Title:

Determining Density of Maize Canopy: I. Digitized Photography[1]

by

E. R. Stoner

M. F. Baumgardner

and

P. H. Swain

[1]Journal Paper No. 4929, Purdue University Agricultural Experiment Station, Contributed by the Laboratory for Applications of Remote Sensing and Department of Agronomy, West Lafayette, Indiana 47907. Supported by: NASA Grant NGL 15-005-112.

[2]Peace Corps, Brazil; Associate Professor, Agronomy Department; and Assistant Professor, Department of Electrical Engineering.

ABSTRACT

This research was designed to study the relationship between different densities of maize (Zea mays L.) canopies and the energy reflected by these canopies. Field plots were laid out, representing four growth stages of maize. Two plot locations were chosen, one on a dark soil and the other on a very light colored surface soil. Spectral and spatial data were obtained from color and color infrared photographs taken from a vertical distance of 10 m above the maize canopies. Estimates of ground cover were made from these photographs and were related to field measurements of leaf area index. Ground cover could be predicted from leaf area index measurements by a second order equation.

Color infrared photography proved helpful in determining the sensity of maize canopy on dark soils. Color photography was useful for determining canopy density on light colored soils, provided the percent ground cover did not exceed approximately 75%.

Microdensitometry and digitization of the three photographically separated dye layers of color infrared film showed that the near infrared dye layer is the most valuable in canopy density determinations. Computer analysis of the digitized photography provided an accurate method of determining canopy density.

Additional key words: Leaf area index, ground cover, remote sensing.

INTRODUCTION

Properties of reflectance and emittance of energy have been studied for many natural earth surface features in connection with research in the field of remote sensing. Usually the spectral properties of individual samples of soils or plant materials are determined in the laboratory, and their properties are generalized to the field situation. Very little work has been done in measuring the spectral properties of the green vegetation - bare soil complex in the field.

Remote sensing has been developing in recent years into a useful tool for the agronomist in characterizing the spectral, spatial, and temporal aspects of soils and plant communities (Hoffer, 1967; LARS, 1967; LARS, 1968; LARS, 1970). Photography has proven useful in determination of the spatial features, and to a certain extent the spectral features of plant canopies.

Photography of plant canopies from the ground level looking vertically upwards has been attempted (McCree, 1968; LARS, 1968) to obtain qualitative views of canopy density and the amount of transmitted light. In viewing the plant canopy from a vertical position, Miller (1969) found that dark colored soils and dark, wet soils had a suitably low reflectance in the 0.7 to 0.9 μm wavelength band so that response in the instantaneous field of view of a crop canopy would be approximately equal to percent cover of vegetation. Hoffer (1967) also found the photographic infrared wavelengths useful in estimating ground cover on dark soils and noted that increasing canopy cover resulted in higher response on infrared film. Hoffer found that the visible photographic wavelengths were best for determining percent vegetative cover.

Myers et al. (1966), in an experiment with stacked leaves, found that as the number of leaf layers increased up to six layers, the reflectance increased in the near infrared except in the 1.45 μm and 1.95 μm water absorption bands. The probable explanation for this enhanced reflectance with multiple leaf layers in the reflective infrared is a retransmission of infrared radiation back through the canopy from lower layer reflection. Myers (1970) reasoned that the leaf layers could be related to an actual measure of leaf density or leaf area index (LAI). Myers reported that Kodak Ektachrome Infrared-Aero film, which is sensitive in the wavelength interval from approximately 0.45 to 0.9 μm, could be used to record variations in reflectance associated with leaf area index.

Miller and Pearson (1971) concluded that no rapid method has been found practical for measuring percent ground cover from the ground location of the observer. The subjectivity involved in ground level estimation of percent ground cover is a serious problem in a complex canopy such as the maize canopy where view angle effects, height effects, and shadowing complicate the scene. Cuellar (1971) suggests methods for estimating ground cover for two different canopy structures, and indicates the difficulties involved in ground cover estimation in tall maize canopies as ground cover approaches 100%.

A more quantitative measure for characterizing the extent of vegetative cover is leaf area index. Miller and Pearson (1971) felt that leaf area index would be a reasonable measure of the above ground portion of the crop biomass, and would be a suitable measure of vegetative cover for remote sensing purposes.

Characteristics of color and color infrared film prevent the researcher from obtaining quantifiable spectral information about plant canopies from these film types. Relative spectral measurements can be made, however, by photographic separation of the dye layers of the film and microdensitometry of these color separations. Computer analysis of digitized photography provides a means for distinguishing between the components of green vegetation and bare soil by analysis of spectrally separable classes. Digitization of low altitude photography thus provides a useful technique for analysis of the spectral and spatial relationships in plant canopies.

MATERIALS AND METHODS

During the summer of 1971 an experiment was carried out utilizing the facilities of the Laboratory for Applications of Remote Sensing (LARS) and the Purdue University Agronomy Farm to study the spectral, spatial, and temporal aspects of increasing density of maize canopy. The objective was to observe and study the reflectance characteristics of maize canopies with both light and dark surface soil backgrounds. To this end, two plot locations were chosen at the Purdue University Agronomy Farm representing a light colored forest soil and a dark colored prairie soil. The light surface soil was Russell silt loam, a well-drained alfisol with a dry Munsell color of 10YR 6/2 and an organic matter content of about 3%. The dark surface soil was Chalmers silty clay loam, a very poorly drained mollisol with a dry Munsell color of 10YR 4/1 and an organic matter content of about 6%.

In order to facilitate data collection and provide a wide range of ground covers on any given date of a photographic mission, four planting dates were used. The Pioneer 3369A maize variety was planted in three replications at each site location on each of the following four dates: April 30, May 22, June 9, and June 30.

Each plot extended 55 m along the northern edge of the Agronomy Farm's bulk maize plots and consisted of twelve subplots 4.57 by 4.57 m in size. Each subplot contained six rows of maize, 4.57 m long in 76 cm rows. Replications of planting dates were assigned randomly to the twelve subplots.

No special fertility treatments were used, and adequate fertility levels were maintained for the Agronomy Farm's bulk maize production. A plant population of about 49,400 plants per hectare was desired, and actual populations of from 43,200 to 50,700 plants per hectare were obtained.

On three dates: July 13, July 21, and August 3, the LARS Hi-Ranger truck was used to obtain vertical photographs over the subplots from an altitude of approximately 10 meters. Color (Kodak Ektachrome-X and Kodachrome II) and color infrared (Kodak Ektachrome Infrared Type 2443) photographs were taken on these dates with two Nikkormat 35 mm cameras with 50 mm focal length lenses. A Kodak Wratten No. 12 filter was used with the Kodak Ektachrome Infrared film, and a skylight filter was used with the Kodak Ektachrome-X and Kodachrome II films. Simultaneous photographs were taken of each plot with the two cameras. The resulting scale on the 35 mm transparencies was 1:200.

At the time of the photographic missions, field measurements of leaf area index were made. Two plants were sampled from each subplot and leaf area was calculated from the average of these measurements. Leaf area index was then calculated from the average leaf area per plant and the plant population per unit of soil.

Thirty photographs were selected for percent ground cover estimation by a point grid technique (Null, 1969). This included 12 Kodachrome II photographs of the Russell silt loam plots taken July 13, 12 Ektachrome-X photographs of the Russell plots taken July 21, 3 Ektachrome-X photographs of the Russell plots taken August 3, and 3 Ektachrome Infrared photographs of the Chalmers silty clay loam plots taken on July 13. These particular photographs were chosen because of their high film quality and because of the diversity of canopy densities represented among them. Point grid estimates of percent ground cover were made from the 35 mm transparencies by having them projected onto a rear-viewing screen with a point grid overlay of 1 point per 5.6 mm and enlarged 15 times. Regression analysis was performed to determine if percent ground cover could be related to leaf area index.

Kodak Ektachrome Infrared film Type 2443, is the latest version of Kodak's multi-emulsion color infrared film. The range of spectral sensitivity of color infrared film is extended into the near infrared wavelenth region, where vegetation typically has a very strong spectral response. Fritz (1971) describes the wavelengths of spectral sensitivity for the film's three dye layers. Knipling (1969) explains the image forming processes in light of response to green vegetation.

Twenty color and color infrared transparencies were chosen for color separation and microdensitometry. The results for only of these photographs, a color infrared photo of Chalmers plot 12, taken on July 13 will be described here. Before the color infrared multi-emulsion film could be densitiometered, it had to be separated into its three emulsion layers by a commercial photographic process. Kodak Ektachrome Infrared film Type 2443 can be photographically separated into the following emulsion layers: green (0.47-0.61 μm), red (0.59-0.71 μm), and infrared (0.68-0.89 μm). Hoffer, Anuta, and Phillips (1971) describe this photographic separation as well as all the other steps in the digitization of photography.

A scanning microdensitometer was utilized to obtain film density measurements of the color separations. This technique permitted the rapid scanning density measurement of many small adjacent lines in sequence. An Optronics Inc.

P-1000 digitizing, rotating-drum microdensitometer was used in this study. A spatial resolution of 50 μm was used, which allowed for a point on the film to be resolved which represented about 1.5 cm on the ground. Over 300,000 individual density measurements were transformed to a digital format from a typical 24 by 36 mm frame of photography. Optical film density is a function of incoming radiance, film characteristics, filters used, optical system characteristics, and the film development process (Anuta and MacDonald, 1971). The digital film data was stored on magnetic tape for analysis using the LARSYS processing system, a computer software system developed at LARS for analysis of digitized spectral data (LARS, 1968, 1970).

The LARS Digital Video Display Unit was used to view the digitized photographic images. Figure 1 shows the digital display images of the three emulsion separations from the digitized frame of photography taken over the Chalmers plot 12 on July 13. Boundaries, drawn with the aid of a light pen, define the two subset areas of interest used in this study.

Analysis of digitized photography was intended mainly as an attempt to distinguish between the components of green vegetation and bare soil in imagery. This involved the determination of separable classes in the data set.

The statistical pattern recognition program LARSYSAA was used for classification purposes (Fu, Landgrebe, and Phillips, 1969). This system uses a maximum likelihood ratio based on the Gaussian assumption to classify statistically separable classes. "Training sample areas" must be provided to supply the LARYSAA processor with statistics for recognition of spectral patterns of density values for similar conditions in the photograph. A clustering program (Wacker and Landgrebe, 1970) was used to define spectrally separable classes for training purposes. Five cluster classes were distinguished in the imagery from Chalmers plot 12, four of which represented green vegetation, the other bare soil.

The smaller subset area outlined in Figure 1 was chosen for detailed analysis and determination of the best wavelength band for classification of green vegetation vs. bare soil. The five cluster classes produced from the clustering of Chalmers plot 12 were used for training the pattern classifier. The LARSYSAA classification processor was then used to classify each image point into one of the five defined classes using statistics from any desired wavelength band. Green vegetation classes and display symbols were pooled for pictorial displays of maize vs. bare soil as well as for calculation of the percent area occupied by green vegetation (Figure 2). Classifications in the three wavelength bands corresponding to the three emulsion separations are shown for the smaller subset area of Figure 1.

RESULTS AND DISCUSSION

A regression analysis was performed on the data from the 30 frames of photography analyzed for percent ground cover by the point grid system. Estimated percent ground cover was plotted against leaf area index (Figure 3). It was desired to see if the ground level measurement of LAI could be used in this situation to estimate percent cover as determined from a view above the canopy. If such a relationship exists, it would greatly aid the ground based observer whose job it is to collect supporting information on canopy density for remote sensing overflights.

In this problem percent ground cover was considered the dependent variable and leaf area index the independent variable. From the graph of the relationship (Figure 3) it was felt that a second order term may be needed to help explain variations in the dependent variable, so the squared term for LAI was also entered into the regression analysis. A stepwise regression resulted in the equation, $\hat{Y} = 2.0972 + 49.3525X - 6.6403X^2$. The variation about the mean percent ground cover explained by the resulting regression was 97.9%.

It is evident from Figure 3 that as LAI increases beyond a certain point (LAI = 3 in this case) percent ground cover does not increase very greatly. A ground cover of 100% was never observed from the low altitude photography. If a prediction equation like the one calculated were available for different row widths and plant populations of maize, estimation of cover from LAI measurements would not be unreasonable, even as cover approached 100%.

From the display maps of the classified subset area for the digitized photography from Chalmers plot 12 (Figure 2) it can be seen that the classification using the near infrared wavelength band represents most closely the actual ground cover situation when compared with the digital display imagery (Figure 1). It can be seen that percent ground cover was overestimated in the classification using the red wavelength separation, while it was slightly underestimated in the classification using the green wavelength separation. Tabular results from the near infrared classification indicated that the percent ground cover was 89.5%, corresponding to an LAI of 2.93.

SUMMARY AND CONCLUSIONS

Color infrared film is potentially useful for ground cover determination from low altitude photography. The near infrared dye layer of this film was the most useful for discrimination between the green vegetation and bare soil components of the maize canopy. Digitization of low altitude photography of plant canopies provides a valuable method for computer assisted determination of percent ground cover.

Color film is of value in ground cover determination from low altitude photography of maize canopies if the soil background is light and the ground cover is less than about 75%. For dark soil backgrounds and ground covers of greater than 75% in maize canopies, color infrared film would be more valuable.

Percent ground cover as determined from low altitude photography can be related to leaf area index of maize canopy for a given row width and plant population. Leaf area index is easy to measure from the ground and gives more information as to the actual crop biomass than does percent ground cover.

Low altitude photography of maize canopies is useful for spatial characterization of ground cover, but quantifiable spectral information is limited due to variability between frames of photography. Microdensitometry and digitization of color and color infrared film provide quantitative techniques for analyzing density differences which may be related to components of green vegetation and bare soil within a given frame of digitized photography.

Acknowledgement is made of Mr. Paul E. Anuta for his assistance in preparation of the digitized photography.

LITERATURE CITED

1. Anuta, P. E., and R. B. MacDonald. 1971. Crop surveys from multiband satellite photography using digital techniques. Remote Sensing of Environment. 2:53-67.
2. Cuellar, J. A. 1971. Correlation of ground cover estimated from aerial photos with ground observations. Spectral Survey of Irrigated Region Crops and Soils. 1971 Annual Report, USDA, Weslaco, Texas. pp. IV.13.-IV.-17.
3. Fritz, N. L. 1971. New color films for aerial photography. Proceedings of the Third Biennial Workshop on Aerial Color Photography in the Plant Sciences. A. Anson (ed.) (American Soc. of Photogrammetry, Florida Dept. Agr., Univ. of Florida and USDA) Gainesville, FL. pp. 45-68.
4. Fu, K. S., D. A. Landgrebe, and T. L. Phillips. 1969. Information processing of remote sensed agricultural data. Proceedings of the IEEE. 57:639-653.
5. Hoffer, R. M. 1967. Interpretation of remote multispectral imagery of agricultural crops. Report of the Laboratory for Agricultural Remote Sensing, Purdue University Agr. Exp. Sta. Res. Bull. 831. pp. 18-30.

6. Hoffer, R. M., P. E. Anuta, and T. L. Phillips. 1971. Applications of ADP techniques to multiband and multi-emulsion digitized photography. LARS Information Note 091071, Laboratory for Applications of Remote Sensing, Purdue University, 19 pp. Accepted for publication in Photogrammetric Engineering.

7. Knipling, E. B. 1969. Leaf reflectance and image formation on color infrared film. In Remote Sensing in Ecology. Univ. of Georgia Press, P. Johnson (ed.) Athens, GA. pp. 17-29.

8. Laboratory for Agricultural Remote Sensing (LARS). 1967. Remote Multispectral Sensing in Agriculture. Vol. II (Annual Report). Purdue University Agr. Exp. Sta. Res. Bull. 832. pp. 13-24.

9. Laboratory for Agricultural Remote Sensing (LARS). 1968. Remote Multispectral Sensing in Agriculture. Vol. III (Annual Report). Purdue Univ. Agr. Exp. Sta. Res. Bull. 844. pp. 53-58.

10. Laboratory for Agricultural Remote Sensing (LARS). 1970. Remote Multispectral Sensing in Agriculture. Vol. IV (Annual Report). Purdue Univ. Agr. Exp. Sta. Res. Bull. 873. pp. 80-86.

11. McCree, K. J. 1968. IR sensitive film for spectral measurements under plant canopies. Agr. Meteorol. 5:203-208.

12. McKee, G. W. 1964. A coefficient for computing leaf area in hybrid corn. Agron. J. 56:240-241.

13. Miller, L. D. 1969. Measurement of resource environments with airborne thermal mappers - where do we stand? Proceedings of the Purdue Centennial Year Symposium on Information Processing. Purdue Univ. pp. 746-763.

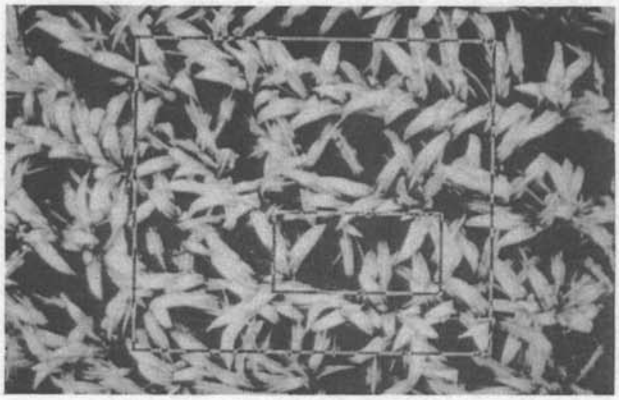
14. Miller, L. D. and R. L. Pearson. 1971. Areal mapping program of the IBP grassland biome: remote sensing of the productivity of the short-grass prairie as input into biosystem models. Proceedings of the Seventh Symposium on Remote Sensing of Environment. Univ. of Mich., Ann Arbor, MI. pp. 165-205.

15. Myers, V. I., C. L. Wiegand, M. D. Heilman, and J. R. Thomas. 1966. Remote sensing in soil and water conservation research. Proceedings of the Fourth Symposium on Remote Sensing of Environment. Univ. of Mich., Ann Arbor, MI. pp. 801-813.

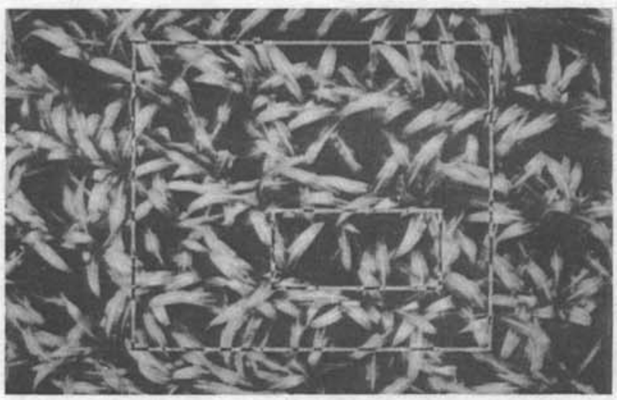
16. Myers, V. I. 1970. Soil, water, and plant relations. In Remote Sensing with Special Reference to Agriculture and Forestry. National Academy of Sciences, J. R. Shay (ed.), Washington, D..C. pp. 253-297.

17. Null, W. S. 1969. Photographic interpretation of canopy density - a different approach. Journal of Forestry. 67:175-177.

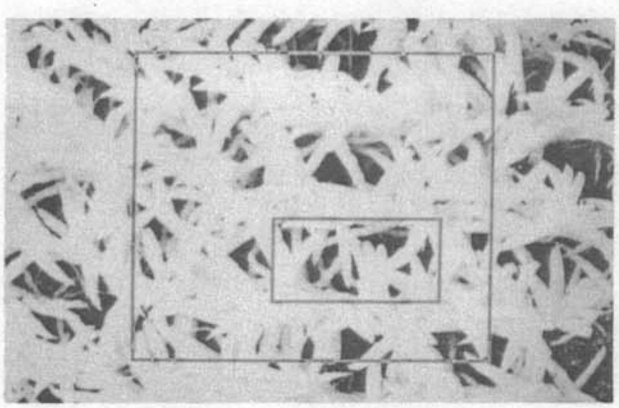
18. Wacker, A. G., and D. A. Landgrebe. 1970. Boundaries in multispectral imagery by clustering. Proceedings of the Ninth IEEE Symposium on Adaptive Processes XI. pp. 4.1-4.8.



Green Separation

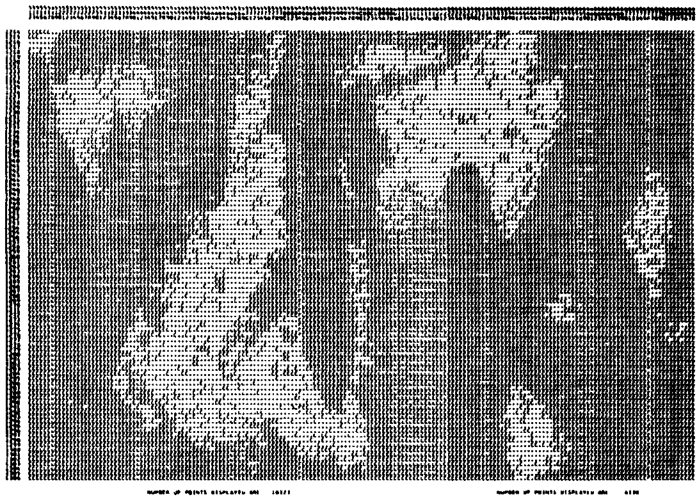


Red Separation

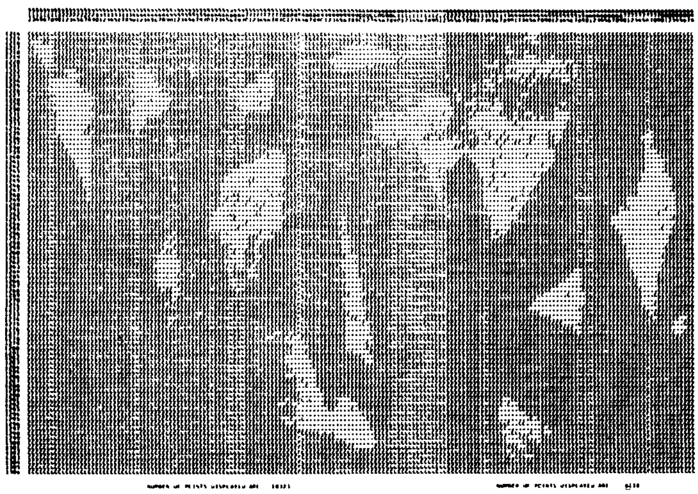


Near Infrared Separation

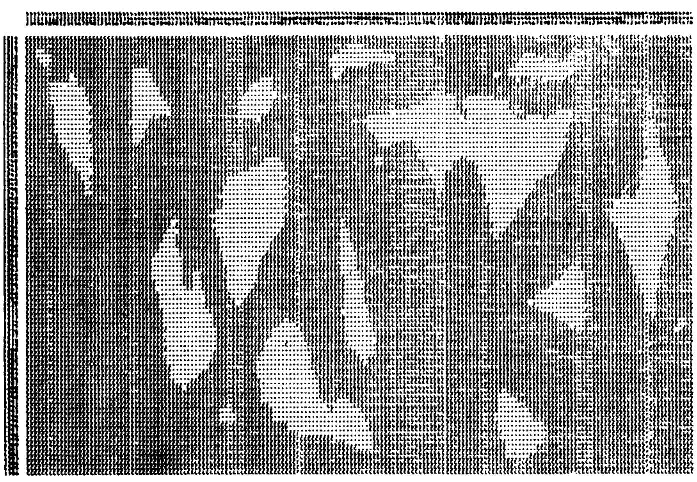
Figure 1. Digital display images from three emulsion layers of photographic separations of color IR film.



Green Wavelength Band



Red Wavelength Band



Near Infrared Wavelength Band

Figure 2. Computer display maps for three ground cover classifications of Chalmers plot 12.

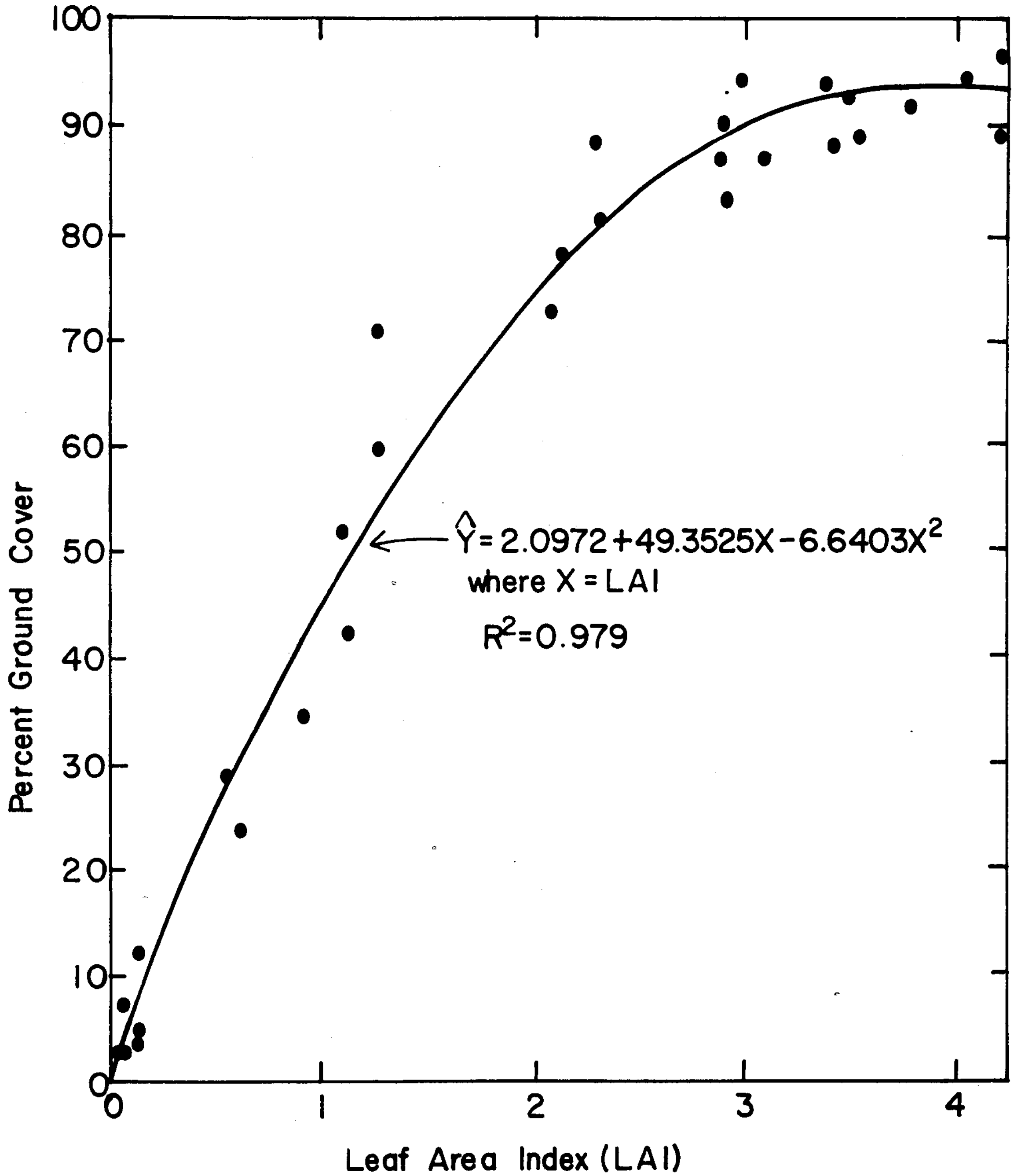


Figure 3. Percent ground cover plotted against leaf area index for 30 observations.