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REMOTE SENSING
AS A MEANS OF DETECTING CROP DISEASE¹

by

Marvin E. Bauer²

INTRODUCTION

Detection and control of crop diseases are important phases of agricultural management. Currently the USDA spends several million dollars annually to detect crop diseases. Many more millions of dollars are spent by farmers trying to control diseases. Field observations and ground surveys are used to gather the information necessary to keep track of ever-changing situations. Present methods give results which often differ from the real time situation. The capability to respond to major natural disasters such as the 1970 corn blight epiphytotic in a way which permits rapid adjustments in forecasts does not now exist. During 1970 an accurate description of the extent and severity of corn blight infection was not compiled until well after the end of the growing season.

Remote sensing is beginning to provide new tools and techniques with which agronomists and plant pathologists can rapidly observe and inventory crop conditions. Detection

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of crop diseases is but one of many possible applications of remote sensing technology. These techniques may provide useful and more timely information about our natural resources and also make available information which has previously been unavailable.

REMOTE SENSING TECHNIQUES

Remote sensing is the science and art of acquiring information about material objects from measurements made at a distance without coming in physical contact with the objects. For example, a camera is a remote sensor because it measures reflected light without touching the object being photographed. Besides a camera with its filters and photographic emulsions sensitive to certain light rays, other remote sensors are the human eye, spectrometers, and radar instruments.

All energy coming to earth is produced by the sun and is either reflected, scattered, or absorbed and then radiated. Since objects have different physical and chemical properties, different amounts of reflected or radiated energy in the form of electromagnetic waves will be emitted by each object. Thus, a scene is made up of many small radiating elements, and every object could conceivably transmit different kinds and amounts of reflected and radiated energy.

Remote sensing makes use of spectral information between 0.4 and 15 micrometers. The human eye is sensi-

tive only to the visible portion (0.4 to 0.7 micrometers) of the spectrum. Color infrared film is sensitive to energy in the 0.4-to 0.9-micrometer wavelengths and, therefore, contains more information about a scene than is available to the human eye alone. Although many advances are being made in making quantitative measurements from film emulsions, human interpretation of photography is basically qualitative in nature.

Quantitative measurements of radiated and reflected energy can also be made with an optical-mechanical scanner, which has a range of 0.4 to 15 micrometers. Over this greater range, encompassing the visible, reflective and thermal infrared wavelengths, considerably more information is available. A scanner records the energy responses of selected wavelength bands in a series of contiguous scan lines onto magnetic tape. These multispectral data are particularly amenable to machine processing since computers can be programmed to recognize data radiation patterns which are indicative of scene properties of interest. In order to teach the computer to recognize significant patterns, small amounts of known data, referred to as training samples, are used as representative of the different existing scenes of the region. The vast majority of the data can then be processed automatically. This automatic process yields a computer-generated map that classifies the scene into as many as 30 categories. The number of categories is dependent on the quantity of ground truth information available.

APPLICATION TO AGRICULTURAL PROBLEMS

During the past five years significant advances have been made in agricultural remote sensing research particularly in the use of multispectral scanner and machine analysis systems. Early classifications of multispectral data used only simple categories such as water, bare soil and green vegetation.

Presently it is a relatively simple task to identify certain crop species with multispectral data and automatic pattern recognition techniques. Dark and light soils can be accurately differentiated. More recent research has been aimed at making still more subtle distinctions in the condition and probable yield of corn and wheat. In addition, researchers have utilized multispectral data to map soil patterns and organic matter content of bare soils.

Reflectance measurements have been successfully used to distinguish between healthy and diseased plants in fields. This is possible because healthy and diseased plants reflect energy differently. Cellular structure changes affect reflectance in the 0.75-to 1.35-micrometer wavelengths. Changes in pigmentation affect reflectance in the 0.5-to 0.75-micrometer range, and wavelengths between 1.35 and 2.5 micrometers are strongly influenced by the amount of water in the leaf. Examples of diseases which have been found to be detectable with aerial infrared film are wheat rust, potato late blight, and citrus foot rot.

In 1970 experiments were conducted by the Laboratory for Applications of Remote Sensing (LARS) at Purdue University to determine if southern corn leaf blight could be detected using remote sensing techniques. Six segments, 8 to 12 miles long and one mile wide, were selected from a flightline extending from Lake Michigan to the Ohio River in western Indiana. The severity of blight infection in each corn field in these segments was rated by agronomists and plant pathologists.

Color infrared photography was collected in late August at altitudes of up to 60,000 feet. Three levels of blight infection (none or slight, moderate, and severe) could be differentiated on the photography. Multispectral scanner data were collected from 3,000-to 7,000-foot altitudes and analyzed using pattern recognition techniques. The above three

blight severity classes could be accurately classified from these data.

THE CORN BLIGHT WATCH EXPERIMENT

In 1971 a much more extensive experiment, called the Corn Blight Watch Experiment, was conducted to evaluate the use of advanced remote sensing techniques and concepts to:

- Detect the development of blight during the growing season across the Corn Belt;
- Assess different levels of infection present;
- Amplify information acquired by field observation and thus assess the current blight status and its probable impact on crop production; and
- Determine the applicability of these techniques to similar situations occurring in the future.

The USDA, the National Aeronautics and Space Administration (NASA), the Agricultural Experiment Stations (AES), and the Cooperative Extension Services (CES) of the states of Illinois, Indiana, Iowa, Minnesota, Missouri, Ohio and Nebraska, the Willow Run Laboratories of the University of Michigan, and LARS joined to plan and implement one of the largest agricultural experiments ever conceived.

A total of 210 sites, each one mile wide and eight miles long, located in the states listed above, were monitored throughout the growing season. The experimental test area contained about 65 percent of the nation's corn acreage. During May, interviewers (ASCS county personnel) delineated all crop fields on current photography and asked specific questions about each corn field in these segments. Following this, a sample of 6 to 10 fields within each segment was selected for biweekly blight inspections by extension agents. The sample fields in each site were stratified so that they were represen-

tative of the major cytoplasm types present in the segment.

The sites were overflown with a high-altitude NASA aircraft which collected color infrared film at approximately two-week intervals from mid-June to mid-September. Using the field observation data as "training field" information, a team of photo-interpreters classified all the corn fields in each segment into blight classes. In this manner, more than 15,000 fields were evaluated every two weeks, while on the ground only a few plants in each of about 1,500 fields were observed.

Multispectral scanner data were collected over 30 of the segments in western Indiana for analysis by pattern recognition techniques. By comparing the spectral measurements from the fields with ground-determined blight severity, all of the corn fields in a segment were categorized into blight classes.

The sampling model was designed so that statistically valid inferences of blight severity could be made from each of the three systems of obtaining information—ground observation, infrared photography and multispectral scanner data. Comparisons of the results obtained by the different methods have been made and will be discussed in this paper.

CORN BLIGHT WATCH EXPERIMENT RESULTS

The ground observations from the Corn Blight Watch Experiment provided quantitative estimates of the incidence and severity of blight infection levels in the Corn Belt region in 1971. A description of the blight situation as measured by ground observations may be useful first. The estimated acreage in each blight severity class for the period of August 23 to 27 is shown in Figure 1. Less than 20 percent of the acreage was infected at moderate or severe levels and less than five percent was severely infected.

Areas with severe blight infection were primarily restricted to southern Illinois and Indiana (Figure 2). The averages shown have been weighted by the acres of each cytoplasm type occurring in the flightlines; the effect of this is to maximize the contribution of the prevailing cytoplasm types in the flightline in such a way that some local areas with small acreages of severely infected Texas male sterile cytoplasm corn had minimal effect on the flightline average.

The photo-interpretation results for the same period are shown in Figure 3. In general, there is good agreement between the expanded field observation estimates (Figure 2) and the photo-interpretive results. Where differences do occur they are principally due to the difficulty of detecting slight and mild blight severity levels on infrared photography.

The correlation of field and photo-interpretive estimates of the segment average blight severity for the period August 23 through September 5 is shown in Figure 4. The correlation coefficient of 0.61 indicates considerable variance between the two estimates. The correlation of field observations and results from the analysis of multispectral scanner data, shown in Figure 5, is 0.86 for the same period. At earlier times during the season when there was less blight present, the agreement between field observations and the remote sensing estimates was not as good. Deviation from the 1:1 line is due to error in both the field and the photo-interpretive or multispectral data analysis results.

Comparisons of the expanded acreage estimates from field observations with the photo-interpretation and the multispectral scanner data analysis estimates show that the acreages in the six individual blight classes were not accurately estimated by either of the remote sensing techniques. The correlation coefficients ranged from 0.2 to 0.7 for photo-interpretation and from 0.4 to 0.8 for multispectral scanner data analysis for the individual blight classes. When the

six individual classes were grouped into two classes (none, slight, and mild infection vs. moderate, severe and very severe blight), the correlation coefficients increased to approximately 0.7 for photo-interpretive estimates (Figure 6) and 0.9 for multispectral scanner data analysis estimates (Figure 7). These results indicate that fields with slight or mild infection can not be accurately differentiated from those with no blight, but that none-to-mild blight can be accurately distinguished from moderate-to-severe blight levels.

Several factors complicate the early detection from aircraft of a disease such as southern corn leaf blight. One is that since the disease starts at the bottom of the plant, infection on the lower leaves may be hidden from the view of the camera or scanner by healthy upper leaves. Consequently, the infected leaves have little or no effect on the spectral measurements or the color infrared photography. Another is that in fields with low populations or excessive weeds, the response from soil and weeds overshadows that from the corn plants. The natural variability due to agronomic factors also contributes to the difficulty of detecting small amounts of infection. Some of these factors are differences in leaf angle, leaf color, and tassel color among different hybrids, and differences due to maturity, population, row direction and the vigor of the crop, which is influenced by such things as available soil moisture and fertility. As we increase our understanding of how these variables influence the spectral response, the potential for early detection of crop diseases will increase.

The question of how well particular diseases can be distinguished from each other and from other stress conditions has not been answered. Further analysis of data from the Corn Blight Watch may give more insight into these problems. Certain stresses such as moisture deficiencies, hail, and insect damage could be detected on the imagery collected in 1971 for the Corn Blight Watch.

CONCLUSIONS

The Corn Blight Watch Experiment was the largest experiment conducted to date to determine the feasibility of crop disease detection with remote sensing over a large geographic area. The results indicated that early detection by remote sensing of diseases like southern corn leaf blight is unlikely at this time. It was demonstrated, however, that remote sensing can provide an accurate assessment of the situation when moderate-to-severe infection levels are present.

The Corn Blight Watch Experiment provided experimenters a real-world situation in which to evaluate the capabilities of remote sensing. Much was learned about the mechanics required to operate a large information system utilizing remote sensing. Key problem areas were identified and efforts are already underway to find solutions to these problems. Future research will be aimed at finding new ways to obtain more information from remote sensing measurements and to make more efficient use of ground observations; for example, the use of calibrated data should extend the boundaries for which training fields are valid to include new sets of data from other times and/or places.

Disease assessment is only one of the agricultural applications of remote sensing which appear promising for the near future. The projected applications of remote sensing to agriculture are many; they include identification and area measurements of major crops, mapping soils characteristics, mapping disease and insect invasions, assessment of crop stresses, and crop yield prediction.

FURTHER REFERENCES

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2. *Remote Multispectral Sensing in Agriculture: Laboratory for Agricultural Remote Sensing Annual Report, Volume 4.* Agricultural Experiment Station Research Bulletin No. 873, Purdue University, Lafayette, Indiana. December, 1970.
3. *1971 Corn Blight Watch Experiment: Interim Report.* September, 1971.

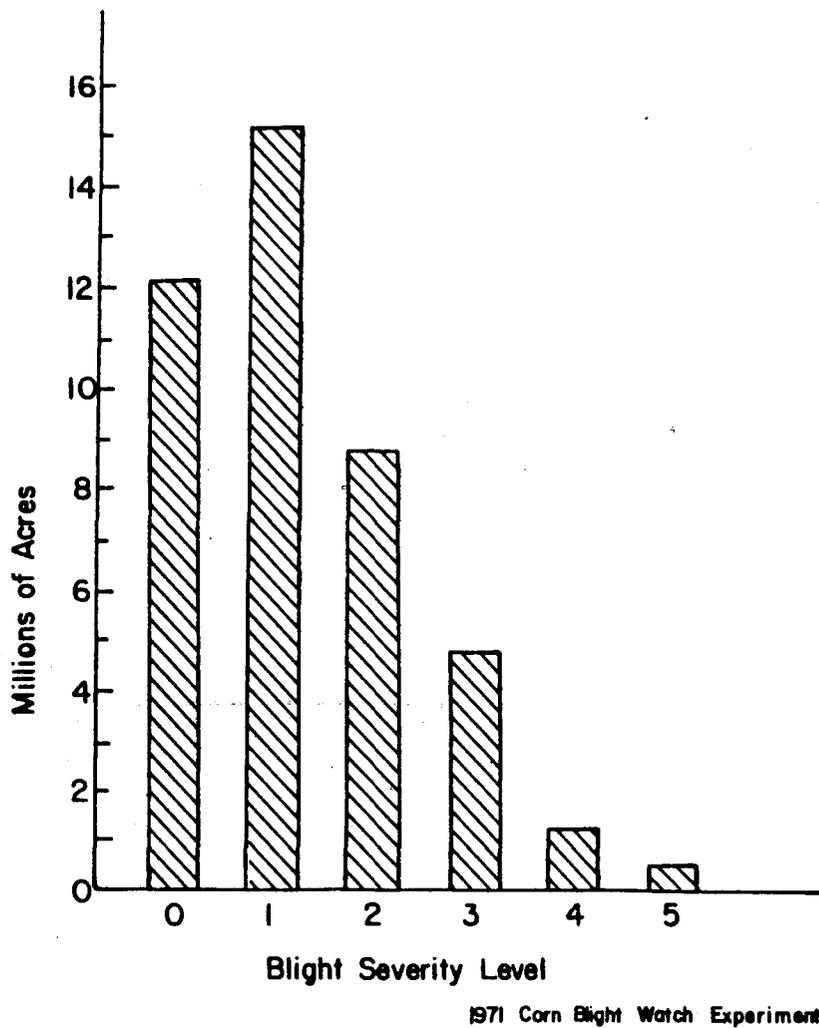


Figure 1. Number of acres in each blight severity class in the Corn Belt, August 23 - 27, 1971.

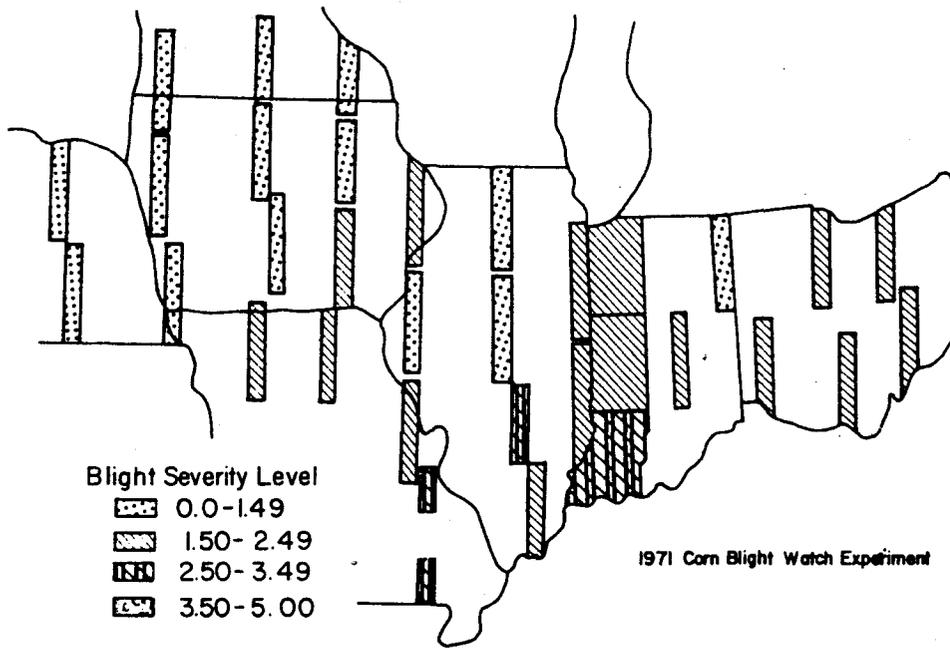


Figure 2. Average blight severity level by flightline, as estimated by expanded field observations, August 23 - 27, 1971.

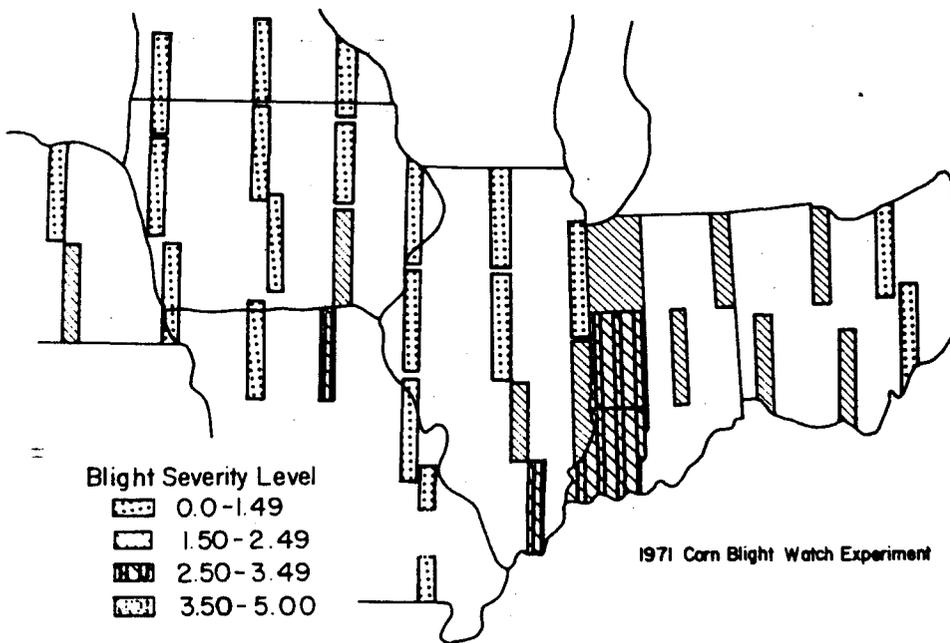


Figure 3. Average blight severity level by flightline, as estimated by photo-interpretation, August 23 - September 5, 1971.

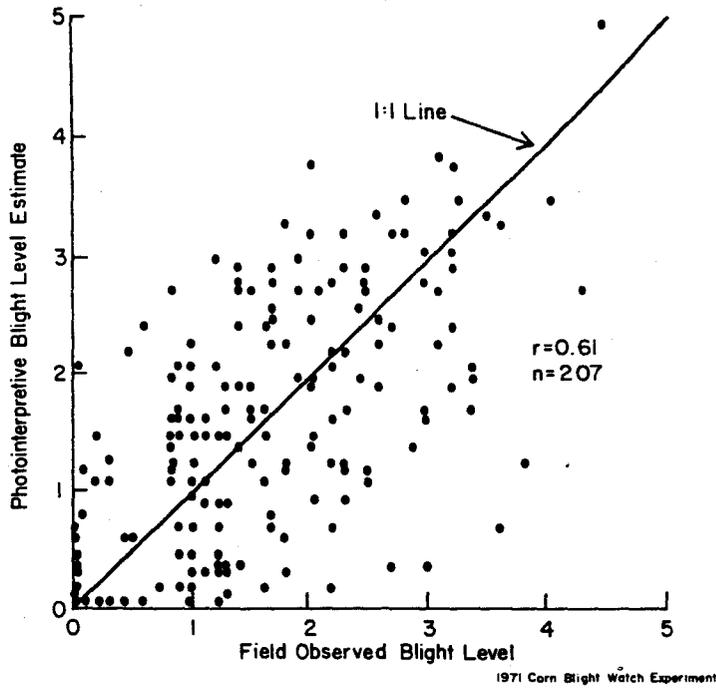


Figure 4. Correlation of field observation estimates and photo-interpretation estimates of segment blight severity averages for August 23 - September 5, 1971.

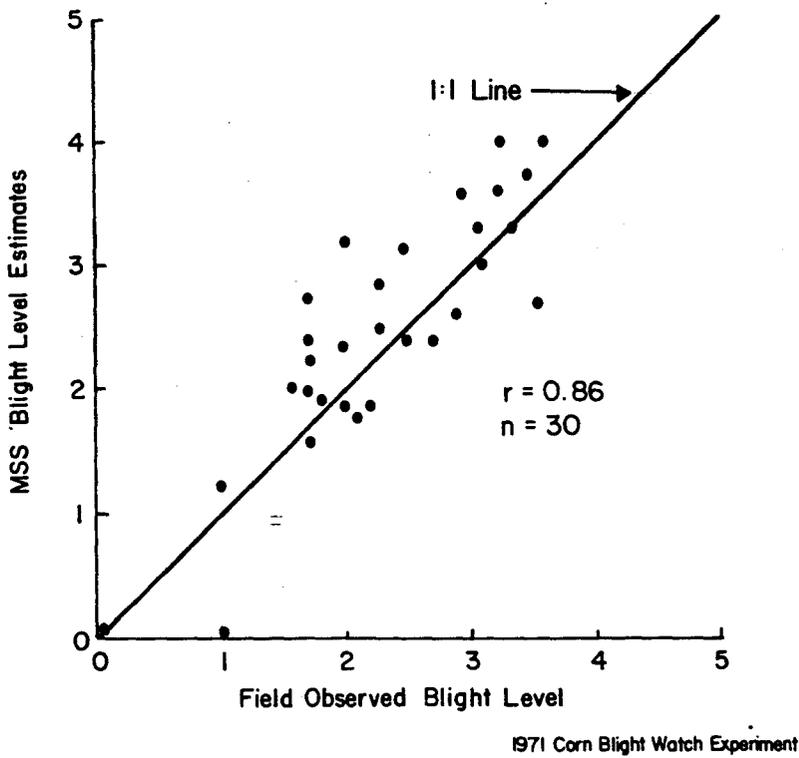


Figure 5. Correlation of field observation estimates and multispectral scanner data analysis estimates of segment blight severity averages for August 23 - September 5, 1971.

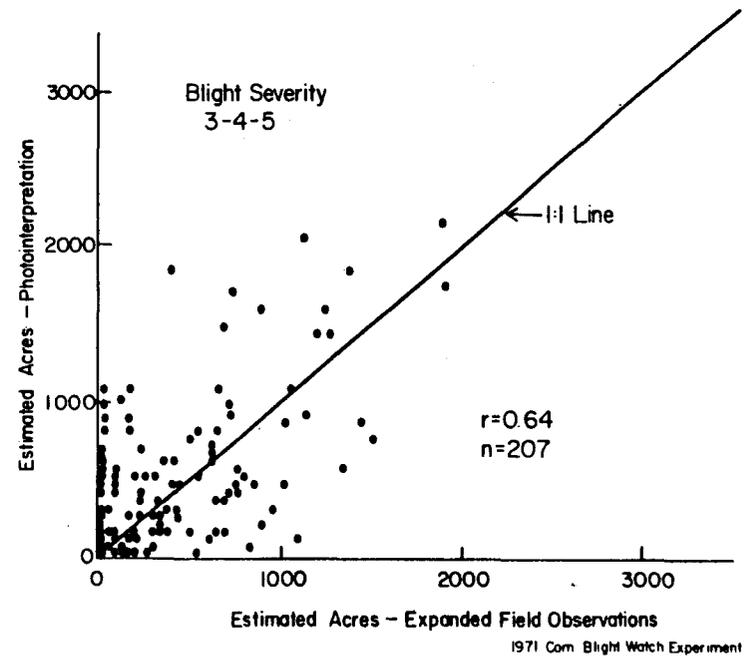
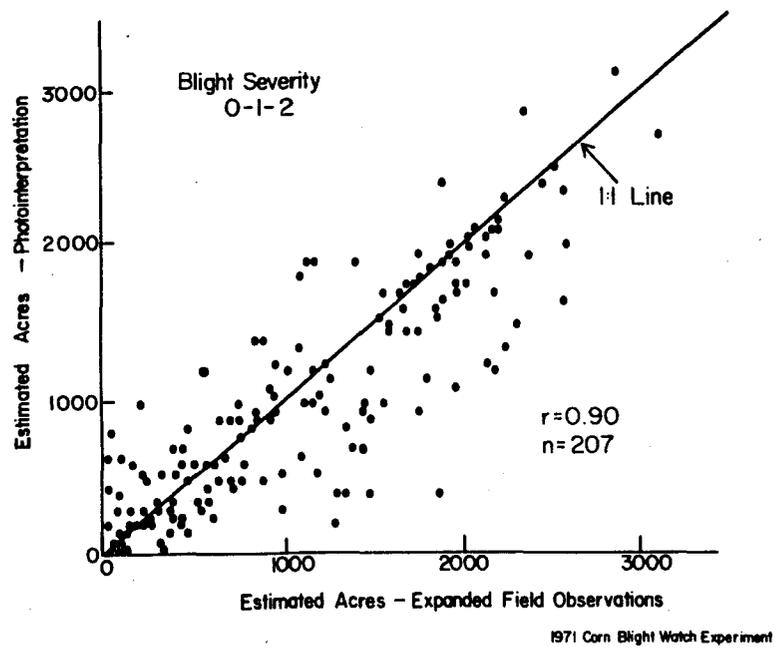


Figure 6. Correlation of field observation and photo-interpretation estimates of acreages of healthy (blight levels 0-1-2) and blighted (3-4-5) corn in the Corn Belt area, August 9 - 22, 1971.

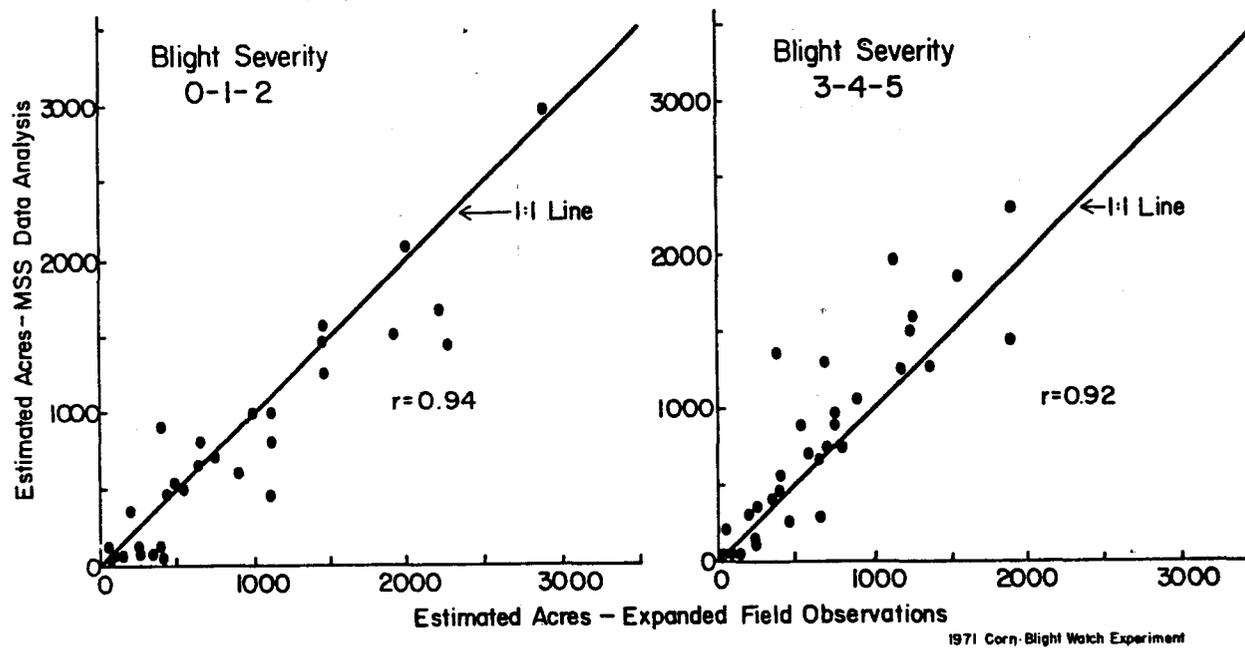


Figure 7. Correlation of estimates from multispectral scanner data and field observations of acreages of healthy (blight levels 0-1-2) and blighted (3-4-5) corn in the intensive study area for the period beginning August 9, 1971.