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Research and Development

Remote Sensing of Sulfur Dioxide Effects on Vegetation—Final Report

Volume I. Summary

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REMOTE SENSING OF SULFUR DIOXIDE EFFECTS ON VEGETATION

FINAL REPORT

VOLUME I - SUMMARY

by

C. Daniel Sapp
Office of Natural Resources
Tennessee Valley Authority
Chattanooga, Tennessee 37401

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Project Officer

James Stemmle
U.S. Environmental Protection Agency
401 M Street, SW.
Washington, DC 20460

Prepared for

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ABSTRACT

Three techniques for detecting and mapping sulfur dioxide (SO_2) effects on the foliage of sensitive crops and trees near large, coal-fired power plants were tested and evaluated. These techniques were spectroradiometry, photometric analysis of aerial photographs, and computer analysis of airborne multispectral scanner data.

Spectroradiometry is a useful, ground-based technique for measuring the changes in reflectance that accompany exposure of sensitive crops to SO_2. Photometric analysis of aerial color-infrared photographs has some practical advantages for measuring the reflectances of forest species or for synoptic point-sampling of extensive areas; these tasks cannot be done effectively by field crews. The relationships among reflectance, foliar injury, and yield of crops are complex and are affected by many extraneous variables such as canopy density. The SO_2 effects are easier to detect on winter wheat than on soybeans, but in either case they cannot be consistently detected by airborne remote sensors except under near-ideal conditions when the injury is moderate to severe. Airborne multispectral scanner data covering affected soybean fields were analyzed using three computer-assisted procedures: unsupervised, supervised, and pseudosupervised; the last method provided the best results. Landsat imagery was also investigated, but the foliar effects of SO_2 were too subtle to detect from orbit.

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The EPA Project Officer for this research project is James Stemmle, 401 M Street, SW., Washington, DC. His contribution to the direction of the research and his constructive review of the reported results are appreciated. The TVA Project Director is Herbert C. Jones, Supervisor, Air Quality Research Section, Air Resources Program, River Oaks Building, Muscle Shoals, Alabama.

SECTION 1

INTRODUCTION

BACKGROUND

The effects on vegetation of sulfur dioxide (SO_2) emissions from large, coal-fired power plants have been recognized as a potential problem for several decades. The traditional method for measuring the effects in the field involves observations of injury to SO_2-sensitive indicator species such as ragweed and blackberry. Records from fixed SO_2 monitoring stations are also used to determine the spatial characteristics of plume contact with the ground.

Some problems exist with the traditional approach to surveying and identifying SO_2 effects. The monitoring network is often inadequate for mapping the limits of the effects, and botanical surveillance is usually restricted to readily accessible areas because of the constraints of time. Highly trained biologists are needed to identify and record the symptoms of injury to foliage.

REMOTE SENSING

Spectroradiometry

Remote sensing--the detection and measurement of characteristics of phenomena from a distance, without direct contact--can assist those engaged in field surveillance of SO_2 effects on crops and trees. The technique provides a permanent record on film or magnetic tape. An instrumented aircraft can continuously cover extensive areas in a matter of hours.

The state of the art of remote sensing requires that ground truth--field observations--be gathered to support the analysis of the remotely-sensed data. Preliminary but detailed information should be gathered concerning the differences in spectral reflectance between the objects of interest (in our study, affected foliage) and the background (unaffected foliage). Spectral measurements may be made in the laboratory or in the field, or in both places. Such measurements would allow the selection of appropriate sensor configurations, films, filters, and airborne scanner channels and bandwidths, thus improving the chances of successful detection of SO_2 effects.

There are at least two methods for making spectral reflectance measurements. The traditional method is to make measurements at discrete points in the field with a portable spectroradiometer. An indirect method which may be more efficient in some instances is to make point measurements of the optical density of aerial photographs of SO_2-affected areas, and then convert these densities to reflectances. The latter method, called photometry, entails a complex calibration of the photographs before the conversion to reflectance can be made. In this study the investigator used both methods. Moreover, field plots of affected plants were used to bridge the wide gap between the laboratory and the uncontrolled environment of crops and trees in the vicinity of the power plant source.

Reflectance Properties and Vegetative Stress

For detecting the effects of air pollution on vegetation, the investigator selected an appropriate region of the electromagnetic spectrum spanning the visible and near-infrared wavelengths. The far-infrared (thermal) wavelengths were also used for measurements. These selections were based partly on the inherent properties of the spectrum and partly on the capabilities and availabilities of remote sensors.

The actual change in reflectance of a species or variety of plant under stress from SO_2 or some other agent is not easily predicted. Visible reflectance generally increases with stress, but the response of reflectance in the near-infrared is variable, although it eventually decreases in advanced senescence. In remote sensing studies, the stress-causing agent cannot usually be identified without ground truth. Foliar markings, which indicate the identity of the agent, cannot be resolved from the distances or altitudes at which the sensor is operated. However, clusters of stressed plants can often be distinguished from a background of normal plants.

Aerial Photography

Color and color-infrared photography show promise for detecting vegetative stress and so were used in airborne cameras to record the patterns of SO_2 injury to sensitive crops and trees. Several flying heights were used; they ranged from 500 m above ground level (AGL) up to almost 4000 m AGL on various missions. It is generally most efficient to fly at the highest altitude that enables the interpreter to detect the phenomena of interest, because more area is photographed per unit of time.

Airborne Multispectral Scanners

The multispectral scanner is at the frontier of remote-sensor technology. Digital processing of multispectral scanner data is advancing our capabilities to reduce the output of the scanner to understandable form. Digital classification and enhancement of detail in the images help the interpreter detect and measure the patterns of most interest to him. During the course of this project, an 11-channel multispectral scanner was employed on several occasions to detect and map SO_2 effects, and two digital image processing systems were used to process the data.

PURPOSE AND OBJECTIVES

The purpose of this 5-year study was to analyze and evaluate remote-sensing techniques to detect and map the effects of SO_2 emissions from large, coal-burning power plants on the foliage of sensitive crops and trees. The objectives were to test, refine, and develop ground-based, airborne, and satellite-borne remote-sensor instrumentation for this purpose.

SCOPE

The scope of the project included four coal-fired power plant sites in the Tennessee Valley region (Figure 1), several experimental plots, and several species of vegetation. Laboratory-based spectroradiometric experiments were performed on soybeans, wheat, and cotton. Techniques included stereoscopic photo interpretation, photometric analysis of aerial photographs, and digital image analysis. Ground truth was acquired by experienced surveillance biologists who observed affected vegetation in the greenhouse, in experimental plots, and in the field near the power plants. Investigations included the following SO_2-sensitive crop and tree species:

	Common Name	Scientific Name
1.	Soybeans	Glycine max (L.) Merr.
2.	Winter wheat	Triticum aestivum
3.	Cotton	Gossypium hirsatim
4.	Virginia pine	Pinus virginiana
5.	Loblolly pine	Pinus taeda
6.	White pine	Pinus strobus
7.	Shortleaf pine	Pinus echinata
8.	Hickory	Carya sp.
9.	Northern red oak	Quercus rubra (L.)
10.	Southern red oak	Quercus falcata Michx.

As the project progressed, its scope had to be narrowed to exclude the hardwoods (hickory and oaks), because SO_2-affected stands of these

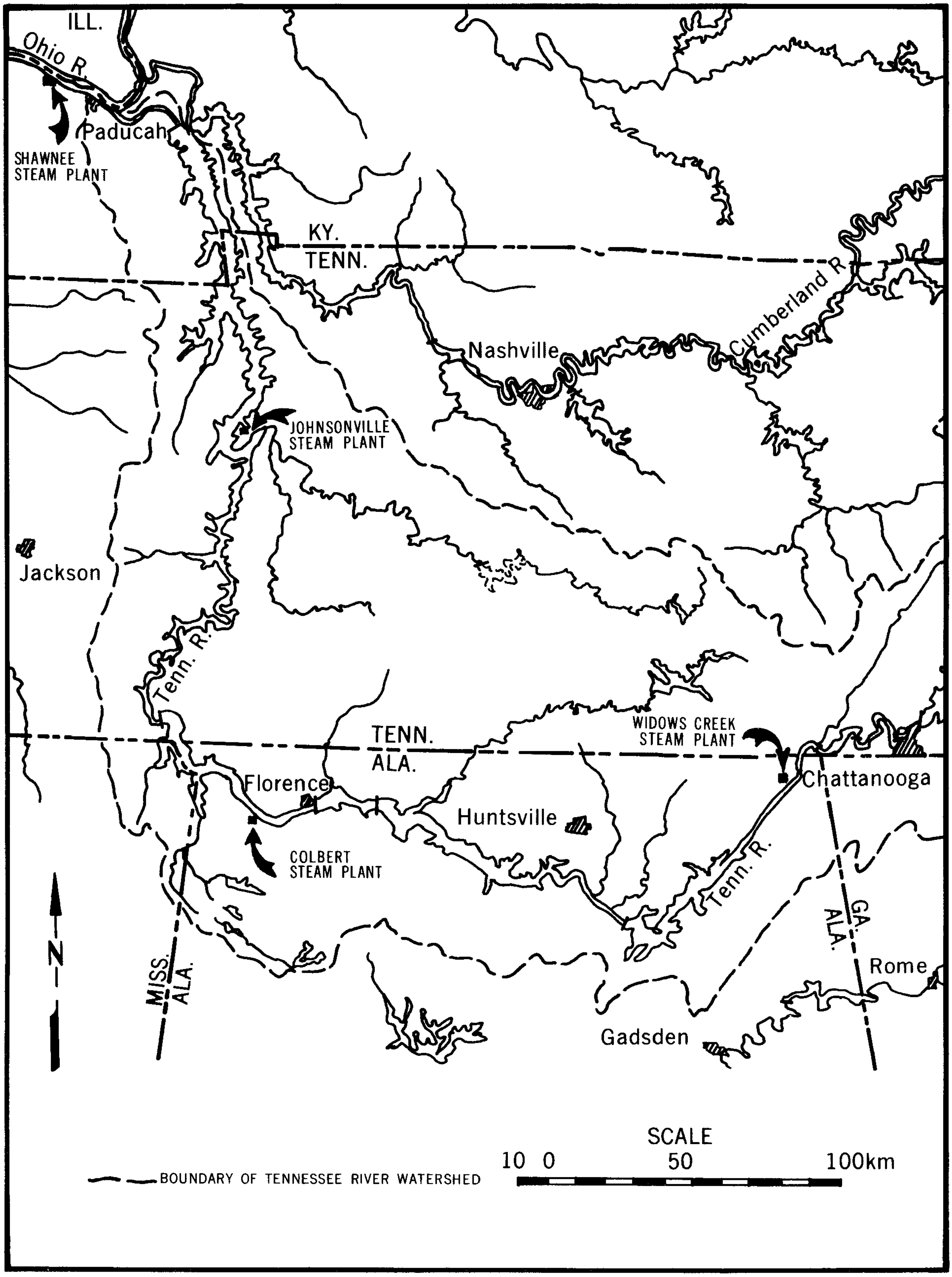

Figure 1. Western part of Tennessee Valley showing four steam plants.

trees were never encountered. Some affected pine stands were found near the Widows Creek Steam Plant and were studied, but the injury was light and discontinuous and could not be consistently detected. Affected wheat and cotton fields were never found, so SO_2 injury to these species was induced through the use of experimental plots. SO_2-affected soybeans were studied intensively and extensively.

HYPOTHESIS

The hypothesis of the research performed during this project was that there is a relationship between the reflectance of the plants and levels of injury to their foliage from sulfur dioxide. Such a relationship would form a theoretical basis supporting the use of remote sensors to detect and map the distribution of SO_2-affected plants.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Spectroradiometry is a useful technique for measuring the changes in visible and near-infrared reflectance that accompany relatively severe, SO_2-induced injury to the foliage of sensitive row crops. The remote-sensor technique is not practical for measuring reflectances of mature trees because of the difficulty in scanning such large objects from specific angles. Spectroradiometry provides valuable information for planning overflights so that the remote-sensor instruments can be tuned to detect and discriminate the SO_2-induced stress.

Laboratory scanning experiments indicate that changes in the total reflectance spectrum of soybeans accompany necrosis but not chlorosis. The ratio of near-infrared to red (IR/red) reflectance correlates significantly (α=.05) with necrosis of the foliage of these plants. In scans of winter wheat, the total visible spectrum, as well as the single bands, green and red, shows close relationships with foliar injury. (Laboratory-based IR scans of wheat were not made.)

Statistical analysis of scans of experimental plots of soybeans and wheat fails to verify laboratory findings. No relationship is apparent when reflectance and observed injury to soybeans are compared, but a relationship is evident between the two variables for wheat. The total reflectance spectrum (visible plus near-infrared), as well as the individual (green, red, and near-infrared) bands, is associated with SO_2 injury.

Photometric analysis of aerial color-infrared photographs of SO_2-affected soybean fields shows no relationship between single-band reflectance and foliar injury. The spectral bands included green, red, and near-infrared wavelengths.

Analysis of airborne multispectral scanner data indicates that SO_2-affected soybean fields can be distinguished from unaffected soybean fields when conditions are nearly ideal. Such conditions are defined generally as a continuous foliage canopy, mature stage of growth, and SO_2 effects that are moderate to severe. Comparison of three data classification procedures shows that a pseudosupervised procedure provides greater accuracy than either supervised or unsupervised. The pseudosupervised procedure can distinguish moderately to severely affected soybeans from unaffected soybeans with errors ranging from 11 to 24 percent.

Experience with three aircraft altitudes for acquiring scanner data indicates that 1800 m AGL flying height is superior to 500 and 3660 m AGL for detecting moderate to severe chlorosis symptoms on the foliage of row crops. Light chlorosis may be undetectable by an airborne scanner or camera regardless of platform altitude. Such effects are certainly undetectable by orbiting sensors, such as those aboard Landsat. This study indicates that unless the SO_2 effects are severe enough to result in necrosis, they will not be detectable from any altitude greater than 150 m AGL by remote sensors. Even when necrosis exists, detection may be possible only under nearly ideal conditions.

The hypothesis that there is a relationship between reflectance and observed levels of SO_2-induced injury to sensitive plants is neither accepted nor rejected in an unequivocal sense. The relationship is apparent when field conditions are nearly ideal for detection and the injury to foliage is relatively severe. The fact that the association (1) was generally apparent in data from controlled laboratory experiments;

(2) was sometimes verifiable in data from semicontrolled experimental plots; and (3) was seldom found in the uncontrolled data from SO_2-affected soybean fields located downwind from power plants suggests that extraneous variables were affecting the results. These variables included, but were not limited to, stage of growth, soil moisture, terrain slope, canopy density, farming practices, level of chlorosis or necrosis, herbicide effects, weeds, and variety of plant.

RECOMMENDATIONS

Because of the complexity of the relationship between reflectance and foliar injury from SO_2, spectroradiometry should be an integral part of planning for remote-sensor overflights of affected crops. The scanning technique is useful for measuring the spectral differences between target and background so that success in detecting stressed vegetation can be predicted. The spectroradiometer is also a valuable laboratory instrument for quantifying levels of foliar injury.

Photometric analysis of aerial photographs is a potential alternative to field-based scanning with a spectroradiometer. It would be advantageous if reflectances need to be sampled at many points over a large area. Our negative findings were probably a result of extraneous variables (e.g., weeds) controlling reflectance.

The color-infrared film type should normally be used instead of conventional color film because the infrared shows the patterns of stress better and provides superior penetration of atmospheric haze.

Airborne multispectral scanning should be employed, if appropriate, to detect and map SO_2-related injury to row crops whenever the foliar symptoms are relatively severe, consisting primarily of necrosis, and the canopy is continuous, dense, and weed-free. These conditions are quite restrictive because SO_2 effects in the field are usually subtle and consist mainly of chlorosis. These light effects cannot be detected consistently with currently available airborne or spaceborne remote sensors.

SECTION 3

RESULTS

LABORATORY SPECTRORADIOMETRY

General

Uniform groups of soybeans and winter wheat were grown in a greenhouse, exposed to controlled doses of SO_2 in a laboratory exposure chamber, observed for foliar effects, and scanned with a spectroradiometer. The resulting data were statistically analyzed to determine the spectral changes plant foliage undergoes when it is affected by SO_2.

Soybeans

Foliar injury (chlorosis and necrosis) was divided into traditional classes: unaffected (0 percent); light (1-10 percent); moderate (11-25 percent); severe (26-50 percent); and very severe (>50 percent). Mean reflectance curves for each class were computed. The areas under the curves were examined with respect to foliar injury. Shifts in narrow bands of blue, green, red, and near-infrared (IR) reflectance were also examined to determine whether statistically significant differences in mean reflectance existed between and among injury classes.

Some significant results were obtained by comparing the mean reflectances of injury classes through an analysis of variance statistical procedure (ANOVA). Significant (α=.05) differences in red- and green-band reflectance were found between unaffected soybeans and affected soybeans having greater than 10 percent necrosis. A significant (α=.05) difference was also found in the ratio of IR to red reflectance (IR/red) between the unaffected and affected soybeans.

The strength of the relationships between reflectance and foliar injury is indicated by the correlation coefficients (r) listed in Table 1.

TABLE 1. SIMPLE CORRELATION COEFFICIENTS (r) FOR SINGLE-BAND REFLECTANCE AND FOLIAR INJURY TO SOYBEANS

Symptom	Reflectance				
	Blue	Green	Red	IR	IR/Red
Chlorosis	+<u>0.20</u>	+<u>0.72</u>	+<u>0.36</u>	-0.10	-<u>0.32</u>
Necrosis	+<u>0.89</u>	+<u>0.92</u>	+<u>0.98</u>	0.00	-<u>0.94</u>

Underlined coefficients are significant, α=.05.

The table warrants a close examination. Except for green reflectance, the r coefficients for chlorosis are below 0.50; for necrosis, the visible reflectance bands, especially red, correlate much higher. IR reflectance alone showed no significant relationship to either symptom.

The ratio of IR to red reflectance has been found to be an indirect indicator of stress in foliage, according to other studies. However, the correlation of -0.32 between chlorosis and the IR/red ratio does not indicate a strong relationship. On the other hand, there is a strong relationship (r = -0.94) between necrosis and the ratio. With increasing necrosis, the IR component of the ratio decreases and the red component increases, thus bringing the ratio value down, closer to unity.

<u>Winter Wheat</u>

Foliar injury (chlorosis and necrosis) was divided into traditional classes: unaffected (0 percent); light (1-10 percent); moderate (11-25 percent); severe (26-50 percent); and very severe (>50 percent). The range of foliar symptoms was broad, consisting primarily of necrosis.

As with soybeans, mean reflectance curves were computed. The areas under the curves were examined with respect to foliar injury, as were changes in visible reflectance for particular wavelengths (blue, green, and red). IR reflectances of wheat were not measured.

The area under the reflectance curves increased with increasing necrosis (r^2 = 0.72) and chlorosis (r^2 = 0.85). The increase in red reflectance was greatest at moderate and severe levels of stress. The increase in green reflectance was greatest at light levels of stress.

Statistical analysis of the visible reflectance curves also included single bands. Simple correlation coefficients were computed to assess the relationship between injury and reflectance (Table 2). They range between +0.73 and +0.90.

TABLE 2. SIMPLE CORRELATION COEFFICIENTS (r) FOR SINGLE-BAND REFLECTANCE AND FOLIAR INJURY TO WINTER WHEAT

Symptom	Reflectance Blue	 Green	 Red
Chlorosis	+0.83	+0.90	+0.81
Necrosis	+0.73	+0.83	+0.85

Underlined coefficients are significant, α=.05.

A one-way analysis of variance showed that significant (F-test, α=.05) differences in reflectance existed among all injury classes of wheat.

FIELD SPECTRORADIOMETRY

General

Experimental 0.40-hectare (ha) plots of soybeans and winter wheat were grown and subdivided; then the subplots were exposed to several controlled doses of SO_2 and observed systematically to determine foliar effects. Then the plots were scanned row by row with a van-mounted spectroradiometer. The resulting data were statistically analyzed using procedures similar to those that were applied to the laboratory-based data described previously.

Soybeans

The affected subplots had higher green and red reflectance, lower IR reflectance, and a lower IR/red reflectance ratio. The reflectance measurements were grouped into three classes: those for unaffected (control) soybeans, those for chlorotic soybeans, and those for necrotic soybeans. Variations in visible reflectance (green and red) correlated significantly (α=.05) with necrosis but not with chlorosis (Table 3).

TABLE 3. SIMPLE CORRELATION COEFFICIENTS (r) FOR SINGLE-BAND REFLECTANCE AND FOLIAR INJURY TO SOYBEAN PLOT

Symptom	Reflectance			
	Green	Red	IR	IR/Red
Chlorosis	+0.47	+0.57	-0.62	-0.68
Necrosis	+0.83	+0.97	-0.65	-0.84

Underlined coefficients are significant, α=.05.

Analysis of variance was used to compare the differences in reflectance between SO_2-affected and unaffected soybeans. A significant (α=.05) difference in IR reflectance was found when chlorotic subplots were compared to unaffected subplots. Similar differences in IR/red reflectance were discovered. Significant differences in red reflectance, IR reflectance, and the ratio were found when necrotic subplots of soybeans were compared to unaffected subplots.

Winter Wheat

Four mean reflectance curves were produced by averaging the individual curves by necrosis class. The classes represented none or light (≤10 percent); moderate (11-25 percent); severe (26-50 percent); and very severe (>50 percent) necrosis. (No chlorosis was found on the wheat.) The three reflectance bands, green, red, and IR, as well as the IR/red ratio, were analyzed. The red band, the IR band, and the ratio seemed to be useful indicators of necrosis (Table 4).

TABLE 4. SIMPLE CORRELATION COEFFICIENTS (r) FOR SINGLE-BAND REFLECTANCE AND NECROSIS IN WINTER WHEAT PLOT

	Reflectance			
Symptom	Green	Red	IR	IR/Red
Necrosis	-0.06	+0.59	-0.53	-0.71

Underlined coefficients are significant, α=.05.

The trends of the relationships were also noteworthy. Red reflectance increased and IR reflectance decreased as the level of necrosis rose. The IR/red ratio decreased as necrosis increased.

A one-way analysis of variance was used to compare the differences in reflectance among the four wheat classes. Significant (α=.05) differences in red reflectance, IR reflectance, and the IR/red ratio, but not green reflectance, were found.

PHOTOMETRIC ANALYSIS OF AERIAL PHOTOGRAPHS

General

A method of calibrating the color-infrared (CIR) photographs was used so that the reflectances of vegetation could be obtained from them. Uncalibrated photographs contain many systematic errors which affect exposure and must be accounted for. The errors result from film processing, atmospheric effects, and variation in illumination. The calibration process, called photometric analysis, included spot measurements of image density, conversion of densities to exposure values, and finally, conversion of these exposures to percent reflectance. Photometric analysis was especially valuable when photographs of a different flight line, altitude, or date had to be compared.

Once reflectances were obtained for particular point locations, they were plotted and compared with ground-truth data on SO_2 effects to ascertain whether any relationships existed.

Overflights

Aerial photographic overflights of areas near 4 of TVA's 12 coal-fired power plants were performed during the 1977 and 1978 growing seasons when the foliar effects of SO_2 on vegetation were still visible to ground observers. Soybean fields near Colbert Steam Plant in northwestern Alabama, Johnsonville Steam Plant in western Tennessee, and Shawnee Steam Plant in western Kentucky were photographed, as were soybeans, winter wheat, and pine trees growing near Widows Creek Steam Plant in northeastern Alabama. Several flying heights and film types were used.

Colbert Site Tests

One extensive test and one intensive test of the photometric analysis technique were conducted using photographs of the Colbert Steam Plant area. The extensive test focused on five soybean fields that fell within a single photographic frame. Four of the fields were affected by SO_2 and one was unaffected. The effects consisted of light levels of chlorosis, but no necrosis. The soybean canopies were nearly continuous, but some areas were infested with weeds and there was evidence of drought-induced stress. A microdensitometer was used to measure optical densities of the CIR film at sample locations within each soybean field. The instrument was filtered so that measurements were made in the green, red, and near-infrared (IR) bands. The single-band densities were converted to reflectance and compared with foliar injury levels. No relationship was indicated. However, the IR/red reflectance ratio decreased as foliar injury increased. Also, the weed-infested fields showed high standard deviations for IR/red measurements, and weed-free fields with continuous canopies showed low standard deviations for IR/red.

The intensive test included a single field of SO_2-affected, mature, weed-free soybeans near Colbert Steam Plant. Measurements of optical density were made systematically at 196 points within the field to determine possible relationships between reflectance and three other parameters: chlorosis, plant height, and elevation of the field. After the densities were corrected to reflectance, regressions of this parameter versus chlorosis, and chlorosis versus elevation were calculated. None of these relationships was significant (α=.05), and the r^2 coefficients were all below 0.25. A comparison of three-dimensional plots of the data for the soybean field showed little similarity between the variations in reflectance and the other parameters.

Johnsonville Site Test

Several incidents of SO_2 injury to vegetation occurred near the Johnsonville area during July 1977 and were photographed from the air by TVA and EPA on different dates. A full range of foliar effects was still visible to the ground observer in many of the soybean fields at the time of the overflights. We obtained copies of all of the film for interpretation and photometric analysis.

Microdensitometer measurements of optical density were made at random point locations in 15 soybean fields where the SO_2 plume had contacted the crop. The number was later reduced to nine because the other six fields consisted of immature plants and incomplete canopies. The optical densities were then converted to reflectance.

Statistical analysis of the Johnsonville data included comparison of the reflectances with ground truth. The IR/red ratio correlated significantly (α=.05) with injury (r^2=0.32), but the direction (positive) of the relationship was not in accordance with theory. None of the single-band reflectances showed any relationship to injury.

ANALYSIS OF MULTISPECTRAL SCANNER DATA

General

Three times since 1975 TVA has arranged multispectral scanner (MSS) overflights of SO_2-affected soybean fields. The first overflight, which covered the Shawnee Steam Plant area, was conducted in 1975 by NASA/Earth Resources Laboratory, from Slidell, Louisiana. The results of analysis of this MSS data were negative because of the effects of diverse farming practices and differing stages of crop growth. The second MSS overflight was conducted in 1977 by the Environmental Protection Agency (EMSL-LV), who scanned affected soybean fields near Colbert Steam Plant. The third MSS overflight was done in 1978 by EMSL-LV, this time over affected fields near Shawnee. Concurrent CIR photography was acquired on all of these MSS overflights, and it was used along with ground truth to support the MSS imagery analysis. Analyses of the 1977 and 1978 data are summarized in this report.

Ground Truth

Colbert Site Test--Evidence of multiple exposures of vegetation to SO_2 was observed in a 1,620-ha area north of the Colbert Steam Plant during July and August 1977. A scanner overflight was conducted on August 29, at which time the soybeans still showed the foliar effects.

Shawnee Site Test--Field surveillance by TVA biologists showed that during early August 1977, vegetation was affected by SO_2 emissions in three areas totaling approximately 857 ha located south and east-southeast of the Shawnee Steam Plant. Effects ranged from very light to severe.

Optimal Flying Heights

The MSS lines over Colbert and Shawnee were flown at 1800 m and 500 m AGL. The lower altitude provided no improvement in accuracy of the results of data classification. Since a low altitude line generates more data per kilometer flown and is therefore more costly to analyze, we then concentrated on the higher altitude data.

Optimal MSS Channels

Existing computer algorithms developed by NASA/Earth Resources Laboratory were used to select the best four channels from eight for detecting and classifying SO_2-affected soybean fields using the Colbert data (Table 5). The selection was required before supervised data classification could be done by the computer, which required a maximum of four channels as input. Two procedures were used, the first procedure resulting from computation of divergence matrices showing optimal separation of data classes, and the second resulting from computation of maximum

TABLE 5. OPTIMAL MSS CHANNELS FOR DETECTING AND CLASSIFYING SO_2-AFFECTED SOYBEAN FIELDS NEAR COLBERT STEAM PLANT IN 1977

Procedure[a]	MSS channel designation[b]	Wavelength (μm)	Spectral region
1	4	0.50-0.55	Green
	7	0.65-0.70	Red
	8	0.70-0.79	Near-IR
	9	0.80-0.89	Near-IR
2	4	0.50-0.55	Green
	6	0.60-0.65	Red
	7	0.65-0.70	Red
	8	0.70-0.79	Near-IR

[a]Procedures discussed in text.
[b]MSS channels 3 through 11 (blue through thermal IR) considered.

divergence among individual areas (agricultural fields). The blue and thermal IR channels were rejected because of their inherently low contrast with respect to vegetation.

Optimal channels were also selected from the Shawnee data (Table 6). Basically the same channels were chosen as for Colbert. There was some open water in the Shawnee north-south flight line, and its influence probably resulted in selection of the blue channel by the computer.

MSS Data Classification

Classifying digital images involved three procedures: unsupervised, supervised, and pseudosupervised. The unsupervised procedure is done without intervention by the analyst, and no preliminary training of the computer is done. Therefore, the need for *a priori* knowledge of the scene is not great. The supervised procedure involves programming the computer with ground truth so it can recognize the phenomena. The pseudosupervised procedure is an efficient combination of the two others,

TABLE 6. OPTIMAL MSS CHANNELS FOR DETECTING AND CLASSIFYING SO_2-AFFECTED SOYBEAN FIELDS NEAR SHAWNEE STEAM PLANT IN 1978

MSS channel designation[a]	Wavelength (μm)	Spectral region
	North-South Flight Lines	
3	0.45-0.49	Blue
7	0.65-0.70	Red
8	0.70-0.79	Near-IR
9	0.80-0.89	Near-IR
	East-West Flight Lines	
5	0.55-0.60	Green
7	0.65-0.70	Red
8	0.70-0.79	Near-IR
9	0.80-0.89	Near-IR

[a]MSS channels 3 through 10 considered. Channel 11 (thermal IR) not considered. Procedure used was interclass distance separation.

and it uses a minimum of ground truth. The supervised and pseudosupervised procedures use a maximum of four input channels, while the unsupervised procedure can use eight.

The three procedures were evaluated by comparing their output which consisted of classified images (maps) depicting patterns of affected and unaffected soybean fields. The ground truth about the proportion of each field that was affected by SO_2 was compared with the classification results.

In MSS data classification, there are errors of omission and errors of commission. The first error results in underclassification and the second, in overclassification of the phenomena of interest.

The accuracy evaluation showed that the pseudosupervised classifier could map soybeans without regard to SO_2 effects with overclassification errors of 0.6 to 5.1 percent. This procedure could differentiate moderately to severely affected soybeans and unaffected soybeans with overclassification errors of 11.3 to 24.4 percent (Table 7). It was not tested on very light to light SO_2 effects. The unsupervised classifier could identify soybean fields without regard to SO_2 effects with overclassification errors of 7.6 percent. However, it could not separate SO_2-affected soybean fields from unaffected soybean fields.

The supervised classification procedure yielded inconclusive results. Because of time constraints, this classifier could not be tested on moderately to severely affected soybean fields. Had it been, the classifier might have yielded better results than the pseudosupervised procedure.

Enhancement of Patterns of SO_2 Effects Within Fields

The I^2S Image Processing System at TVA's Mapping Services Branch in Chattanooga was used to enhance and display selected scenes of MSS data covering the Shawnee area. The effects on soybeans ranged from very light to severe. A density level-slicing procedure was used to display the background in monochrome and the SO_2 effects in orange. The correspondence of patterns with field observations of injury was fairly close in some fields where the soybean canopies were dense and continuous. The scanner system was apparently not successful in detecting very light and light chlorosis. Moreover, the instrument did not consistently detect moderate and severe injury to the crop.

Multispectral scanner imagery from the orbiting Landsat vehicle was obtained for the Shawnee Steam Plant to cover a period when the SO_2 effects on soybean fields should have been visible to the ground observer. Preliminary analysis of the four individual MSS bands and the color composite provided no indication of patterns associated with the effects, so this task was discontinued.

TABLE 7. ERRORS RESULTING FROM PROCEDURES FOR DETECTING AND CLASSIFYING SO_2 EFFECTS ON SOYBEANS

Task	Site with Light SO_2 Effects		Site with Moderate to Severe SO_2 Effects	
	Unsupervised	Supervised	Unsupervised	Pseudosupervised
Separation of soybeans from other land cover	+7.2%	*	+7.6%	+5.1% (first flight line) +0.6% (second flight line)
Separation of SO_2-affected from unaffected soybeans	+142.0%	*	+101.4%	-24.4% (first flight line) +11.3% (second flight Line)

*Inconclusive results, error not determined
+Overclassification
-Underclassification
Zero percent would indicate no error

TECHNICAL REPORT DATA

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15. SUPPLEMENTARY NOTES This project is part of the EPA-planned and -coordinated Federal Interagency Energy/Environmental R&D Program.

16. ABSTRACT Three techniques for detecting and mapping sulfur dioxide (SO_2) effects on the foliage of sensitive crops and trees near large, coal-fired power plants were tested and evaluated. These techniques were spectroradiometry, photometric analysis of aerial photographs, and computer analysis of airborne multispectral scanner data.

Spectroradiometry is a useful, ground-based technique for measuring the changes in reflectance that accompany exposure of sensitive crops to SO_2. Photometric analysis of aerial color-infrared photographs has some practical advantages for measuring the reflectances of forest species or for synoptic point-sampling of extensive areas; these tasks cannot be done effectively by field crews. The relationships among reflectance, foliar injury, and yield of crops are complex and are affected by many extraneous variables such as canopy density. The SO_2 effects are easier to detect on winter wheat than on soybeans, but in either case they cannot be consistently detected by airborne remote sensors except under near-ideal conditions when the injury is moderate to severe. Airborne multispectral scanner data covering affected soybean fields were analyzed using three computer-assisted procedures: unsupervised, supervised, and pseudosupervised; the last method provided the best results. Landsat imagery was also investigated, but the foliar effects of SO_2 were too subtle to detect from orbit.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air pollution *	Infrared photography	Transport processes	
Electric power plants	Photometry	Char., meas. & monit.	
Photointerpretation	Reflectance	Crop & forest species	
Remote sensing *	Sulfur dioxide *	Digital image analysis	
Environmental surveys *	Plant pathology	Multispectral scanning	
		Microdensitometry	
		Tennessee Valley	

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