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Using Landsat Digital Data to Detect Moisture Stress in Corn-Soybean Growing Regions

Landsat and meterological data along with knowledge of the agronomic properties of the crop being monitored must be considered.

Abstract: *As a part of a follow-on study to the moisture stress detection effort conducted in the Large Area Crop Inventory Experiment (LACIE), a technique utilizing transformed Landsat digital data was evaluated for detecting moisture stress in humid growing regions using sample segments from Iowa, Illinois, and Indiana. At known growth stages of corn and soybeans, segments were classified as undergoing moisture stress or not undergoing stress. The remote-sensing-based information was compared to a weekly ground-based index (Crop Moisture Index). This comparison demonstrated that the remote sensing technique could be used to monitor the growing conditions within a region where corn and soybeans are the major crop.*

Introduction

Since the conclusion of the Large Area Crop Inventory Experiment (LACIE) a new program for Agriculture and Resources Inventory Surveys through Aerospace Remote Sensing (AGRISTARS) has been initiated by five federal agencies of the United States: Department of Agriculture, USDA; National Aeronautics and Space Administration, NASA; Department of Commerce, USDC; Department of Interior, USDI; and the Agency for International Development, USAID. AGRISTARS will develop technology using remote sensing for other major crops and areas not examined during LACIE.

Landsat data were used in LACIE to monitor production in selected wheat-producing regions of the world. Trained analyst-interpreters labeled as small grains or non-small grains, a small amount (less than 1 percent) of a 5 × 6 nautical mile segment for training of pattern recognition algorithms to determine the acreage in these crops. As the spectral appearance of the crop is a function of its growth stage and weather conditions, it was necessary to develop procedures to indicate the growth stage of wheat and to determine if the region (segment) was undergoing moisture stress or not. A technique utilizing transformed Landsat digital data for detection of agricultural drought was empirically defined during the 1976 South Dakota drought (Thompson, 1976; Thompson and Wehmanen, 1977). This technique (Green Index Number [GIN]) was evaluated over the U.S. Great Plains in 1977 and used operationally to detect droughts in the 1977 USSR and Australia wheat crop (Thompson and Wehmanen, 1979). The results of these studies demonstrated that

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Landsat digital data could be used to monitor water stress of agricultural vegetation in semi-arid wheat growing regions; however, the procedure was not evaluated over more humid regions with different crops. The objective of this study was to evaluate the applicability of the GIN concept over a more humid region where wheat is not the major crop. Corn and soybeans were selected for evaluation as they are major crops to be studied by AGRISTARS.

APPROACH

During the 1978 crop growing season, 5 × 6 nautical mile segments were randomly located over part of the U.S. corn-soybean growing region. Landsat digital data were acquired during 1978 for these segments. A subset of these segments was selected for evaluation of the GIN technique in humid regions. All segments (129) from Iowa, Illinois, and Indiana were classified as moisture stressed or normal by using the GIN technique (Thompson and Wehmanen, 1979), and were compared to the Crop Moisture Index (CMI) (Palmer, 1968) for the same time period. This region was selected for evaluation because of the homogenity of the area (soils and crops). As the CMI is available for Crop Reporting Districts (CRD) that represent several counties, it was desirable to select a region where the soils and crops within the area would be uniform.

The GIN computation is based on work by Kauth and Thomas (1976). The basic idea of Kauth and Thomas is that a particular weighted difference (linear combination) of the infrared and visible channels of Landsat data measures growing vegetation; however, any of the "green vegetation indices" such as perpendicular vegetative index, normalized difference, IR/red ratio, etc., could be used (Tucker, 1979; Deering, 1978; Richardson and Wiegand, 1977). During the conduct of LACIE, the need for a large area drought monitoring system arose during the 1976 Great Plains drought. At that time it seemed natural to use the greenness measure as a basic datum and summarize it in some way to measure growing conditions over large areas. While Landsat does not measure drought per se, it does reflect the conditions of reduced photosynthetically active leaf area caused by moisture stress. In the early experiment, Landsat data collected over wheat fields throughout the 1975 and 1976 wheat growing season in Texas and Nebraska were used to determine the number of counts in the Kauth-Thomas Greenness Factor above the bare soil greenness for an adequate moisture year (1975) and a drought stressed year (1976) (Thompson, 1976a). From this study, the level 15 was selected because it represented the breaking point between a good cover of healthy green vegetation and vegetation undergoing moisture stress. During the drought that occurred South Dakota in 1976, data from LACIE 5 × 6 nautical mile segments were used with the level 15 breaking point to empirically develop the GIN technique for monitoring crop growing conditions in wheat growing areas were ground truth is not available (Thompson, 1976b; Thompson and Wehmanen, 1977). In the present paper, we are testing general ideas developed in semi-arid wheat growing regions for application in humid corn-soybean growing regions. Using corn and soybean fields located outside the study area, Landsat data were analyzed over the growing season to adjust the initial parameter for the cut-off level for healthy and stressed vegetation. From this study, the cut-off level was raised from 15 to 20 for regions where corn and soybeans are the major crop. Thus, the GIN in the more humid region is defined as the percentage of image elements (pixels) in a Landsat scene (segment) having greenness values above bare soil ≥20. The procedure for computing GIN is defined by:

For a Landsat digital count (DC) observations where

$$X = \begin{matrix} X_1 \text{ Landsat MSS 4 DC} \\ X_2 \text{ Landsat MSS 5 DC} \\ X_3 \text{ Landsat MSS 6 DC} \\ X_4 \text{ Landsat MSS 7 DC} \end{matrix}$$

Z is computed where

$$Z = \begin{matrix} Z_1 \text{ Kauth-Thomas Soil Brightness Factor} \\ Z_2 \text{ Kauth-Thomas Greenness Factor} \\ Z_3 \text{ Kauth-Thomas Yellowness Factor} \\ Z_4 \text{ Kauth-Thomas Non-Such Factor} \end{matrix}$$

$$Z = RX$$

where R = Kauth-Thomas rotation of Landsat II data

$$R = \begin{matrix} 0.33231 & 0.60316 & 0.67581 & 0.26278 \\ -0.28317 & -0.66006 & 0.57735 & 0.38833 \\ -0.89952 & 0.42830 & 0.07592 & -0.04080 \\ -0.01594 & 0.13068 & -0.45187 & 0.88232 \end{matrix}$$

and Z is rounded to the nearest integer value.

Each vector is inspected automatically and any pixel is accepted if

$$10 \leq Z_1 \leq 100$$

$$-10 \leq Z_2$$

$$-15 \leq Z_3 \leq 0$$
$$-5 \leq Z_4 \leq 5$$
$$X_4 > 12$$
$$12X_1 - 34X_4 < 108$$

This screening procedure removes most of the nonagriculture pixels in a segment and is a refinement from Thompson and Wehmanen (1979).

The pixels which meet the above test are used to compute the Green Index Number (GIN) by first computing the cumulative histogram (H), where

$$H(a) = \frac{\text{Number of pixels with } Z_2 > a}{22932}$$

and the bare soil greenness line (s) is defined by $H(s) = 1$ percent and the Green Index Number (GIN) by GIN $(a) = [1\text{-}H(s + a)] \times 100$. In the previous study, a was fixed at 15. For this study $a = 20$ was used.

Data collected from Landsat 3 was transformed to simulate Landsat II using the following multiplicative transformation.

Landsat 2 digital counts = A(Landsat 3 digital counts) where

$$A = \begin{matrix} 1.116 & \text{MSS4} \\ 1.230 & \text{MSS5} \\ 1.246 & \text{MSS6} \\ 1.062 & \text{MSS7} \end{matrix}$$

The GIN for a predominantly corn-soybean segment that is not undergoing moisture stress should be outside the stressed region (Figure 1). The start of the boundary for the stressed region was defined as the approximate spring emergence day for corn. Normally in the study area, soybeans are planted after corn; thus, they are shown emerging 5 days after corn. By allowing the starting point to be tied to the crop emergence, the difference between years and regions can be accounted for. The boundary for the stressed region reflect the fact that a normal corn-soybean segment greens up for 50 days and then exceeds a GIN 30 until the crop is mature. When crop maturity is reached, the value decreases. Each acquisition for a segment was plotted and the segment was classified as moisture stressed or not moisture stressed. For comparison, these segments were also classified using the CMI for Crop Reporting Districts (CRD). A CRD was classified as undergoing moisture stress if its CMI fell below −0.5. Some segments had ground observation statements concerning the general condition of the crops throughout the growing season. The data used in the study consisted of 129 segments located throughout Iowa, Illinois, and Indiana. These segments were located within cropland. The remote sensing classification was evaluated against the Crop Moisture Index (USDC-NOAA and USDA-ESCS, 1978). This index measures the degree to which moisture re-

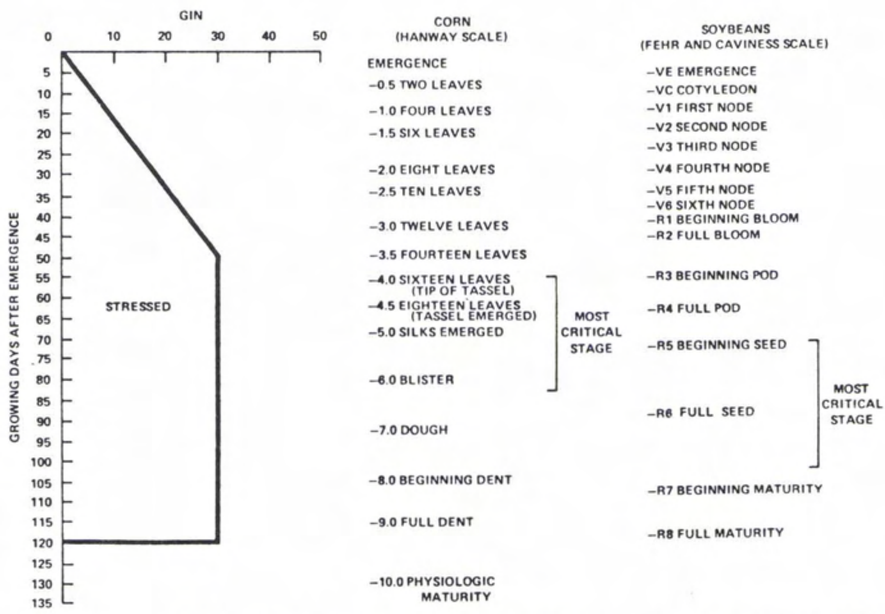

FIG. 1. Green Index Numbers (GIN) stress scale related to corn and soybean growth scales.

quirements of growing crops were met during the previous week (Palmer, 1968). The index is computed from average weekly values of temperature and precipitation. These values are used to calculate the actual moisture loss, using previous soil moisture condition and current rainfall. If the potential moisture demand, or potential evapotranspiration, exceeds available moisture supplied, actual evapotranspiration is reduced and the CMI gives a negative value. However, if moisture meets or exceeds demand, the index is positive (Table 1). The CMI represents the average moisture conditions over a several-county region (Crop Reporting District), so local moisture conditions may vary because of rainfall distribution or different soils. The specific type of agriculture is not considered in the CMI, but it assumes a water-use curve typical of the leaf area index of the crop which predominates in the region.

Results

Each Landsat acquisition was classified using GIN based on the crop growth stage (Figure 1). For this study, the Weekly Weather and Crop Bulletin and actual crop growth stage information was used to set the boundary for the GIN. Ground observations were made on approximately ten fields each of corn and soybeans corresponding to the Landsat overpass for a subset of the segments. These observations included crop growth stage information. Models are presently being developed for predicting crop growth development that will enable the procedure to be applied in regions where actual crop development information is not available. Three segments were selected to demonstrate the classification by GIN and corresponding CMI classification (Figure 2). Segment 828 located in Kankakee County, Illinois, demonstrates a segment classified dry by both GIN and the CMI (Figure 3). A segment was considered as undergoing moisture stress if the CMI was ≤ -0.5 at the time of the Landsat overpass. In Figure 3, the 12 June GIN value of 7 corresponds to the CMI value of −0.63. The GIN value should be approximately 20 at this time; thus, for this acquisition, this segment would be flagged as undergoing moisture stress. The CMI also indicates moisture stress at this time. The 29 June overpass would also be flagged as stressed by GIN. During this timeframe, precipitation occurred and the CMI began to respond. This is reflected in the next GIN value of 60 and the following dates. The GIN falls off during the late August and September overpass as the CMI goes negative. A segment that is considered normal or having adequate moisture, as indicated by GIN and the CMI, is shown in Figure 4. The CMI never goes below −0.5 and the GIN is always above the stress bounds indicated in Figure 1. If a comparison is made between Figures 3 and 4 during the early season, segment 828 has a GIN of 7 while segment 856 has a GIN value of 55 on 12 June. One is undergoing stress and

Table 1. Crop Moisture Index (CMI) Ratings and Corresponding Condition Statements (From Weekly Weather and Crop Bulletin)

Index Increased or did not Change	
Above	3.0 Excessively wet, some fields flooded
2.0 to	3.0 Too wet, some standing water
1.0 to	2.0 Prospects above normal, some fields too wet
0 to	1.0 Moisture adequate for present needs
0 to	−1.0 Prospects improved but rain still needed
−1.0 to	−2.0 Some improvement but still too dry
−2.0 to	−3.0 Drought eased but still serious
−3.0 to	−4.0 Drought continues, rain urgently needed
Below	−4.0 Not enough rain, still extremely dry
Index Decreased	
Above	3.0 Some drying but still excessively wet
2.0 to	3.0 More dry weather needed, work delayed
1.0 to	2.0 Favorable, except still too wet in spots
0 to	1.0 Favorable for normal growth and field work
0 to	−1.0 Topsoil moisture short, germination slow
−1.0 to	−2.0 Abnormally dry, prospects deteriorating
−2.0 to	−3.0 Too dry, yield prospects reduced
−3.0 to	−4.0 Potential yields severely cut by drought
Below	−4.0 Extremely dry, most crops ruined

FIG. 2. Moisture stress study states, crop moisture index divisions, and location of three example segments.

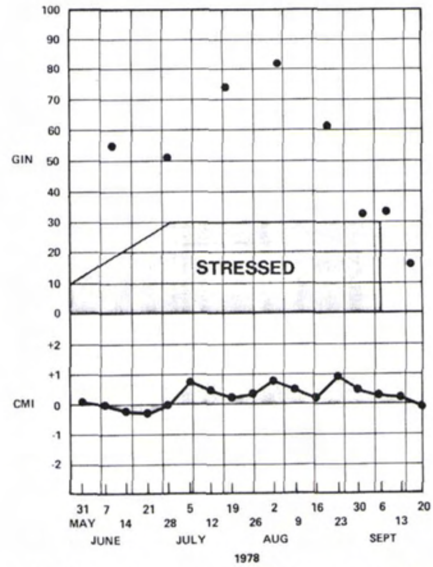

FIG. 4. Example segment 856, located in Warren County, Indiana showing adequate moisture conditions by both the CMI and GIN classifications.

the other is not. More noticeable is the 8 September overpass where segment 856 GIN value is 33 and segment 828 GIN value is 6. As indicated by the CMI, segment 828 was undergoing moisture stress. Figures 3 and 4 provide results, while not quantitative, that indicate that Landsat reflects the growing conditions of the vegetation within the scene and can be used for monitoring of crop conditions.

The final data set of 129 segments shows a fair degree of agreement between the remote sensing classification (GIN) and the CMI classification. The contingency table (Table 2), which compares the two classification methods, shows that the classification based on the CMI and GIN are the same 80 percent of the time.

An inspection of the disagreements of the classification results disclosed that the soils at the segment level have different water holding capacities than those used in the CMI model. Also, rainfall at the segment location may differ from the amount recorded at the weather stations used in computing the CMI. The subjective ground observation statements concerning the general condition of the crops within a segment support the remote sensing classification (GIN) in that segments flagged as undergoing drought stress were the same as those flagged by GIN, except for the disagreements exemplified by Figure 5. In this example, segment 136 was classified as dry by GIN, based on the GIN of 10 on 31 July. The CMI is above +1.0 for the two weeks during and preceding the Landsat overpass. A CMI value above +1.0 indicates excess moisture, including some standing water (Table 1). The oxygen to the plants is reduced and the plant is not able to translocate water for photosynthesis and, thus, is undergoing moisture stress similar to drought stress. If the soil is wet, the plant will appear to the eye wilted as when the soil is dry. Nine of the eleven erroneous dry classifications by GIN occurred when the CMI was above +1.0 (Table 2). If the CMI criterion was changed to include above +1.0 as a

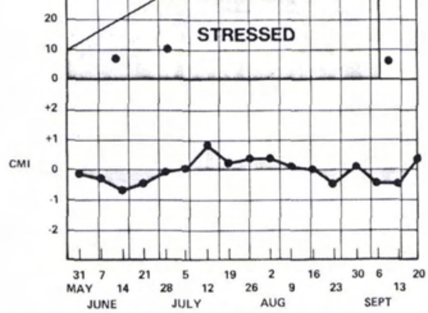

FIG. 3. Example segment 828, located in Kankakee County, Illinois, showing dry conditions by both the CMI and GIN classifications.

TABLE 2. CONTINGENCY TABLE OF GIN AND CMI CLASSIFICATION METHODS

		Crop Moisture Index (CMI)		
		Normal	Dry	
Green Index Number (GIN)	Normal	95	5	100
	Dry	11	18	29
		106	23	129

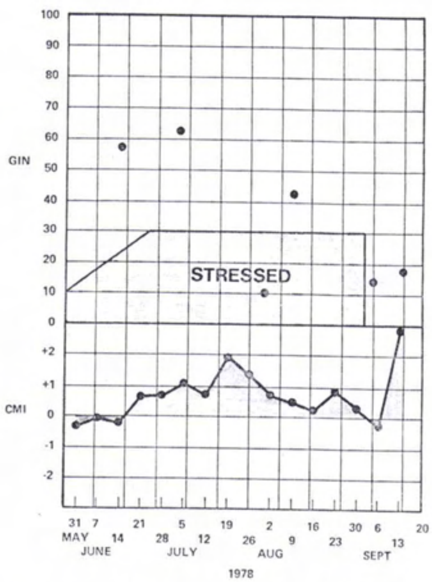

FIG. 5. Example segment 136, located in Decatur County, Iowa, showing stressed classification by GIN and non-stressed classification by the CMI.

stress bound along with the −0.5 value, the contingency table (Table 3) shows that the classification based on the CMI and GIN are the same 95 percent of the time. Thus, it appears that the GIN is detecting moisture conditions through crop responses. If excess moisture is present, the response is similar to that response when not enough moisture is present for the plant. By combining Landsat with meteorological data, growing condiitons can be monitored in moist humid regions where corn and soybeans are the major crops.

CONCLUSIONS

The results of this study demonstrate that a technique developed for monitoring agricultural vegetative water stress in semi-arid wheat growing regions can be extended into more humid corn-soybeans growing regions by optimizing the procedure for the specific crops to be monitored. In addition to being able to detect dry conditions, it appears that excess moisture conditions can also be determined utilizing Landsat data. Recent results reported by Tucker *et al.* (1979) from handheld radiometer *in situ* data in the red (0.65-0.70 μm) and photographic infrared (0.775-0.825 μm) IR radiances indicate that spectral measurements were sensitive to the severity of drought stress in alfalfa and winter wheat. These small scale quantitative results of Tucker *et al.* combined with our large area qualitative Landsat results support the monitoring of growing conditions using remote sensing from space. However, the study emphasizes that one data source cannot be used alone in a global crop monitoring system. Landsat and meteorological data along with knowledge of the agronomic properties of the crop being monitored must be considered. Landsat (remote sensing) provides an early indication of below or above average crop conditions for a particular date which then can complement and verify results from other sources such as crop-weather models.

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TABLE 3. CONTINGENCY TABLE OF GIN AND CMI CLASSIFICATION METHODS

		Crop Moisture Index (CMI)		
		Normal	Stressed	
Green Index Number (GIN)	Normal	95	5	100
	Dry	2	27	29
		97	32	129

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