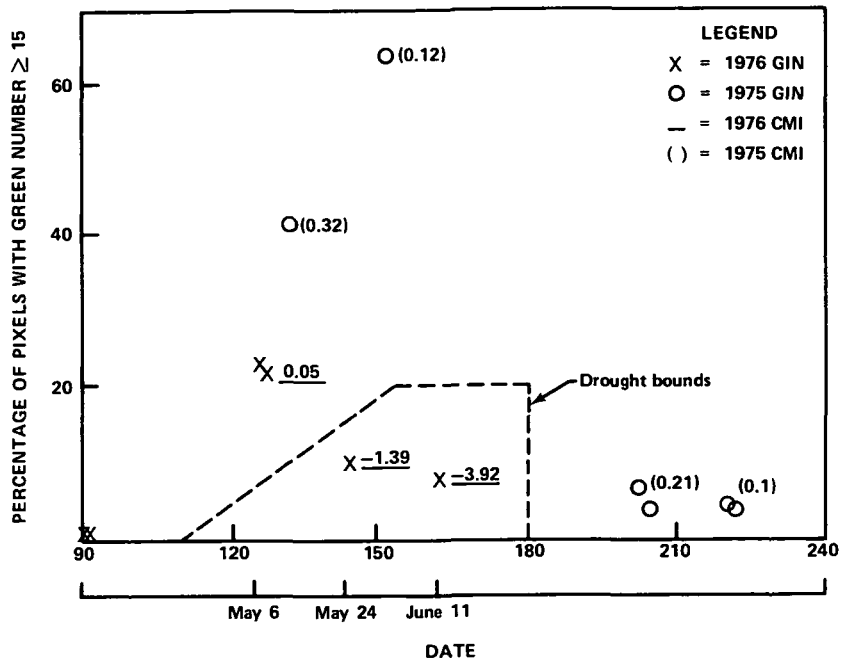


FIGURE 4. GRAPHIC PLOT. GIN versus time with CMI values for segment J.

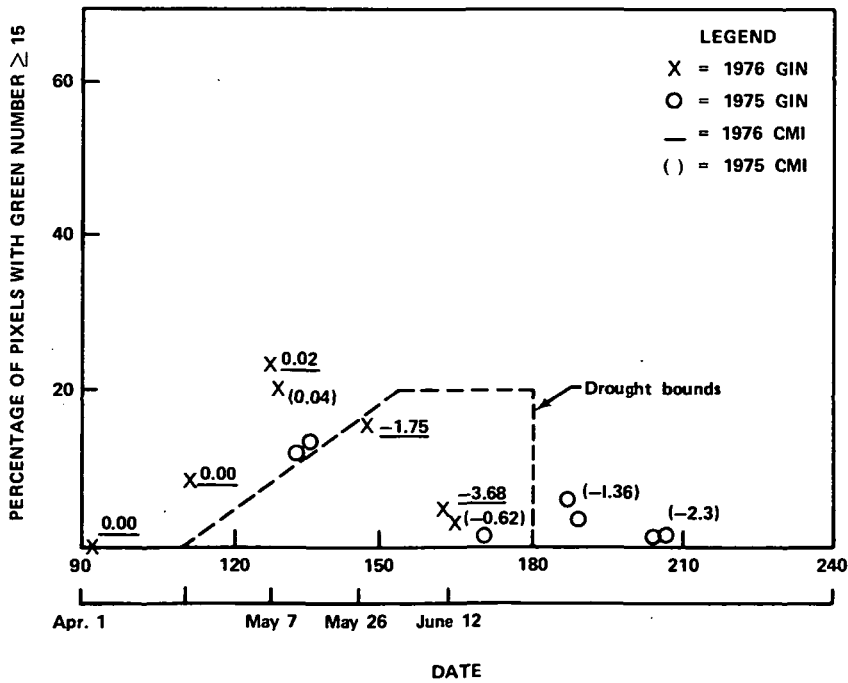


FIGURE 5. GRAPHIC PLOT. GIN versus time with CMI values for segment L.