2-1 PN-AAW-877

ISN-49669

Aflatoxin in Maize

A Proceedings of the Workshop

El Batan, Mexico, April 7-11, 1986

Sponsored by: CIMMYT, UNDP and USAID

The International Maize and Wheat Improvement Center (CIMMYT) is an internationally funded, nonprofit scientific research and training organization. Headquartered in Mexico, CIMMYT is engaged in a worldwide research program for maize, wheat, and triticale, with emphasis on food production in developing countries. CIMMYT is one of 13 nonprofit international agricultural research and training centers supported by the Consultative Group for International Agricultural Research (CGIAR). The CGIAR is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR consists of 40 donor countries, international and regional organizations, and private foundations.

CIMMYT receives support through the CGIAR from a number of sources, including the international aid agencies of Australia, Austria, Brazil, Canada, China, Denmark, Federal Republic of Germany, France, India, Ireland, Italy, Japan, Mexico, the Netherlands, Norway, the Philippines, Saudi Arabia, Spain, Switzerland, United Kingdom and the USA, and from the European Economic Commission, Ford Foundation, Inter-American Development Bank, International Bank for Reconstruction and Development, International Development Research Centre, OPEC Fund for International Development, Rockefeller Foundation, and the United Nations Development Programme. Responsibility for this publication rests solely with CIMMYT.

Correct Citation: Zuber, M.S., E.B. Lillehoj, and B.L. Renfro, eds. 1987. Aflatoxin in Maize: A proceedings of the workshop. CIMMYT, Mexico, D.F.

ISBN 968-6127-12-7

Acknowledgements

We are thankful to several organizations, groups and individuals for making significant contributions to the success of the workshop on the aflatoxin problem in maize and the publication of this proceedings. We are grateful to the participants for the preparation of papers and for their deliberations which resulted in the recommendations included in the proceedings. The US University Collaborative Maize Research Working Group is to be commended for their proposal that this workshop be held and for their continuous support since that time.

Support for travel and living costs is gratefully acknowledged from CIMMYT, the United Nations Development Programme and USAID. The three of us also value the encouragement and support given to us by our directing staffs. The Visitor Services of CIMMYT deserve special thanks for making the participants comfortable and for handling the workshop organization and activities so efficiently.

The skillfull editorial work by Elizabeth Cuéllar, as well as the editorial assistance of Kelly Cassaday, is valued highly. We also thank CIMMYT Communications staff members Patricia Martinez, Maricela A. de Ramos and Silvia Bistrain for typesetting; Miguel Mellado E., Rafael de la Colina, José Manuel Fouilloux, and Bertha Regalado for providing the design and layout of this proceedings, and Alma McNab for overseeing the translations of papers and abstracts.

M.S. Zuber
E.B. Lillehoj
B.L. Renfro
Workshop Organizers

Forecasting Vegetative Stress Via Remote Sensing Techniques

C.J. Johannsen, Agricultural Data Network, and K.J. Ranson, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana, USA

Abstract
The ability to detect plant stress from space-borne platforms has become more promising because of increasing knowledge about stress (chlorophyll and temperature changes) and the development of better instruments. The recent Landsat satellites with thematic mappers (TM) and the Spot satellite with improved resolution promise better detection of stress, although these intruments still require a cloud-free day for acquiring data. Future satellite instruments, such as those proposed in the Earth Observation System (EOS), which will be placed on the Space Station in about 1994, offer further possibilities for detecting stress. Models that use climatological as well as remote sensing data are encouraging for predicting areas of stress. It should not be necessary to wait until plants are strongly affected before knowing about drought conditions.

Resumen
La capacidad de detectar (mediante los cambios en la clorofila y la temperatura) desde plataformas espaciales los efectos que las condiciones ambientales adversas tienen en las plantas se ha convertido en una posibilidad real a causa de los mayores conocimientos que se tienen acerca de estos efectos y la creación de mejores instrumentos. Los nuevos satélites Landsat, provistos de planímetros temáticos (PT) y el satélite Spot, con una mejor resolución de imagen, prometen una mejor detección, aunque todavía se requieren días despejados para que estos instrumentos puedan obtener información. Los instrumentos de satélite del futuro, como los propuestos en el Sistema de Observación de la Tierra (SOT), que se colocarán en la Estación Espacial alrededor de 1994, ofrecen nuevas posibilidades de detección. Los modelos que emplean información climatológica y de detección a distancia ofrecen muchas posibilidades para predecir las áreas donde las plantas pueden estar experimentando los efectos de las condiciones adversas. No debería ser necesario esperar a que las plantas den muestras de estar seriamente afectadas para determinar que hay sequía.

Recent research in remote sensing shows that much has been learned about crop identification and the delineation of maturity stages, cultural practices and stress (2). These achievements have come about because of the design and construction of better remote sensing instruments, an improved understanding of the interaction of soil and vegetation, and the refinement of analysis techniques. This paper will consider remote sensing, use of data bases and geographic information systems, as well as the extent to which vegetation (especially maize) and vegetation stress can be identified. Finally, the promise of future work on modeling for stress detection will be evaluated.

Remote Sensing

Remote sensing is the science and art of acquiring information about material objects from measurements made at a distance and without physical contact; included in this definition are photography, scanning images, radar, sonar and similar data-gathering techniques.

An important extension of the definition is data extraction or analysis to obtain useful information. Data acquired by remote sensing are measurements of variations in the electromagnetic energy that may reveal spectral, spatial and temporal variations in the scene (15). Researchers need to think seriously about these variations before planning to acquire or use a remote sensing product. An agricultural scene, for example, can be identified by the color of light emanating from it (spectral variations), by the relatively uniform shapes of local crop fields (spatial variations), by the way in which the scene changes during the growing season (temporal variations), or by a combination of these factors.

Frequent reference is made in remote sensing articles to the electromagnetic spectrum (Figure 1). The optical

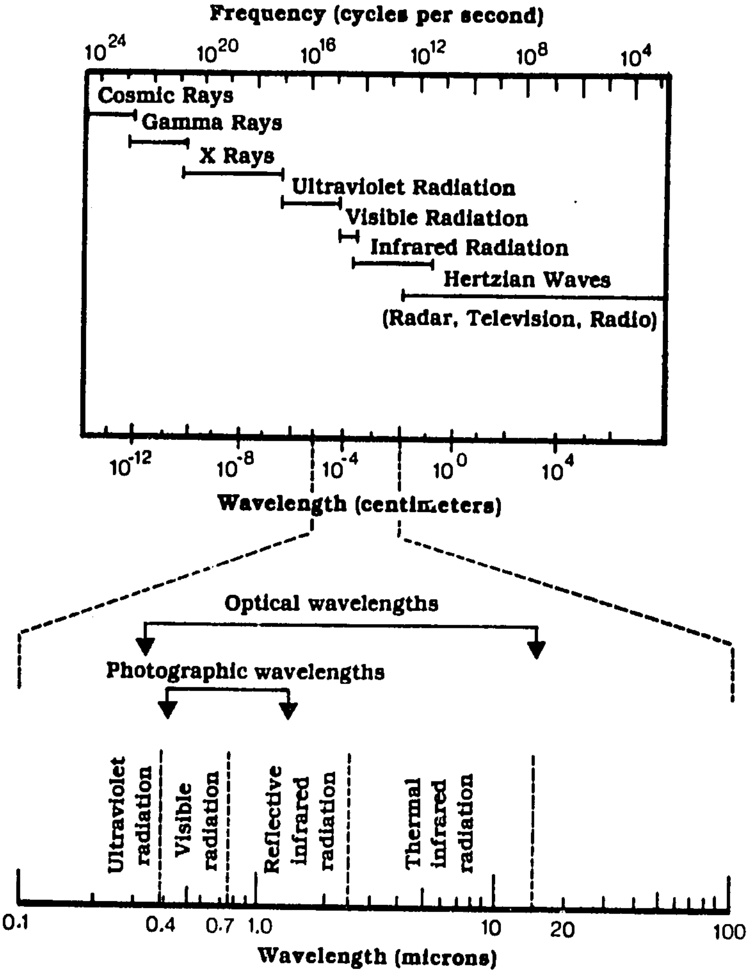

Figure 1. The electromagnetic spectrum; the lower part emphasizes the regions of primary importance to most remote sensing users

Note the relatively small range of wavelengths to which the eye is sensitive

wavelength portion of this spectrum covers the range of 0.3 to 15.0 micrometers. The visible portion (0.4 to 0.7 micrometers) is the most familiar to us since this is the range to which the human eye is sensitive. Wavelengths below 0.4 micrometers are ultraviolet readings and have little value to land surface remote sensing, since much of the energy in these wavelengths is absorbed by the atmosphere. Those wavelengths from 0.7 to approximately 3.0 micrometers are called the reflective infrared; the region from 3.0 to 15.0 micrometers is the emmisive or thermal infrared region. Wavelengths above 1 cm are in the microwave region. This region, where data are collected by passive microwave and radar sensors, has become more important in recent years because of improved design and collection capabilities, providing the opportunity to collect data on cloudy days, since measurements from optical wavelengths are limited to cloud-free days.

Remote sensing in agriculture began when the US National Aeronautics and Space Administration (NASA) provided funds to the US Department of Agriculture (USDA), and research was initiated at the University of California at Berkley; the University of Michigan; the Agricultural Research Service station at Wesleco, Texas; and the Laboratory for Agricultural Remote Sensing (LARS) at Purdue University, West Lafayette, Indiana. Measurements were made of plants and soils in the laboratory and field using spectrometers and radiometers. The first aircraft scanner data over the Purdue Agronomy Farm were obtained with the University of Michigan aircraft in 1965. Other US universities initiated remote sensing work in the late 1960s and early 1970s.

The first satellite data were actually obtained from the Apollo flights in 1964. A scene over the Imperial Valley in California was digitized and analyzed by Anuta *et al.* (1). Landsat data were first analyzed in 1972 with 80-meter (0.64 ha) resolution followed by thematic mapper (TM) data of 30-meter (0.09 ha) resolution from Landsats 4 and 5, which are currently operating. The French launched the Spot Satellite in February, 1986, and it will provide 10-meter (0.01 ha) resolution data. The National Oceanographic and Atmospheric Administration (NOAA) GOES satellites with their advanced very high resolution radiometer (AVHRR) became available in 1980, giving scientists the opportunity to map vegetation on a global basis with spatial resolutions of 1 and 4 km.

Data Bases and Geographic Information Systems

The techniques available for analyzing remotely sensed data have been reviewed by Reeves (19), Swain and Davis (20) and Bauer (2). In particular, ancillary data, such as surface observations, soil maps and weather information can be combined with remotely sensed data. When this information is correlated in an orderly format (for example, geographically arrayed by a computer) it is referred to as a data base.

An example of the use of a data base would be the combination of elevation data with Landsat data (8). In mountainous terrain, certain tree species exist within certain elevation ranges. Therefore, digital, geographically oriented topographic data can be merged with Landsat data to separate species that appear spectrally similar.

Data bases also permit more flexibility in the use of remotely sensed data as well as ancillary data. Weismiller and colleagues (25) spatially registered Landsat data at a scale of 1:24,000 and overlaid this with digitized township, watershed and physiographic boundaries. This technique allowed separation of soil associations by three landscape positions; the data base can also delineate by categories the hectares of soil and vegetation by slope group and by watersheds. The accuracy of runoff estimates in watershed analysis is greatly increased by this approach (12).

With the addition of temporal remotely sensed data and ancillary data, land cover can be determined by soil type, soil interpretations can be provided, erosion hazard areas determined, land use changes charted and a variety of other applications done. Some of these data base applications can be obtained without using remote sensing data directly.

Developing data bases ultimately leads to the need for geographic information systems (GIS). A GIS is a formal process for gathering, storing, analyzing and disseminating information about natural resources and socioeconomic data (8). Many resource scientists have found that such a system provides a cost-effective procedure for planning, developing and organizing natural resources research.

Identification of vegetation

From its beginnings in the 1960s, remote sensing in agricultural research has concentrated on crop identification. Early work, extensively reviewed by Colwell (4), concentrated on physiological studies of individual plant leaves. The interaction of electromagnetic energy with individual leaves becomes increasingly complex in an assemblage of leaves in a crop canopy. Efforts have centered on parameters to determine the reflectance of a vegetative canopy, including:

- Transmittance of leaves;
- Number and arrangement of leaves;
- Characteristics of other components of the vegetation canopy (stalks, trunks, limbs);
- Characteristics of the background, such as reflectance of soil and residues;
- Solar zenith angle;
- Look angle; and
- Azimuth angle

A series of regional and global projects was conducted to provide a focus on agricultural remote sensing and to improve the technology. These programs were the Corn Blight Watch Experiment (18), the Crop Identification Technology Assessment of Remote Sensing (CITARS) project (7), the Large Area Crop Inventory Experiment (LACIE) (17) and the AgRISTARS program (6). Through these programs, researchers developed and refined analysis techniques and began use of multitemporal data with a national focus on remote sensing by a number of federal agencies, including NASA, NOAA, the USDA and the US Department of State.

This research determined that it was difficult to quantify reflectance for a specific crop because of dynamic changes due to growth, development stages, stress and varying cultural practices. Therefore, instead of focusing on a specific crop, remote sensing scientists devoted their attention to such research factors as leaf area index (LAI), percent soil cover and leaf angle distribution (LAD) (2).

Identification of stress

Vegetative stress may be described as an adverse condition imposed on the plant from biological or environmental factors. Crop growth and yield are influenced by light, carbon dioxide supply, temperature, water supply and nutrients interacting with the genetically determined biochemical and physiological systems of the plant. When changes in any one of these factors exceed the ability of the plant to compensate, growth and yield are reduced and the limiting factor constitutes stress (14).

The effects of stress on a plant can be manifested in a variety of ways that may be detected by remote sensing technology. Desiccation of plant tissue causes changes in cellular composition and structure which affect the reflectance of sunlight (14). For example, Figure 2 shows that reflectance measured from maize leaves increases as leaf moisture content decreases (9). These changes in reflectance are accompanied by changes in the plant canopy, such as the wilting of soybean leaves or rolling of maize leaves. Changes in plant architecture, while conserving water in the plant, also produce changes in composite (plant + soil) reflectance that can be detected from aircraft and satellite-borne instruments.

Nutrient deficiency is another form of stress that produces characteristic reflectance patterns. Plants deficient in nitrogen tend to have reduced chlorophyll density and consequently reduced absorption of red light (0.68 μm) (16). In addition, nitrogen-stressed plants will have less foliage than normal plants; the result is higher canopy reflectance in the red band and lower reflectance in the near- and middle-infrared regions. The composite effect of reduced nitrogen levels on reflectance of maize is illustrated in Figure 3.

A useful indicator of stress in plants is the relative change in the amount of green leaves or phytomass. Transformations of spectral data that utilize chlorophyll absorption (Red) and near-infraded (NIR) wavelengths have been shown to be sensitive to leaf area and phytomass. The ratio of NIR to Red (NIR/Red) spectral data and the normalized difference (NIR - Red)/(NIR + Red) are two commonly used vegetation indices (18). Figure 4 presents the relationships of NIR/Red with maize canopy LAI and phytomass from data acquired at the Purdue

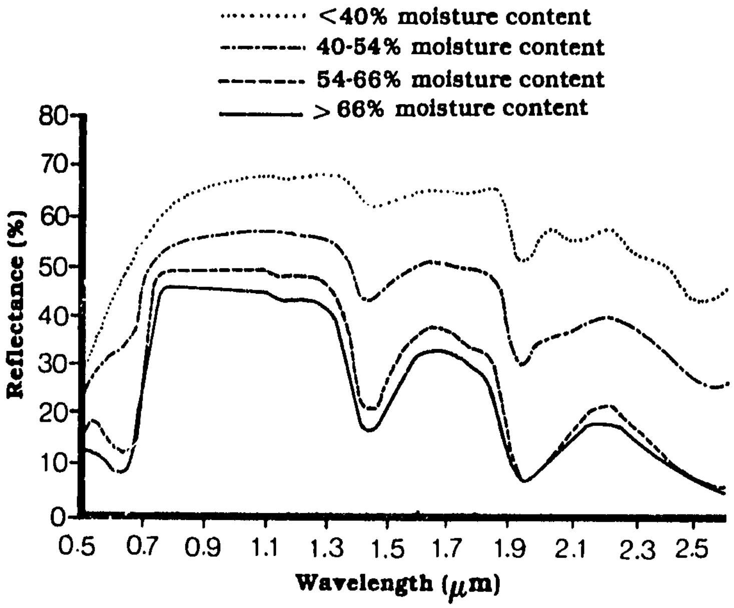

Figure 2. Spectral reflectance of maize leaves with different moisture contents

Source: Hoffer and Johannsen (9).

Agronomy Farm. Tucker and co-workers have demonstrated the feasibility of monitoring global changes in green phytomass using AVHRR data transformed to normalized differences (19,20). The effects of sun angle, look angle, atmosphere, and canopy structure are known to affect the usefulness of vegetation indices. Research to correct for these effects continues in NASA, NOAA and the USDA.

Plant temperature is also known to vary with stress. If transpiration is reduced by a deficit of water, damage from disease or insects to conducting vessels, or by excess soil water salinity, then the net result is an increase in plant temperature (10). Instruments sensitive to thermal infrared portions of the spectrum (8 to 14 μm) can be used to detect crop temperatures. For example, experiments using thermal-infrared scanners and ground observations have demonstrated that recently irrigated crops were up to 20°C cooler than nonirrigated portions of the same field (24). Jackson and colleagues have developed a crop water stress index based on a linear relationship between the difference in air temperature, remotely measured canopy temperature and air vapor pressure deficit (11). These relationships suggest that remotely sensed temperatures of crops, coupled with meteorological parameters, may be used to effectively monitor stress over large areas. These techniques may be limited in areas where meteorological ground stations are scarce.

Modeling for Stress Detection

The task of detecting and recognizing stress in crops is made more difficult by the natural variability in the scene

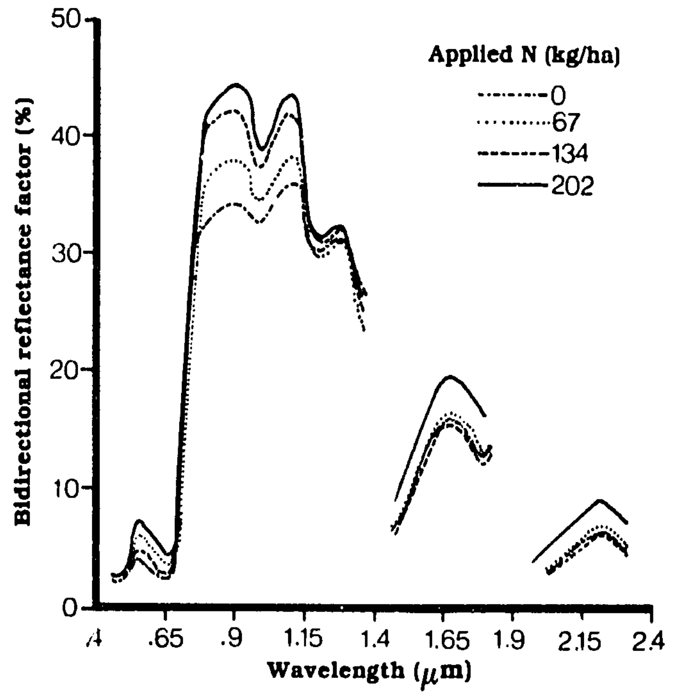

Figure 3. Spectral reflectance of maize grown with different levels of applied nitrogen

Source: Walburg *et al.* (23).

which may mask subtle stress-induced changes in crop reflectance or temperature. In the most promising techniques for monitoring stress, models are used that indicate the stress potential for a given crop and region. The Energy Crop Growth (5) and Crop Water Stress Index (11) models have been used to assess crop stress and production. The early warning and crop condition assessment project under the NASA AgRISTARS program developed crop stress indicator models that combine satellite observations with daily precipitation, maximum and minimum

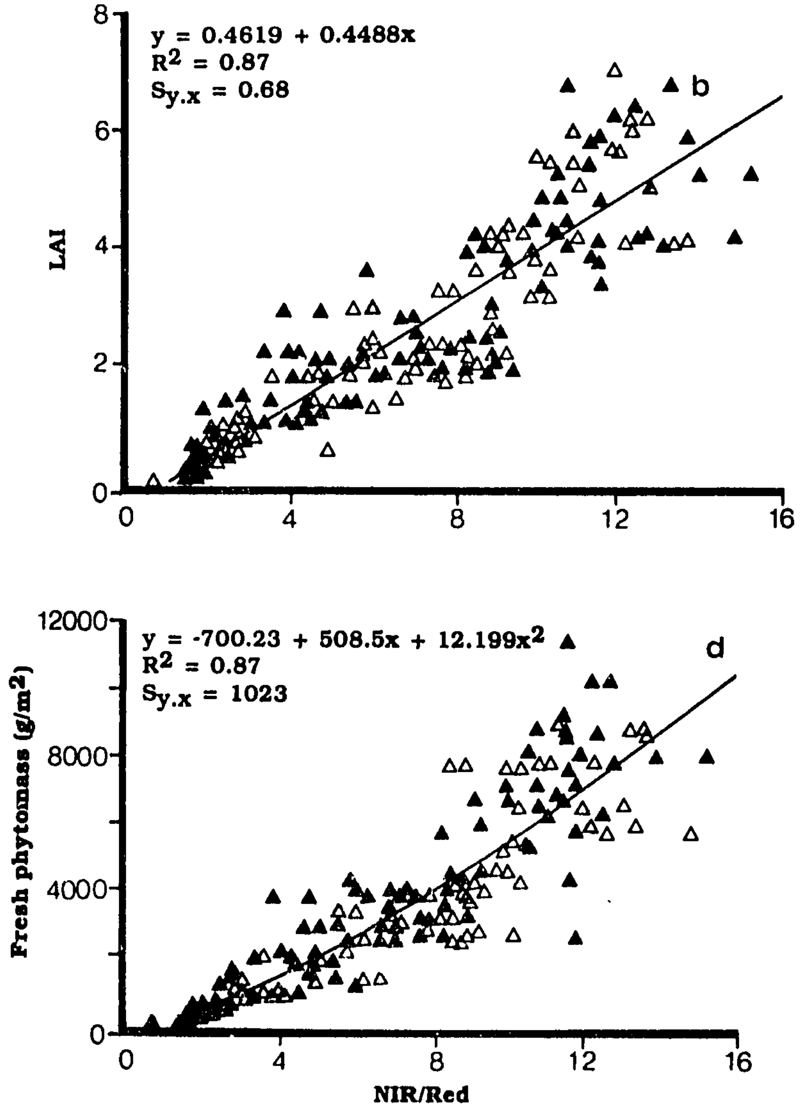

Figure 4. Relationship of maize leaf area index (LAI) and fresh phytomass to the ratio of near-infrared to red (NIR/Red) reflectance

temperatures, evapotranspiration and solar radiation (3). In addition, a satellite-derived stress index was developed using day and night temperatures obtained from NOAA weather satellites and ground-measured air temperatures. This index approximates the ratio of actual to potential evapotranspiration, which is related to crop water stress (25). The application of this technique has been limited to areas with a good network of ground meteorological stations; however, the concept has global implications.

One of the most significant developments of crop assessment models is the derived capability to combine a referenced data base with a geographic information system. This makes it possible to produce computer-generated maps that pinpoint areas where the potential for crop stress may be high.

References

1. Anuta, P.E., S.J. Kristof, D.W. Levandowski, T.L. Phillips and R.B. MacDonald. 1971. Crop, soil and geological mapping from digitized spectral satellite photography. *In* Seventh International Symposium on Remote Sensing of the Environment, Ann Arbor, Michigan, USA. Pp. 1983-2016.

2. Bauer, M.E. 1985. Spectro inputs to crop identification and condition assessment. IEEE Proceedings 73:1071-1085.

3. Boatwright, G.O., and V.S. Whitelead. 1986. Early warning and crop condition assessment research. IEEE Transactions of Geoscientific Remote Sensors GE-24:54-64.

4. Colwell, R.N., 1983. Manual of Remote Sensing. American Society of Photogrammetry, Falls Church, Virginia, USA.

5. Daughtry, C.S.T., K.P. Gallo, L.L. Biehl, E.T. Kanemasu and G. Asrar. 1984. Spectral estimates of agronomic characteristics of crops. *In* Proceedings of the Machine Processing Remotely Sensed Data Symposium, Purdue University, West Lafayette, Indiana, USA. Pp. 248-256.

6. Hall, F.G. 1984. Remote sensing of vegetation at regional scales. *In* Proceedings of the SPIE (Remote Sensing) 475:70-80.

7. Hall, F.G., M.E. Bauer and W.A. Malila. 1974. First results from the crop identification by remote sensing technology assessment project. *In* Proceedings of the Ninth International Symposium on Remote Sensing of the Environment. Pp. 1171-1192.

8. Hoffer, R.M. 1975. Natural resources mapping in mountainous terrain by computer analysis of ERTS-1 satellite data. Laboratory for Applications of Remote Sensing Research Bulletin 919. Purdue University, West Lafayette, Indiana, USA.

9. Hoffer, R.M., and C.J. Johannsen. 1969. Ecological potentials in spectral signature analysis. *In* Remote Sensing in Ecology, P.L. Johnson, ed. University of Georgia Press, Athens, Georgia, USA.

10. Jackson, R.D. 1984. Remote sensing of vegetation: Characteristics for farm management. Paper 475-10 presented at the Society of Photooptical Instrumentation Engineers. Arlington, Virginia, USA, April 29 - May 4, 1984.

11. Jackson, R.D., S.B. Idso, R.J. Reginatto and P.J. Pinter. 1981. Canopy temperature as a crop water stress indicator. Water Resources Research 17:1133-1138.

12. Johannsen, C.J., and T.W. Barney. 1981. Remote sensing applications for resource management. Journal of Soil and Water Conservation 36:128-133

13. Justice, C.O., J.R.G. Townshend, B.N. Holben and C.J. Tucker. 1985. Analysis of the phenology of global vegetation using meteorological satellite data. International Journal of Remote Sensing 6:1271-1318.

14. Knipling, E.B. 1967. Physical and physiological basis for difference in reflectance of healthy and diseased plants. Paper presented as the Workshop on Infrared Color Photography in the Plant Sciences. Florida Department of Agriculture, Winter Haven, Florida, USA, March 2-3, 1967.

15. Landgrebe, D.A. 1976. Computer-based remote sensing technology: A look into the future. Remote Sensing of the Environment 5:229-246.

16. Lawlor, D.W. 1979. Effects of water and heat stress on carbon metabolism of plants with C3 and C4 photosynthesis. *In* Stress Physiology in Crop Plants, H. Mussell and R. Staples, eds. John Wiley and Sons, New York, N.Y., USA.

17. MacDonald, R.B., and F.G. Hall. 1980. Global crop forecasting. Science 208:670-679.

18. MacDonald, R.B., M.E. Bauer, R.D. Allen, J.W. Clifton, J.D. Erickson and D.A. Landgrebe. 1972. Results of the 1972 corn blight watch experiment. *In* Proceedings of the Eighth International Symposium on Remote Sensing of the Environment. Pp. 157-190.

19. Reeves, R.G., ed. 1975. Manual of Remote Sensing. American Society of Photogrammetry, Falls Church, Virginia, USA.

20. Swain, T.H., and S.M. Davis, eds. 1978. Remote Sensing: The Quantitative Approach. McGraw-Hill, New York, N.Y., USA.

21. Tucker, C.J. 1979. Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of the Environment 8:127-150.

22. Tucker, C.J., J.R.G. Townshend and T.E. Goff. 1985. African land-cover classification using satellite data. Science 227:369-374.

23. Walburg, G., M.E. Bauer, C.S.T. Daughtry and T.L. Housley. 1982. Effects of nitrogen nutrition on the growth, yield and reflectance characteristics of corn. Agronomy Journal 74:677-683.

24. Wiegand, C.L., M.D. Heilman and A.H. Cerbermann. 1969. Detailed plant and soil thermal regime in agronomy. *In* Proceedings of the Fifth International Symposium on Remote Sensing of the Environment, University of Michigan, Ann Arbor, Michigan, USA. Pp. 325-342.

25. Weismiller, R.A., I.D. Persinger and O.L. Montgomery. 1977. Soil inventory from digital analysis of satellite sensor and topographic data. Soil Science Society of America Journal 41:161-170.