AVHRR Monitoring of U. S. Crops During the 1988 Drought

*William L. Teng**
USDA Foreign Agricultural Service, Washington, DC 20250-1000

ABSTRACT: Effects of the 1988 drought on crops in the U.S. Corn Belt were assessed and monitored by the Foreign Crop Condition Assessment Division (FCCAD), U.S. Department of Agriculture. The primary data were vegetation index numbers (VINs), each of which was calculated as an average vegetation index of a geographically referenced cell of AVHRR pixels. Using VINs, the FCCAD was able to detect the existence of drought early in the season, monitor changing conditions, and provide objective assessments of the drought's extent and severity. Field observations confirmed the image analyses, and underlined the importance of the timing of extreme weather events with respect to crop stages for interpreting VINs. The analyses were conducted in an operational environment, providing a unique test of the AVHRR data for large area, near real-time crop monitoring. Because large area, operational remote sensing of crops is quite different from traditional, controlled, small plot research studies, more work is needed to link the two; this would improve crop assessment capabilities.

INTRODUCTION

THE 1988 GROWING SEASON was one of the driest and hottest in U.S. history. The major impact on crops was a decrease in production relative to that in 1987 of 30 percent for corn and 20 percent for soybeans (Final forecast, NASS (1988)). As part of its mission, the Foreign Crop Condition Assessment Division (FCCAD) of the U.S. Department of Agriculture's Foreign Agricultural Service assessed and monitored the 1988 drought and its effects on crops in the Corn Belt (Figure 1).

There have been many studies on the use of remotely sensed data to assess and monitor drought-affected vegetation (Thompson and Wehmanen, 1980; Tucker *et al.*, 1980; Brown *et al.*, 1982; Holben *et al.*, 1983; Tucker *et al.*, 1984; Jackson and Ezra, 1985; Henricksen and Durkin, 1986; Tucker and Choudhury, 1987). Several of these were based on field radiometer data that approximated channels 1 and 2 of the Advanced Very High Resolution Radiometers (AVHRR, 0.58 to 0.68 μm and 0.725 to 1.10 μm, respectively) carried on the National Oceanic and Atmospheric Administration (NOAA) polar-orbiting meterological satellites. Their results generally showed that the spectral response of vegetation canopy to drought stress was due to physiological and anatomical changes in the leaf and, to a lesser extent, geometrical changes in the canopy (Tucker *et al.*, 1980; Holben *et al.*, 1983; Jackson and Ezra, 1985). These changes increased red reflectance by reducing red absorption in the leaf chlorophyll.

A few of the studies have used AVHRR Local Area Coverage (LAC, 1.1-km resolution at nadir) data to assess agricultural drought in a temperate environment. None, however, has monitored an ongoing drought, which was the focus of the work reported here. This paper documents a unqiue test of the applicability of AVHRR LAC data for operational, large area, near real-time assessment and monitoring of a major crop disaster. The focus is on four states in the Corn Belt—Iowa, Illinois, Indiana, and Ohio (Figure 1). These states produce approximately half of the total U.S. corn and soybean output (SASS, 1988a); thus, results from these areas should provide a good indication of the overall condition of the crops.

OPERATIONAL PROCEDURE

The FCCAD's general operational procedure for monitoring crop condition has been described by Philipson and Teng (1988). In brief, the FCCAD calculates a Normalized Vegetation Index (NVI) from the AVHRR data: channel 2 minus channel 1 divided by the sum of the two channels. The input data values for channels 1 and 2 are converted to percent albedo using NOAA-supplied coefficients (Kidwell, 1988); multiplied by 10 to "stretch" for display; and truncated, whereby values above 255 are set to 255 and values below 0 are set to 0. The pixels are then screened for clouds, based on threshold values of both channels. Those pixels with values below the threshold—the "good" pixels—are accumulated in a geographically referenced grid, whose cells are nominally 46.3 km on a side. Good pixels for which channel 2 minus channel 1 is greater than a defined minimum value of 25.0—the "green" pixels—are also accumulated in each cell. In the FCCAD system, cell vegetation index numbers (VINs) are calculated only from green pixels, and VINs are not stored in the database unless they are derived from cells with at least 80 percent good pixels. For the 1988 drought analysis, only cells with at least 92 percent good pixels were used. Atmospheric effects are accounted for only to the extent of visually screening the images for haze-affected areas and deleting the cell VINs calculated from those areas. AVHRR scan angle effects are reduced by limiting the cell VIN calculations to approximately the middle 50 percent of the total swath width.

The time series of VINs, or "VIN curves," for 1988 were monitored from the time of crop emergence in April through crop senescence in October. The VIN curves were interpreted qualitatively by visually comparing them with those of previous years, following the procedure described by Philipson and Teng (1988). Although AVHRR VINs from both NOAA-9 and NOAA-10 satellites were available, the NOAA-9 data were emphasized because there were more years of data for comparison.

In comparing VIN curves, their integrals (areas under the curve) for different time periods were also estimated qualitatively. Tucker *et al.* (1980) divided VIN curves into four periods and found that the integrated period of maximum VINs (corresponding to maximum green leaf biomass) was most highly correlated with the final yield. Boatwright *et al.* (1988) constructed spectral yield models of corn and soybeans based on the relationship of yield with areas under the VIN curve for selected time periods. Although these results have yet to be implemented in the FCCAD system, they provide a basis for incorporating the concept of areas under the curve into the VIN curve analysis.

The interpretation of VIN curves was done while considering (1) crop stage estimates (from weekly state crop and weather reports and visual interpretation of satellite images), (2) crop

* Presently with ST Systems Corporation, Goddard Space Flight Center, Code 675, Greenbelt, MD 20771.

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 56, No. 8, August 1990, pp. 1143–1146

0099-1112/90/5608–1143$02.25/0

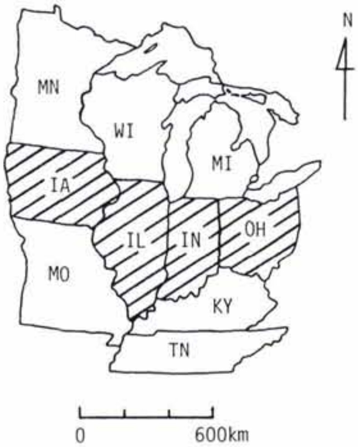

FIG. 1. U.S. Midwest Corn Belt. MN-Minnesota; WI-Wisconsin; MI-Michigan; IA-Iowa**; Il-Illinois**; IN-Indiana**; OH-Ohio**; MO-Missouri; KY-Kentucky; TN-Tennessee. **Major crop production states discussed in text and shown in Figure 2.

mix and distribution (from state statistics), (3) precipitation and temperature data, and (4) soil moisture model results. Confirmation of drought effects was obtained in the field during a crop evaluation tour as well as through observations by other travelers, local news, and state reports.

ANALYSIS AND INTERPRETATION OF AVHRR VINS

The AVHRR VINs provided clear indications of the drought early in the 1988 season, particularly in the eastern part of the Corn Belt. Figure 2a shows the four major states with grid cells rated as one of three levels of crop condition relative to those of 1987—similar or somewhat worse, worse, and much worse. These levels were visually interpreted from a comparison of 1988 and 1987 VIN curves (NVI) as of early June. The distribution of drought-affected areas derived from the AVHRR data only generally matched the distribution derived from the Crop Moisture Index (CMI) and the Drought Severity Index (DSI), which are short-term and long-term meteorological measures of drought, respectively (NOAA and USDA, 1988). This difference in distribution had been noted previously (Thompson and Wehmanen, 1980; Walsh, 1987). The result should be expected, because both the CMI and DSI are based on discrete meteorological data that are not directly related to factors influencing the spectral response of vegetation.

Figure 2b shows the situation as of late July-early August. During this period, the contribution of soybeans to the cell VIN generally surpassed that of corn, and the VIN was near peak. Corn was mostly past the critical stages of tasseling and silking, while soybeans were mostly in the critical stage of pod filling.

In general, crop condition in the Corn Belt worsened from west to east. This was clearly evident in early June (Figure 2a) and remained so through the crop season, even though the areas of worse to much worse conditions (relative to 1987) expanded as the drought intensified (Figure 2b). The early drought effects on crops—delayed planting, germination, and emergence—were most apparent in Indiana and Ohio. Figures 3a to 3f are examples of cell VIN curves (NVI) from the four states showing the variation in crop condition. The November yield forecasts (SASS, 1988b) also showed a general decrease from west to east, except for Illinois, which received less precipitation than did the neighboring states.

VINs for northeast Indiana and northwest Ohio provided the earliest firm indication of a major crop disaster (Figures 3d and 3e). This was especially the case in northwest Ohio where crop condition was already below average in 1987. Because the crops in June were not yet in their critical stages with respect to moisture demand, a partial recovery later in the crop season could not be completely ruled out at the time. However, given the extraordinarily low VINs in June and the concurrent dry weather forecasts, it was concluded that the poor crop condition would probably persist or worsen through corn pollination in early to mid-July. This was the case, although precipitation that occurred from late July through August (corresponding to the increase in VINs in Figures 3d and 3e) helped to generally improve the yield prospects.

In Iowa, there was a shifting boundary between relatively good crop condition towards the north and west and relatively bad crop condition towards the south and east. Although the broad levels of crop condition shown in Figure 2a did not show this boundary in early June, it was apparent in the corresponding AVHRR images. By late July-early August, the southwest-northeast trending boundary was distinct (Figure 2b). Field information from travelers crossing the boundary in early August confirmed the sharp change in crop condition. Figure 3f is a VIN curve for a cell that is about 80 km east-southeast from the cell in Figure 3a (cell center to cell center); it shows an early decrease in VINs and a corresponding narrow peak. The presence of the area of relatively good crop condition was eventually recognized, as indicated by the increased October yield forecasts for Iowa corn and soybeans (SASS, 1988b).

The interpretation of VINs was mostly consistent with field observations as well as crop forecasts. Many of the observed, adverse effects of the drought and high temperatures influence

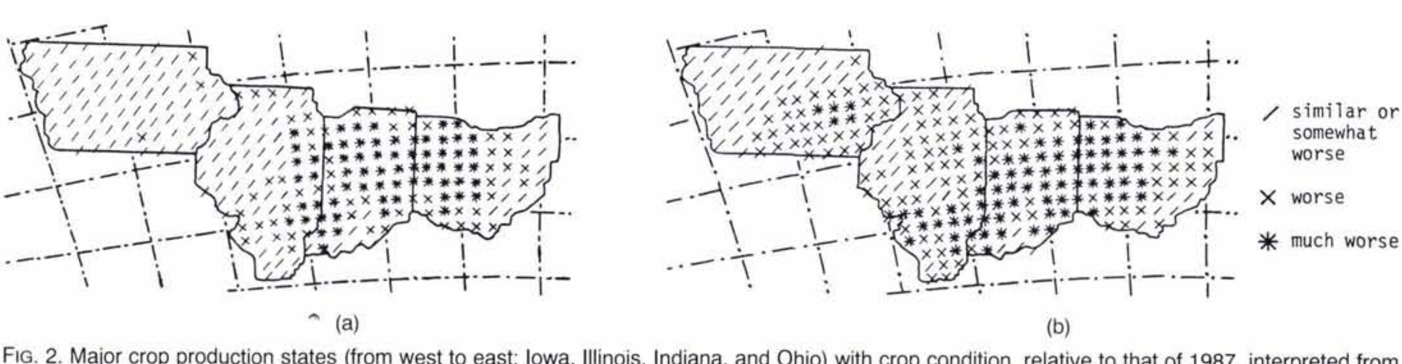

FIG. 2. Major crop production states (from west to east: Iowa, Illinois, Indiana, and Ohio) with crop condition, relative to that of 1987, interpreted from AVHRR VINS (NVI) as of (a) early June and (b) late July-early August, 1988. Grid lines are shown for every fifth 46.3- by 46.3-km cell.

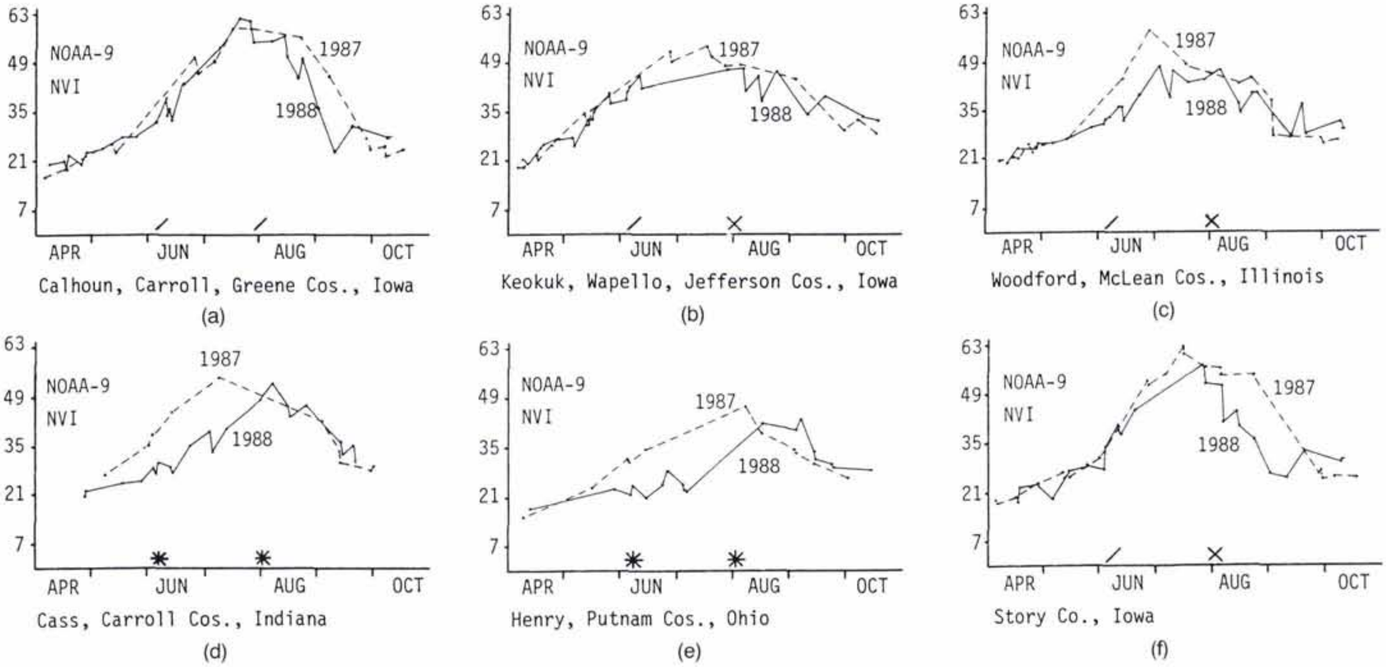

FIG. 3. Normalized vegetation index (NVI) curves of cells overlying parts of the indicated counties. VINs are derived from NOAA-9 AVHRR data. The symbols along the time axis of each curve represent interpreted levels of crop condition (*cf.* Figure 2) as of early June and late July-early August, 1988.

the VINs. These included low plant populations, uneven stands, small kernals and beans, weeds, spider mites, and smut.

DISCUSSION

Each VIN in the FCCAD database represents the averaged spectral response of all vegetation in a geographically referenced cell of mixed AVHRR pixels (Philipson and Teng, 1988). Despite the large area represented by each cell, the cell VINs proved adequate for the successful assessment and monitoring of crops during the 1988 drought in the Corn Belt.

As previously noted, however, it is important that other factors affecting crop condition be considered when interpreting VIN curves. This is because cell VINs represent the total vegetative spectral response, which depends on many factors. Although meteorological data are important in general, it is the extreme weather events and their timing with respect to crop stage that are critical. In 1988, for example, the damage to corn was due to dry and hot conditions, but the critical factor was the occurrence of these conditions during the pollination stage in early to mid-July (Aldrich *et al.*, 1975). The 1987 season was also fairly dry in the Corn Belt (although not nearly as dry as the 1988 season), but the precipitation was timely.

The comparison of multi-year VINs that do not correspond to the same crop stage is a problem. Currently, crop calendar information is acquired from various field sources and image interpretation. The information is used to qualitatively adjust for differing crop stages. The use of VIN curves based on growing degree days rather than calendar days might serve as a substitute for crop calendar information and improve the interpretation of the curves (Tucker *et al.*, 1980). This follows from the basic relationship of temperature to biological activity and, specifically, to crop development.

There are several factors that are not currently, strictly accounted for in comparing VIN curves. The problem of differing seasonal rates of crop development was noted. The mix and proportion of different vegetation types in each cell may not be constant or nearly constant from year to year. The extent to which changes in mix and proportion affect the multi-year VIN curve comparison needs to be determined.

To improve the visual interpretation of VIN curves, it would be useful to smooth them in some way. The jaggedness of the curves (Figures 3a to 3f) is probably due to a combination of factors related to the sensor, atmosphere, and vegetation. To correct or account for all of them is not currently feasible, at least in an operational environment. Van Dijk *et al.* (1987) have proposed a promising method to smooth the VIN curve so as to reduce some noise in the AVHRR data without detailed knowledge of the causes of the noise.

One serious problem in crop monitoring is the comparison of VINs derived from different sensors (e.g., AVHRR on NOAA-9 and NOAA-10). Some work has been done for the FCCAD on empirically converting AVHRR VINs derived from one NOAA satellite to VINs from another; however, the conversions remain to be tested. A longer-term and more fundamental solution is the intercalibration of the various sensors (Price, 1987).

The requirements of an operational monitoring program introduce certain constraints on the application of remote sensing that are not usually present in a controlled, small plot research environment. These include near real-time response, large areal and frequent coverage, and large amounts of data processing and storage. Also, because the responsibilities for data processing, analysis, and storage are often divided among different groups, changes in the operational procedure can be difficult to implement. Thus, the problems of incorporating new research findings rest not only on the inherent differences in constraints and priorities between research and application, but also on the nature of the operational organization. More work remains on linking the two environments, so as to improve crop monitoring capabilities.

CONCLUSIONS

The experience of the FCCAD in assessing and monitoring the effects of the 1988 drought on crops in the U.S. Corn Belt has shown that vegetation index numbers, averaged over geographically referenced cells of mixed AVHRR pixels, are adequate for large area, operational monitoring of crops. The usefulness of the AVHRR data is most apparent in monitoring the effects of episodic weather events on crops.

ACKNOWLEDGMENT

The author is grateful for the review and comments provided by Warren Philipson of Cornell University. The views expressed herein are those of the writer, and do not necessarily reflect official positions of the Foreign Agricultural Service of the U.S. Department of Agriculture.

REFERENCES

Aldrich, S. R., W. O. Scott, and E. R. Leng, 1975. *Modern Corn Production*. 2nd ed. Champaign: A & L Publications. pp. 20–21.

Boatwright, G. O., G. D. Badhwar, and W. R. Johnson, 1988. *An AVHRR Spectral Based Yield Model for Corn and Soybeans*. Final Report, Project No. 8103, 'USDA-AVHRR Data." USDA-ARS, Beltsville, Maryland.

Brown, R. J., M. Bernier, G. Fedosejevs, and L. Skretkowicz, 1982. NOAA AVHRR crop conditions monitoring. *Can. J. of Remote Sensing*. 8:2:107–117.

Henricksen, B. L., and J. W. Durkin, 1986. Growing period and drought early warning in Africa using satellite data. *Int'l. J. of Remote Sensing*. 7:11:1583–1608.

Holben, B. N., J. B. Schutt, and J. McMurtrey, III, 1983. Leaf water stress detection utilizing thematic mapper bands 3, 4 and 5 in soybean growth. *Int'l. J. of Remote Sensing*. 4:2:289–297.

Jackson, R. D., and C. E. Ezra, 1985. Spectral response of cotton to suddenly induced water stress. *Int'l. J. of Remote Sensing*. 6:1:177–185.

Kidwell, K. B., 1988. *NOAA Polar Orbiter Data Users Guide*. NESDIS, NOAA, Wash., D.C.

NASS, 1988. National Agricultural Statistics Service, U.S. Dep't. of Agriculture, Wash, D.C.

NOAA and USDA, 1988. *Weekly Weather and Crop Bulletin*, June 14. 75:24. Wash., D.C.

Philipson, W. R., and W. L. Teng, 1988. Operational interpretation of AVHRR vegetation indices for world crop information. *Photogrammetric Engineering and Remote Sensing*. 54:1:55–59.

Price, J. C., 1987. Calibration of satellite radiometers and the comparison of vegetation indices. *Remote Sensing of Environ*. 21:15–27.

SASS, 1988a. *Annual Reports*. State Agricultural Statistics Service of Iowa (Des Moines), Illinois (Springfield), Indiana (W. Lafayette), and Ohio (Columbus).

———, 1988b. *Farm Reports*. State Agricultural Statistics Service of Iowa, Illinois, Indiana, and Ohio.

Thompson, D. R., and O. A. Wehmanen, 1980. Using Landsat digital data to detect moisture stress in corn-soybean growing regions. *Photogrammetric Engineering and Remote Sensing*. 46:8:1087–1093.

Tucker, C. J., and B. J. Choudhury, 1987. Satellite remote sensing of drought conditions. *Remote Sensing of Environ*. 23:2:243–251.

Tucker, C. J., J. A. Gatlin, and S. R. Schneider, 1984. Monitoring vegetation in the Nile Delta with NOAA-6 and NOAA-7 AVHRR imagery. *Photogrammetric Engineering and Remote Sensing*. 50:1:53–61.

Tucker, C. J., B. N. Holben, J. H. Elgin, Jr., and J. E. McMurtrey, III, 1980. Relationship of spectral data to grain yield variation. *Photogrammetric Engineering and Remote Sensing*. 46:5:657–666.

Van Dijk, A., S. L. Callis, C. M. Sakamoto, and W. L. Decker, 1987. Smoothing vegetation index profiles: an alternative method for reducing radiometric disturbance in NOAA/AVHRR data. *Photogrammetric Engineering and Remote Sensing*. 53:8:1059–1067.

Walsh, S. J., 1987. Comparison of NOAA AVHRR data to meteorologic drought indices. *Photogrammetric Engineering and Remote Sensing*. 53:8:1069–1074.

(Received 2 August 1989; accepted 16 October 1989)