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A LANDSAT AGRICULTURAL MONITORING PROGRAM*

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I. ABSTRACT

A Landsat Agricultural Monitoring Program (LAMP) was established to monitor Iowa's corn crop in near real-time. The Program utilized Landsat data in conjunction with collateral data sources to monitor crop development and identify/assess anomalies and crop stress. Throughout the growing season, data were screened manually and by computer for indications of crop condition. Alarms were generated by weather related events and/or by changes in the satellite imagery. These alarms were then assessed as to their nature, extent, severity and projected impact on crop production. Landsat digital data, coupled with specially gathered collateral data, were used to update this initial alarm impact assessment. During the 1976 growing season, LAMP identified and assessed the effects of heavy rains, hail, tornadoes and drought on corn production in Iowa.

II. INTRODUCTION

The Landsat Agricultural Monitoring Program (LAMP) established a Crop Monitoring Center to assess the utility of satellite remote sensing data for crop production monitoring. The Center was developed to monitor corn in Iowa and was tested during Iowa's 1976 growing season. The State of Iowa was chosen because it represents a large agricultural region well suited for Landsat coverage and because of its importance to U.S. and world agriculture. The more than twelve million acres of corn planted in Iowa in recent years represented approximately 18 percent of total U.S. corn acreage, more than any other state. The more than one billion bushels of corn produced in 1975 represented more than 19 percent of total U.S. corn production and in excess of 10 percent of total world production.

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The successful operation of a Crop Monitoring Center would allow local, state and federal policy planners to "watch" crop production developments during the current growing season and provide useful and timely information that could impact current agricultural policy decisions. If, for example, an operational center had been established and continuously monitored Russia's wheat crop during the 1975 growing season, the world agricultural community would have realized the magnitude and potential impact of the drought in Russia. Accurate and timely information could have been communicated to agricultural policy planners, thus minimizing the drought's impact on the world food market. Indeed, having accurate and timely crop production information is worth billions of dollars in benefits to U.S. and world agriculture.[1,2]

III. IOWA ALARM CENTER CHARACTERISTICS

The Crop Monitoring Center utilized Landsat imagery in conjunction with climatic and field reports to monitor crop development, detect crop alarms and estimate crop yield. A functional block diagram of the Center's operation is illustrated in Figure 1. Corn crop monitoring was performed continually throughout the growing season. All Landsat images of the target area were interpreted for crop changes occurring between each eighteen-day satellite cycle (nine days with two Landsats), and were compared to Landsat images from previous seasons. Weather and crop reports were monitored to aid in crop development and condition interpretation from Landsat imagery. Current and historical Landsat/collateral data were entered into a Corn Data Base (CDB) established for Iowa and were used to aid the crop monitoring activity during the 1976 growing season. During the monitoring phase, all Landsat and collateral data were screened to detect "alarms"; that is, acute or chronic situations that may affect corn production. An alarm may be caused by unfavorable weather, floods, hail, tornado, drought, freeze, insects or disease, and may be detected from either Landsat imagery or collateral data.

When an alarm was generated, the Center responded by paralleling its monitoring operation with an assessment mode to determine the extent and potential impact of the alarm. Additional information such as Landsat digital data, selected aircraft overflights and special collateral data were requested to provide support data for assessment. In some cases, personnel were dispatched to investigate an alarm first-hand.

The outputs of the monitoring and assessment operations were used to modify crop production forecasts. They can also be used as inputs to models for simulating corn physiology or forecasting yields. Alarm acreage estimates and/or yield estimates can be used to adjust crop production forecasts or to modify statistical crop sampling strategies during the crop season. After the initial assessment, the repetitive Landsat coverage and continuous collateral data monitoring process were used to update alarm assessments. The progress of an alarm can be monitored, or the replanting and recovery after an event followed. Continual monitoring and assessment of an alarm enables the Center to periodically update production estimates throughout the growing season.

The establishment of a detailed and complete CDB is important for the efficient and timely operation of the Center. At the beginning of the project, information on corn physiology, Iowa's climate, and soils and historical corn production statistics were collected and entered into the CDB. Contained in the CDB are models and trends that describe a normal or average crop season for corn which were used as the basis of comparison for the current season. These models and trends describing an average crop season were formulated at the county, crop reporting district and state levels, enabling the Center to monitor the current season at the local as well as state level.

Collateral information contained in the CDB include: topographic maps, county highway maps, land use maps, aerial photography, soils maps and information, climate information, production statistics, and Landsat data. The CDB was updated during the crop season with current collateral and Landsat data.

Continuous monitoring of Landsat data and collateral data sources during the 1976 growing season enabled the Center to detect and assess several events such as heavy rainfall, hail, tornadoes and drought that impacted corn production in Iowa.[3,4,5] This paper describes the efforts of the Center to assess and monitor the effects of drought in Iowa in 1976.

IV. DROUGHT ALARM IDENTIFICATION AND ASSESSMENT

A. IDENTIFICATION

Successful corn production is dependent upon an adequate supply of water during the growing season. In Iowa, this supply comes from summer rainfall and subsoil moisture reserves. Normal crop season precipitation in Iowa is not enough to meet the physiological needs of the corn crop and therefore a subsoil moisture reserve must be utilized to sustain normal growth. If the available moisture is deficient then corn suffers moisture stress resulting in stunted growth, delayed development and yield reductions.

During the 1976 season the Center continually monitored temperature, precipitation and soil moisture comparing the current season with the 30-year norms. Areas of the state that historically tend to be droughty or reported low soil moisture reserves were given particular attention. By late July, parts of northwestern Iowa had reported several weeks of below normal precipitation and above normal seasonal temperatures. An alarm was generated for this area to assess the extent and severity of the drought.

A single Landsat frame, including portions of northwestern, west central and central Iowa, was selected for drought analysis due to expected large variations in drought stress. Within the frame, a test site in Sac County was selected for ground truth collection (Figure 2).

Records for the Sac City weather stations show that under 6 inches of rainfall fell from June through September compared to a 30 year norm of 12 inches. Two inches were recorded in one week in July; only four tenths of an inch of rain was recorded in August. The Sac County Cooperative Extension Service and the Agricultural Stabilization and Conservation Service (ASCS) reported severe drought in the northern part of the county.

B. ASSESSMENT

Ground truth information was obtained for the Sac County test site from a car survey of fields made in early September and from information supplied by the Federal Crop Insurance Corporation (FCIC) and ASCS. Crop identification and field location were recorded on a mylar transparency overlaid on an enlarged Landsat image of the test site.

In addition, yield data for twenty fields within the test site area were supplied by FCIC, ASCS, and private farming operators. The size of the twenty fields ranged from 71 acres to 455 acres averaging 199 acres. Yields for the fields ranged from 3.3 to 126 bushels per acre. A threshold yield limit was established to separate drought stressed corn fields from nonstressed fields. After interviewing Sac County FCIC, ASCS and Cooperative Extension personnel and surveying historical yield data for Sac County, 70 bushels per acre was established as the upper limit for the stressed corn field category. The stressed field category consisted of eight fields, while the nonstressed classification was comprised of 12 fields.

Prior to Landsat multispectral digital analysis, the data were "normalized" using a linear transform to reduce the influence of factors such as differences in sun angle, sensor response, data calibration and atmospheric interference, all of which tend to distort the data. The normalization procedure transforms MSS radiance data to relative reflectance.[6] Without a procedure for data normalization, temporal analysis of Landsat data important for agricultural application would be almost meaningless. When comparing temporal multispectral data of corn it is important that spectral changes are "real" and not due in part to interference from variable factors such as haze.

Normalized reflectance values for four band widths (band 4, 0.5 - 0.6 μm; band 5, 0.6 - 0.7 μm; band 6, 0.7 - 0.8 μm; and band 7, 0.8 - 1.1 μm) and for seven dates were obtained for all twenty corn fields. Mean reflectance values were determined for all stressed and nonstressed corn fields and plotted as temporal spectral profiles (Figure 3 a, b). Reflectance values for bands 4 and 5 were slightly but consistently higher for stressed fields than for nonstressed fields. Near-infrared reflectance values (bands 6 and 7) for both classifications were similar for the June 27 and July 5 dates, but begin to diverge after July 23. This divergence is due in part to the physiological changes occurring in the corn plant during the tasseling/silking period, which normally takes place in late July. Claassen and Shaw[7] found that a 53 percent grain yield reduction was associated with stress at 75 percent silking. The multispectral scanner aboard Landsat appears to be sensitive to physiological differences in the corn fields due to moisture stress.

A stress classification was developed for July 23, August 2, August 19 and September 6 using the IMAGE 100 interactive system by training on the stressed fields and then developing a composite stress signature. Histograms indicating the frequency of pixels along a gray level or radiance scale were interactively trimmed to further improve the accuracy of the stress signature. Figure 4 shows the results of the extension of the stressed signature (black) across the test site area on July 23. By September 6, the drought area widened due to the lack of rainfall during the latter part of the growing season (Figure 5).

The August 19 Landsat image was bulk classified to determine the extent of the stressed corn conditions over a large area (Figure 6, light gray). The greatest concentration of classified pixels occurred in the northwest corner of the scene near the test site area where the signature was developed. The stress classification extended eastward along an arc from the upper-left to the right-center of the image generally following the boundary of the Clarion-Nicolett-Webster soils association. However, a portion of the city of Des Moines was also included in the classification. This suggests that stressed corn signatures cannot be extended over large heterogeneous areas, but should be developed for and extended within relatively homogeneous strata.

Correlation analysis was used to determine the relationship between yield and field reflectance for each of the four Landsat bands for four different dates (Table 1). Band 7 showed the highest correlation with yield for all dates, followed by bands 6, 5 and 4. The near-infrared bands were positively correlated with yield, while bands 4 and 5 were negatively correlated. Highest correlation for all bands was on July 23, except for band 5, which showed highest correlation to yield on August 19. Lowest correlations occurred on September 6 for bands 4 and 5, and on June 27 for bands 6 and 7.

Correlation analysis was also used to determine the relationship between yield and six Landsat band ratios (Table 2). All correlations were positive except for the band 6 over band 7 ratios, which were negative for all dates except September 6. Highest correlation was found for band 6 over band 7 on July 23. In general, the Landsat band ratios examined were more highly correlated with yield than single Landsat bands, but no single band ratio was consistently higher on all dates.

A least-squares regression was calculated for yield using band 7 reflectance on July 23. The regression equation calculated was:

$$\hat{y} = 14.40x - 290.23$$

where "$\hat{y}$" is the estimated grain yield in bushels per acre and "x" is mean normalized band 7 reflectance as illustrated in Figure 7. The regression equation accounted for 82 percent of the variation in corn yield.

IV. CONCLUSIONS

The Crop Monitoring Center established by the LAMP study was able to identify, monitor and assess a number of alarm conditions impacting Iowa corn production in 1976. The successful operation of the Center depended on the combined utilization of Landsat and collateral data for accurate identification and assessment of the extent/severity of alarms.

Landsat multispectral data was found to be: 1) sensitive to crop condition, 2) useful for stressed corn signature development and extent assessment and 3) related to final corn yield. Further yield model development is needed before Landsat data can be useful for accurate yield forecasting.

The ability to determine the effect an "alarm" condition such as drought has on state, U.S. and world agriculture allows one to continually update and improve the accuracy of crop production estimates. Knowledge of the areal extent of an alarm and information as to its severity could guide USDA statisticians to selecting a more representative sample describing the current condition of agricultural crops and thereby generate more accurate production estimates.

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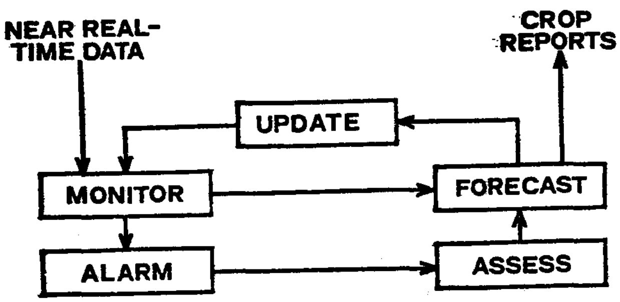

Figure 1. LAMP Alarm Center Configuration

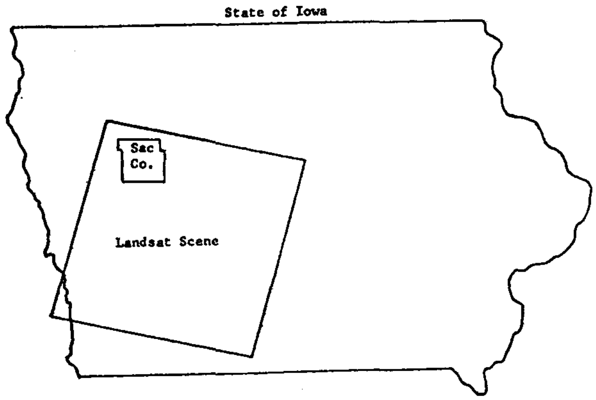

Figure 2. Location of Landsat Scene and Sac County Test Site

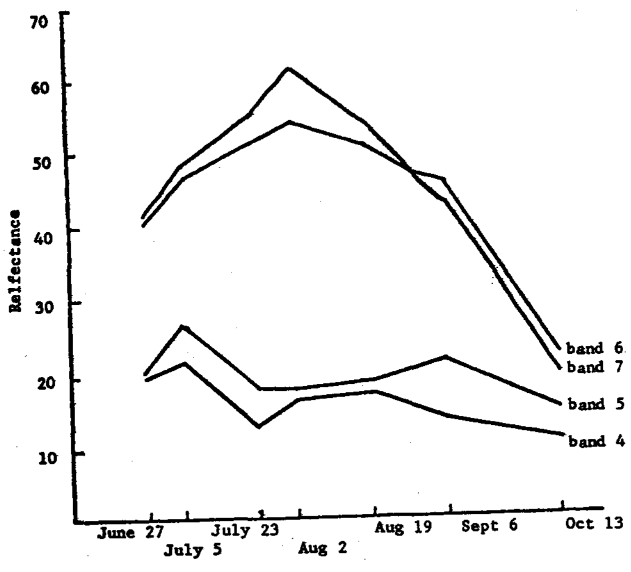

Figure 3a. Temporal Spectral Profile for Non-stressed Corn, Sac County Test Site, 1976

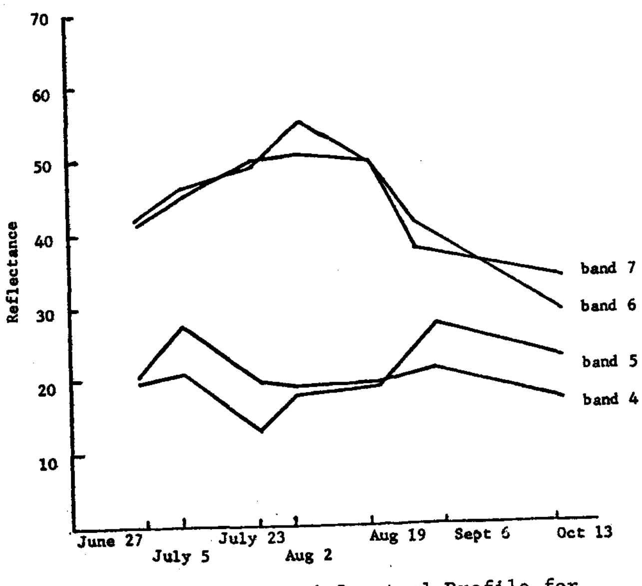

Figure 3b. Temporal Spectral Profile for Stressed Corn, Sac County Test Site, 1976

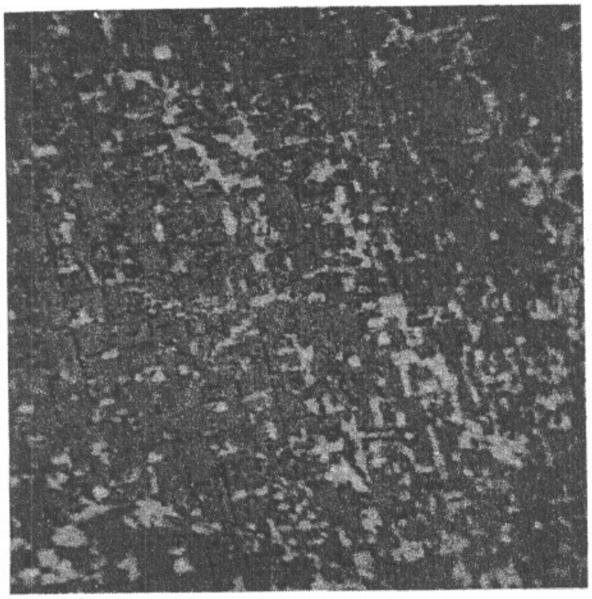

Figure 4. Classification of Stressed Corn, Sac County Test Site, July 23, 1976

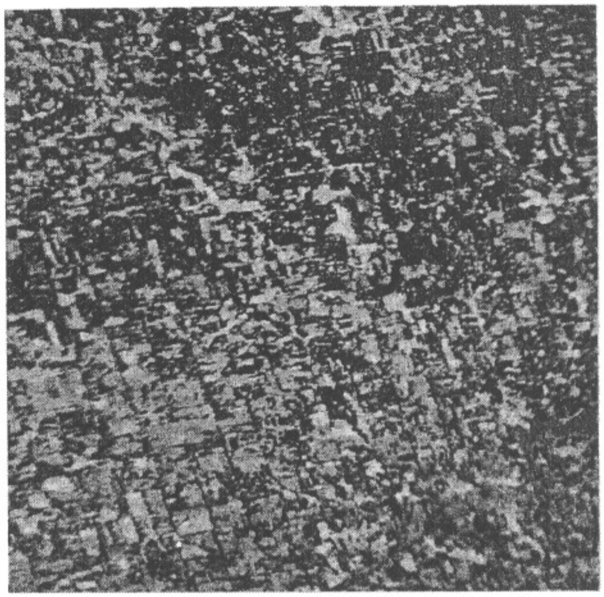

Figure 5. Classification of Stressed Corn, Sac County Test Site, September 6, 1976

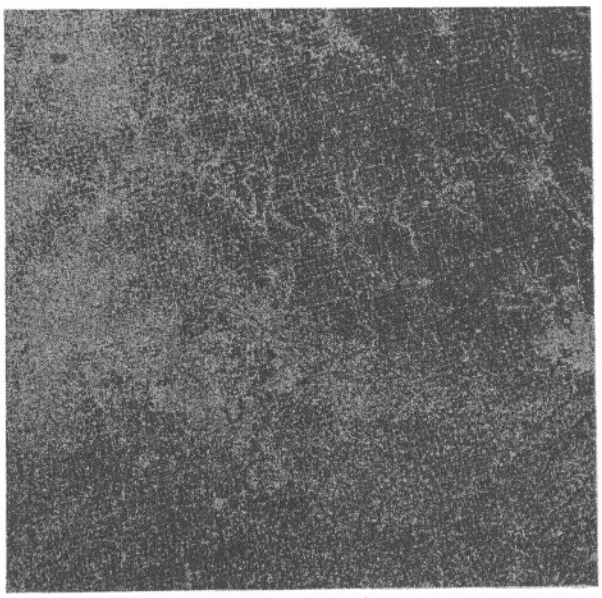

Figure 6. Bulk Classification of Stressed Corn, Landsat Scene #2575-16132, August 19, 1976

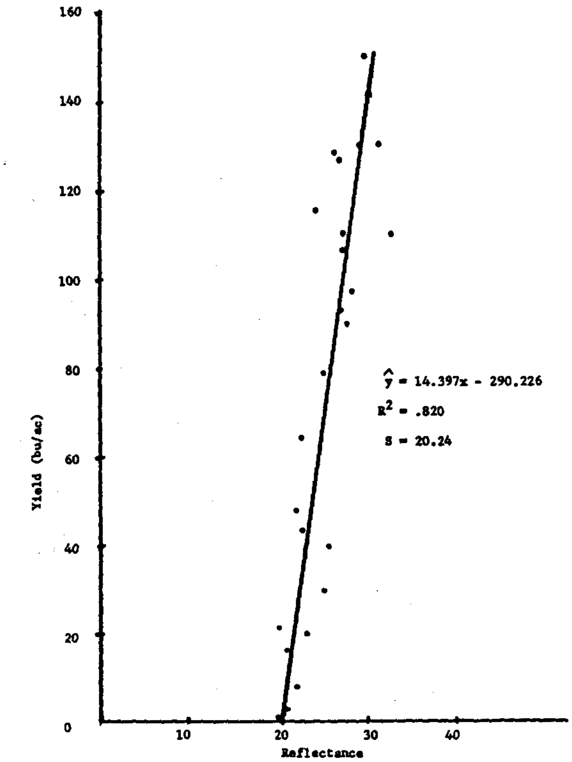

Figure 7. Relationship Between MSS Band 7 at Silking and Corn Yield

MSS Band	June 27	July 23	August 19	September 6
4	-.153	-.706*	-.659*	-.087
5	-.486**	-.705*	-.748*	-.099
6	.522*	.857*	.722*	.858*
7	.682*	.906*	.804*	.875*

* Significant at the .01 level
** Significant at the .05 level

Table 1. Correlation of Landsat Bands with Corn Yield

MSS Band Ratio	June 27	July 23	August 19	September 6
4/5	.591*	.606*	.254	.287
6/4	.564*	.900*	.808*	.729*
7/4	.621*	.922*	.841*	.642*
6/5	.558*	.869*	.805*	.137
7/5	.753*	.907*	.790*	.635*
6/7	-.465**	-.913*	-.819*	-.758*

* Significant at the .01 level
** Significant at the .05 level

Table 2. Correlation of Landsat Band Ratios with Corn Yield

Andrew Aaronson received his B.S. in Agricultural and Resource Economics from the University of Rhode Island in 1973 and his M.S. in Agricultural Economics from Rutgers University in 1975. He joined General Electric Earth Resources Analysis and Management Center in 1976 as an Earth Resources Analyst and has since been involved in defining mission requirements and systems design for future Landsat spacecraft. Mr. Aaronson's chief responsibilities are providing quantitative and statistical methods support to remote sensing applications.

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Peter E. Buchman is an Earth Resources Analyst at the General Electric Earth Resources Analysis and Management Center. He received his B.S. in Environmental Planning from Huxley College and his M.S. in Regional Planning from the University of Pennsylvania. Mr. Buchman's chief responsibilities are in computer and remote sensing applications for land capability analysis, geographic information systems, and environmental monitoring/modeling. Prior to joining General Electric in 1974, Mr. Buchman was an environmental and economic planning consultant.

Thomas Wescott received his B.A. in Physics from the State University of New York at Buffalo in 1968. He is currently an Earth Resources Engineer working in the area of digital image analysis and in the development of techniques for image analysis. He has been involved in the application of satellite imagery in agriculture, hydrology, land cover, forestry, and ocean bathymetry. Mr. Wescott has also been engaged in the development and use of radiometric techniques for the interpretation of multispectral photography.