REMOTE SENSING APPLICATIONS IN FORESTRY

A report of research performed under the auspices of the

FORESTRY REMOTE SENSING LABORATORY,
SCHOOL OF FORESTRY AND CONSERVATION
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA

A Coordination Task Carried Out in Cooperation with
The Forest Service, U.S. Department of Agriculture

For

EARTH RESOURCES SURVEY PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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REMOTE SENSING OF CHANGES IN MORPHOLOGY AND PHYSIOLOGY OF TREES UNDER STRESS

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Dept. of Agriculture

by

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ABSTRACT

This is the third annual progress report describing the results of continuing studies of forest trees subjected to varying types of stress.

Statistical evaluations of reflectance data for sugar maple (*Acer saccharum*) indicated that remote detection of plant damage due to salt accumulation is most likely at wavelengths between 1.43 and 2.19 micrometers. Significant increases in reflectance were observed in the photographic infrared spectral region (0.8 to 1.2 micrometers) for low levels of salt, but not for high levels of salt.

Reflectance measurements made for foliage on watered and unwatered yellow poplar (*Liriodendron tulipifera*) seedlings agree with data previously reported by Weber and Olson (1967). Leaves which reached full size before watering ceased showed a slight increase in reflectance at most wavelengths when the plants were subjected to severe moisture stress. Leaves which unfolded under severe moisture stress were less reflective at all wavelengths. White ash (*Fraxinus americana*) leaves unfolding under severe moisture stress were more reflective than leaves on watered plants, however. Results with sugar maple were similar to those for ash.

Radiometric temperatures were consistently higher for stressed than unstressed plants.

Reflectance measurements for foliage from red and white pines (*Pinus resinosa* and *P. strobus*) infected with the root-rotting fungus *Fomes annosus* indicate that the 0.60 to 0.66, 0.78 to 1.0, and 1.2 to

2.6 micrometer bands may provide data leading to earlier detection of this disease.

ACKNOWLEDGMENTS

The research described in this report is being conducted as part of the Earth Resources Survey Program in Agriculture/Forestry sponsored by, and with financial assistance from, the National Aeronautics and Space Administration (~~Contract No. R-09-038-00[illegible]~~). The work is a cooperative undertaking of the Forest Service, U. S. Department of Agriculture, and The University of Michigan School of Natural Resources. Part of the salaries of professional employees are contributions of The University of Michigan and the Forest Service.

The generous support of Dr. Warren H. Wagner, Jr., Director of The University of Michigan Botanical Gardens, and the entire staff of the Botanical Gardens, is gratefully acknowledged.

Special thanks are also extended to Dennis Waterman, Mrs. Elaine Gillies and Mrs. Felicia Clemons for their assistance in gathering the field and laboratory data and processing the data for publication.

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INTRODUCTION

Early detection of stress in vegetation is one of the keys to correcting the condition causing the stress. Such early detection is difficult to achieve over large areas using ground methods, but remote sensing techniques offer considerable promise in certain cases.

Controlled studies of changes in reflectance and emittance characteristics of foliage on trees subjected to different levels of moisture stress were begun at The University of Michigan in 1965. Results of work completed through the 1968 growing season were described by Weber and Olson (1967) and Olson and Ward (1968). This report summarizes additional work performed through September, 1969. Three different studies are included.

STUDY I: INVESTIGATION OF CHANGES IN FOLIAR REFLECTANCE AND EMITTANCE OF BROADLEAVED SEEDLINGS EXPOSED TO VARYING TREATMENTS. (Study Leader - J. M. Ward)

Collection of foliar reflectance data under this study has been completed. Results of statistical evaluations of the data were reported at the Sixth Symposium on Remote Sensing of Environment in

October (Ward, 1969) and a copy of this report is appended as Appendix A to this report.

Work Currently in Progress

Preparation of microtome sections for a detailed analysis of anatomical differences between leaves from plants subjected to different treatments is nearly complete. Relationships between these anatomical differences and previously reported reflectance differences for the same plants are being evaluated.

Inoculation of the surviving plants with the Verticillium wilt fungus is planned. Effects of the fungus on reflectance and emittance characteristics of the foliage will be evaluated to determine if the salt treatments increased the susceptibility of the treated plants to this organism.

STUDY II: DIFFERENCES BETWEEN RING- AND DIFFUSE-POROUS SPECIES IN THEIR RESPONSE TO MOISTURE STRESS.
(Study Leader - W. G. Rohde)

Previous work suggested that a fundamental difference may exist between ring- and diffuse-porous species in their responses to moisture stress (Weber and Olson, 1967). This study is designed to provide additional information on response characteristics of these two broad groups of broadleaved trees.

Methods

Two and three year old seedlings of several species were subjected to varying degrees of moisture stress by withholding water. Weekly reflectance measurements were obtained from leaves on watered and unwatered plants throughout one growing season without detaching the leaves from the plants. A Beckman DK-2a spectrophotometer was used and measurements were made over the spectral range from 0.5 to 2.6 micrometers (um). The direct digital readout component of the spectrophotometer system was inoperative, increasing the time which will be required to reduce the data. Radiometric temperatures were measured with a Barnes IT-3 radiometer. Hourly measurements were made on several days to determine the magnitude of diurnal changes in radiometric temperature differences between stressed and watered plants. More complete descriptions of methods and techniques are contained in our two previous annual reports (Weber and Olson, 1967; Olson and Ward, 1968).

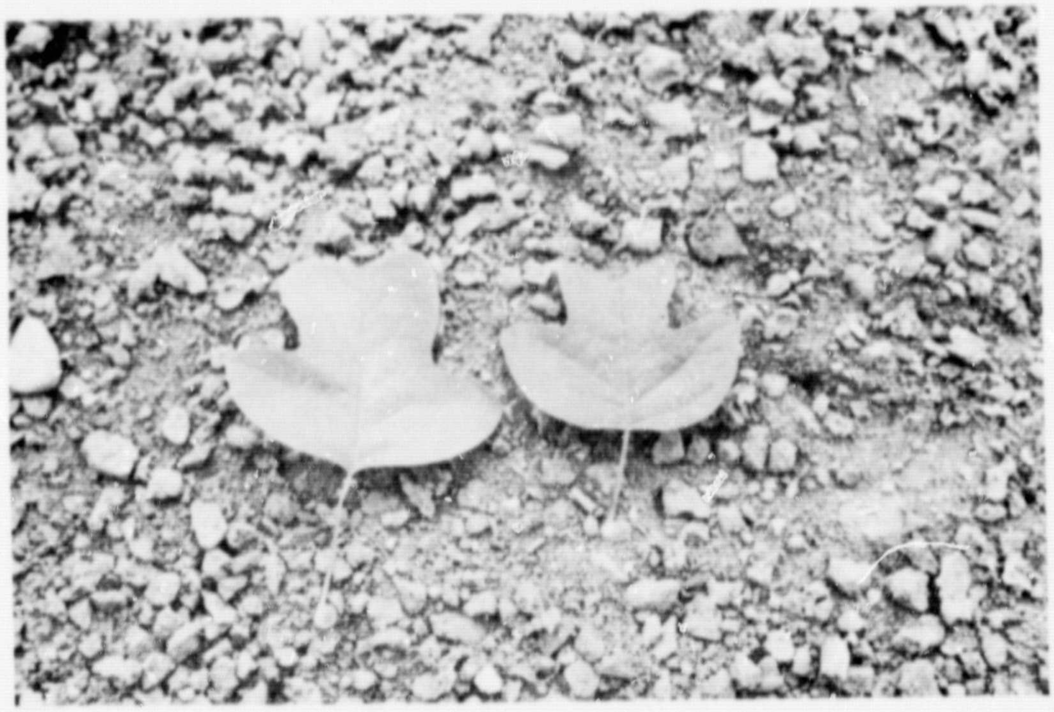
Results

Results with yellow poplar (Liriodendron tulipifera) agreed with those previously reported by Weber and Olson (1967). Leaves unfolding under high levels of stress were less reflective at most wavelengths than leaves on the well-watered plants (Table 1 and Figures 1 and 2). Leaves which reached full size (hereafter referred to as "mature") before the plants were subjected to moisture stress became somewhat more reflective, at most wavelengths, than leaves on plants watered regularly throughout.

Data for other species indicate that not all species show the same symptoms when exposed to moisture stress. Leaves developing on white ash (Fraxinus americana) seedlings under high stress are more reflective than leaves developing at low stress on well-watered plants (Figure 3). Yellow poplar is a diffuse-porous species, while white ash

Table 1. Comparison of Percent Light Reflectance (Relative to MgO) of Watered and Unwatered Yellow Poplar Seedlings.

Tree No.	Date	Tree Condition	Spectral Region (um) .49-.51	.52-.54	.59-.61	.62-.64	.79-.81	.89-.91	.99-1.01	1.09-1.11	1.19-1.21	1.42-1.44	1.63-1.65	1.93-1.95	2.18-2.20
LT02	3-27-69	Watered	12.0	15.3	9.3	10.7	35.1	49.4	48.3	47.5	45.5	18.8	34.4	6.2	20.2
LT04	3-27-69	Unwatered	10.0	11.1	6.6	10.0	32.0	46.5	45.5	44.6	43.2	20.3	34.0	6.7	20.6
LT02	4-22-69	Watered	11.3	14.9	9.6	11.3	33.8	51.3	50.4	49.5	47.6	22.2	36.9	7.8	22.2
LT04	4-22-69	Unwatered	11.7	14.5	8.6	10.3	33.7	48.4	47.2	46.3	44.7	21.8	35.0	7.8	21.7
LT02	5-12-69	Unwatered	11.8	15.8	10.8	11.6	32.4	50.3	49.5	48.9	47.2	23.0	37.0	8.5	22.4
LT04	5-12-69	Unwatered	11.2	16.2	10.9	10.7	30.5	48.2	47.3	46.7	45.1	24.0	36.3	9.7	23.3
LT02	5-16-69	Unwatered	12.9	17.4	11.7	14.8	36.4	50.5	50.2	48.9	47.4	24.7	37.9	9.6	24.1
LT04	5-16-69	Unwatered	12.7	17.3	12.7	13.3	33.8	48.6	48.1	47.4	46.2	24.8	36.9	9.9	24.1
LT02	5-20-69	Unwatered	15.0	24.1	22.8	20.9	51.2	51.8	52.0	51.6	50.3	32.9	42.7	17.7	30.9
LT04	5-20-69	Unwatered	13.9	18.0	12.8	10.7	48.0	47.6	47.3	46.7	45.3	26.3	37.3	10.7	29.0



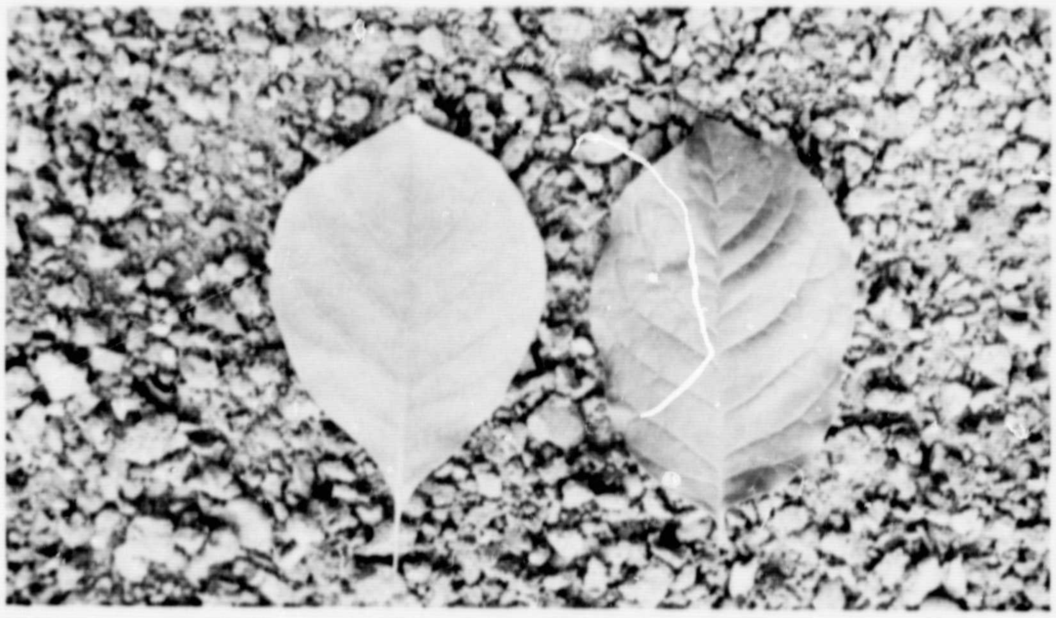
Kodachrome II/No Filter

Ektachrome IR/Wratten 12 Filter

Figure 1. Color and false-color photographs of yellow poplar leaves that developed under low (left) and high (right) levels of moisture stress. Leaves that developed under stress were consistently darker than leaves that developed on well-watered plants.

Kodachrome II/No filter

Figure 2. Visual appearance of a single yellow poplar seedling which received ample water, received no water, and then was watered again. Alternating layers of light and dark leaves are visible. The dark leaves developed during periods when the seedling received no water.



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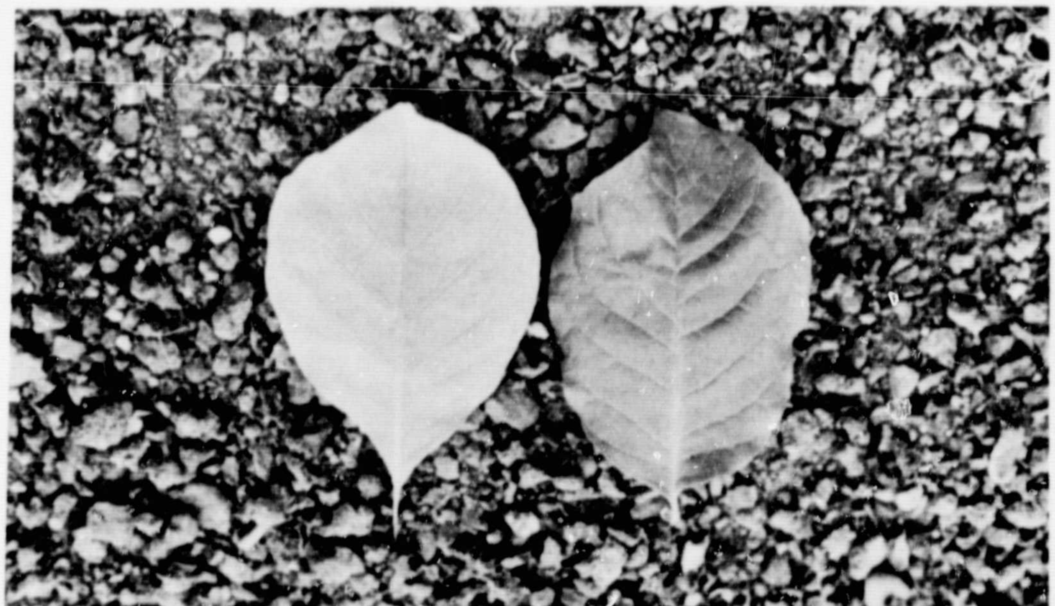


Figure 3. Color and false-color photographs of white ash leaves that developed under low (left) and high (right) levels of moisture stress. Leaves that developed under stress were consistently lighter than leaves which developed on well-watered plants.

is ring-porous. Results similar to those for white ash were obtained for sugar maple (Acer saccharum), a diffuse-porous species whose leaf-flushing characteristics resemble those of ring-porous trees.

Additional reflectance data were obtained for quaking aspen (Populus tremuloides) and yellow birch (Betula alleghaniesis), both diffuse-porous, and are being studied. Data from mature leaves on sugar maple, quaking aspen, and yellow birch seedlings under severe moisture stress show a distinct relationship between foliar moisture content and leaf reflectance. Although reflectance patterns are similar for all three species, reflectance changes are observable at higher foliar moisture contents in sugar maple than in the other two species.

Radiometric temperature data for yellow poplar, white ash, sugar maple, and red oak are similar. All species gave higher radiometric temperatures for unwatered plants than for those watered regularly (Figures 4-7). Of these four species, the difference in temperature was least in sugar maple, a result which may be related to wilting (Figure 8).

To check the effects of wilting on apparent temperatures, leaves on well-watered sugar maple seedlings were tied in a nearly vertical position. Radiometric temperatures of such plants were consistently cooler than plants with leaves in a horizontal position by 3° to $6^{\circ}C$. This suggests that detection of plant moisture stress with thermal sensors may be more difficult if the fol age on the stressed trees has wilted.

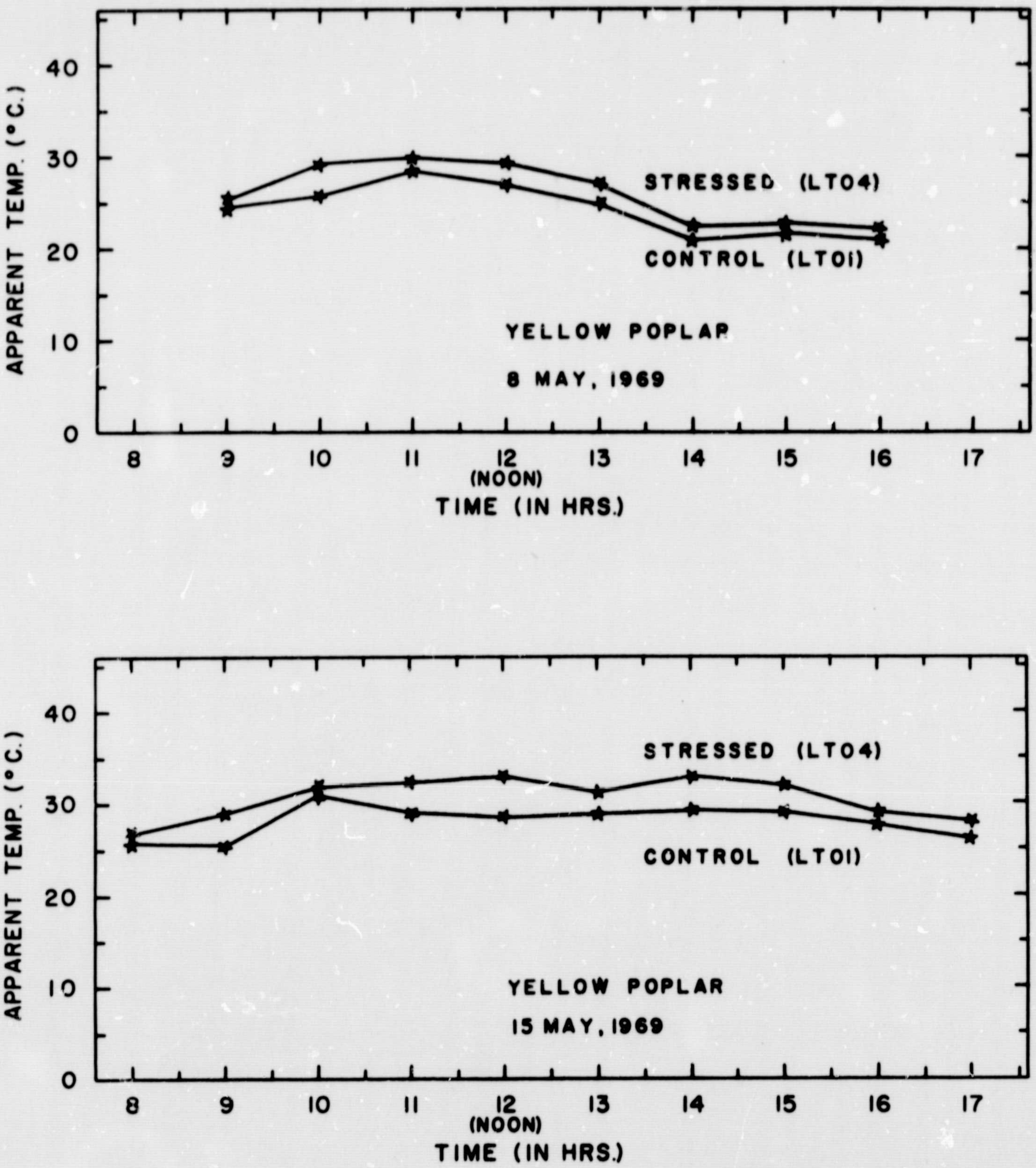
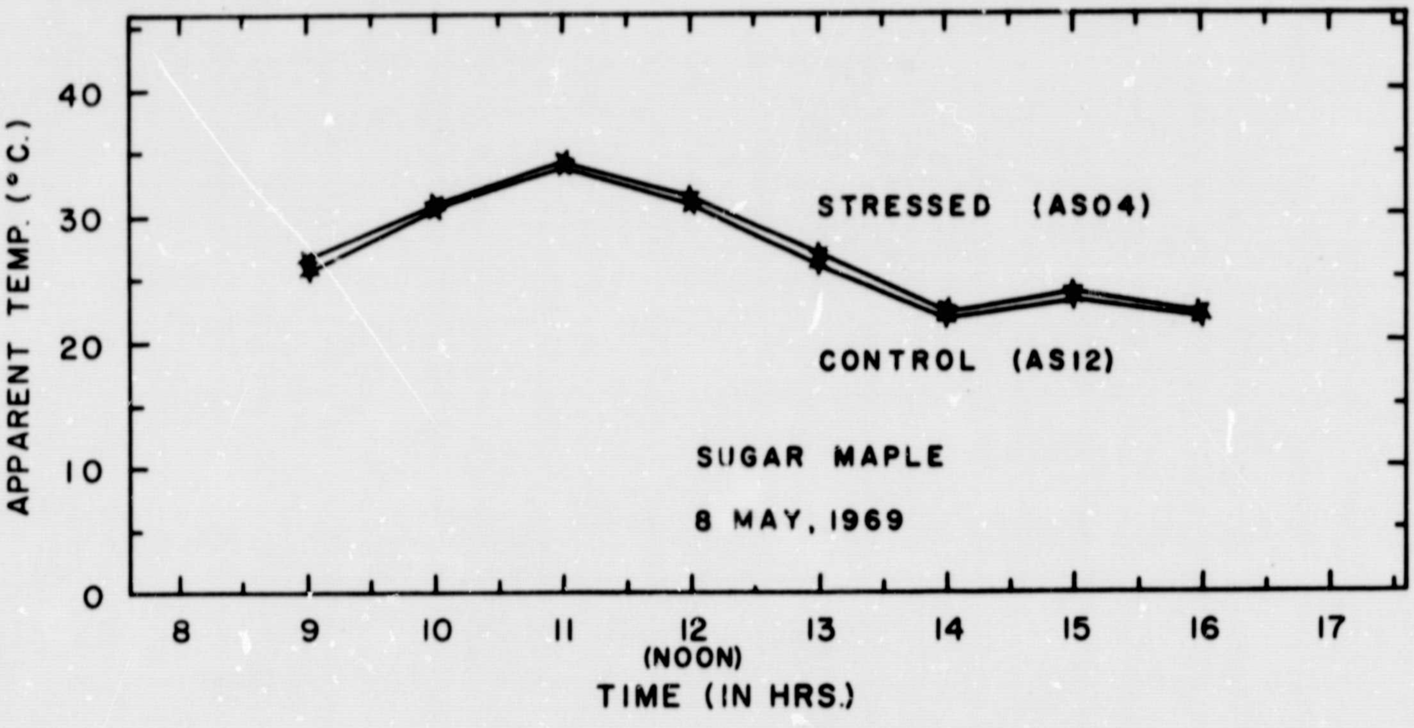


Figure 4. Variation in radiometric temperature of foliage on two yellow poplar seedlings on two different days. Tree LT04 had received no water since 1 February 1969 and was consistently warmer than tree LT01 which had been watered regularly.



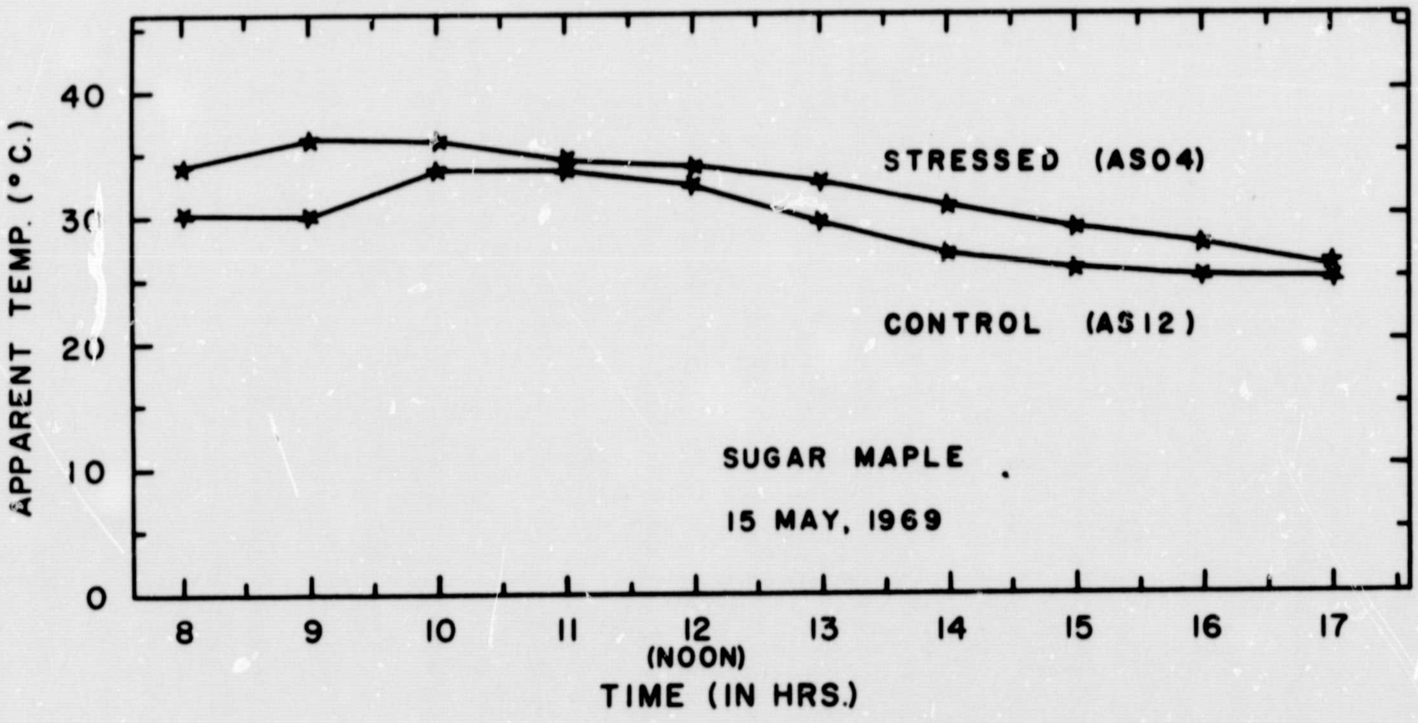


Figure 5. Variation in radiometric temperature of foliage on two sugar maple seedlings on two different days. Tree AS04 had received no water since 1 February 1969. By 15 May its temperature was consistently higher than that of tree AS12 which had been watered regularly.

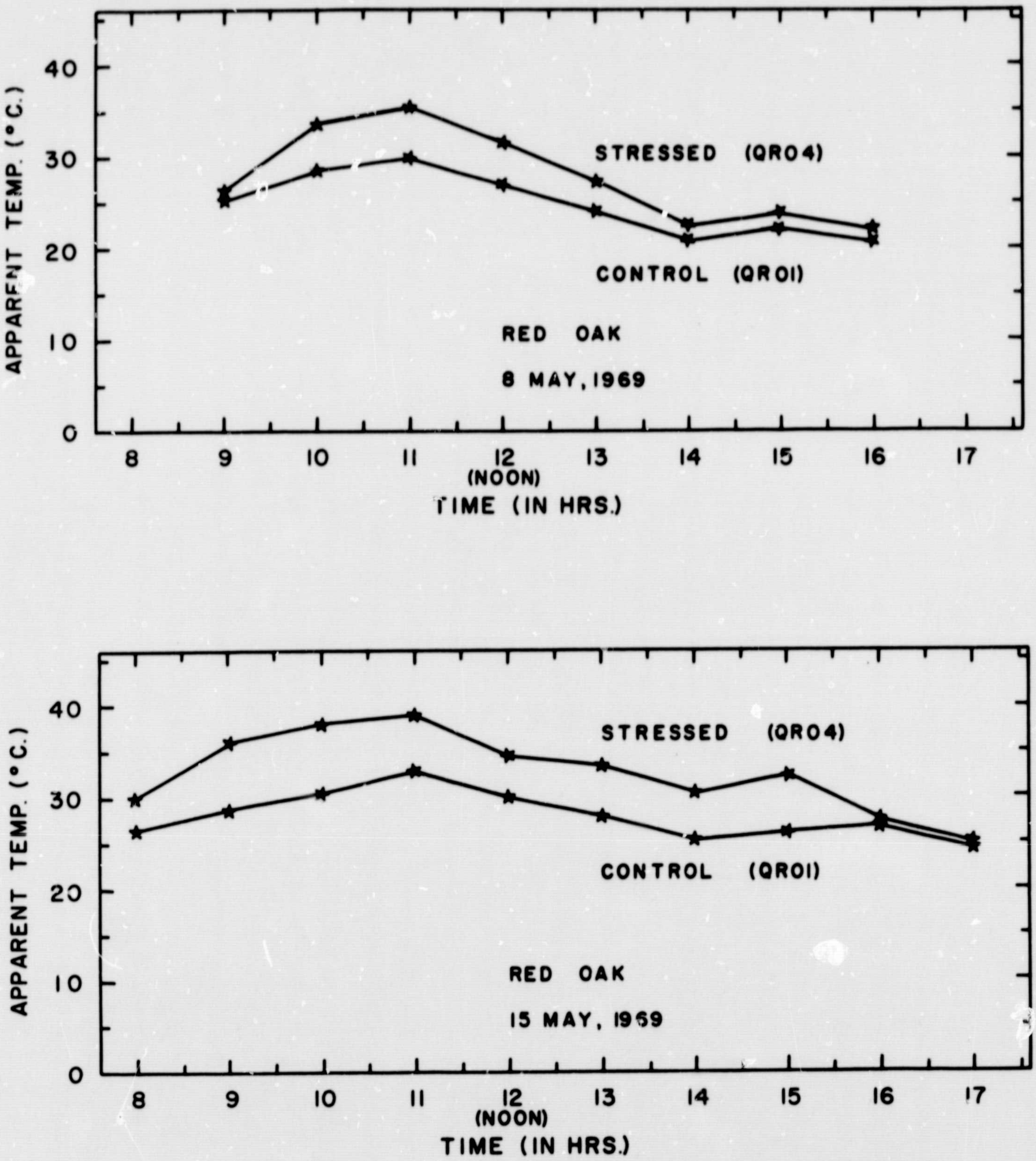
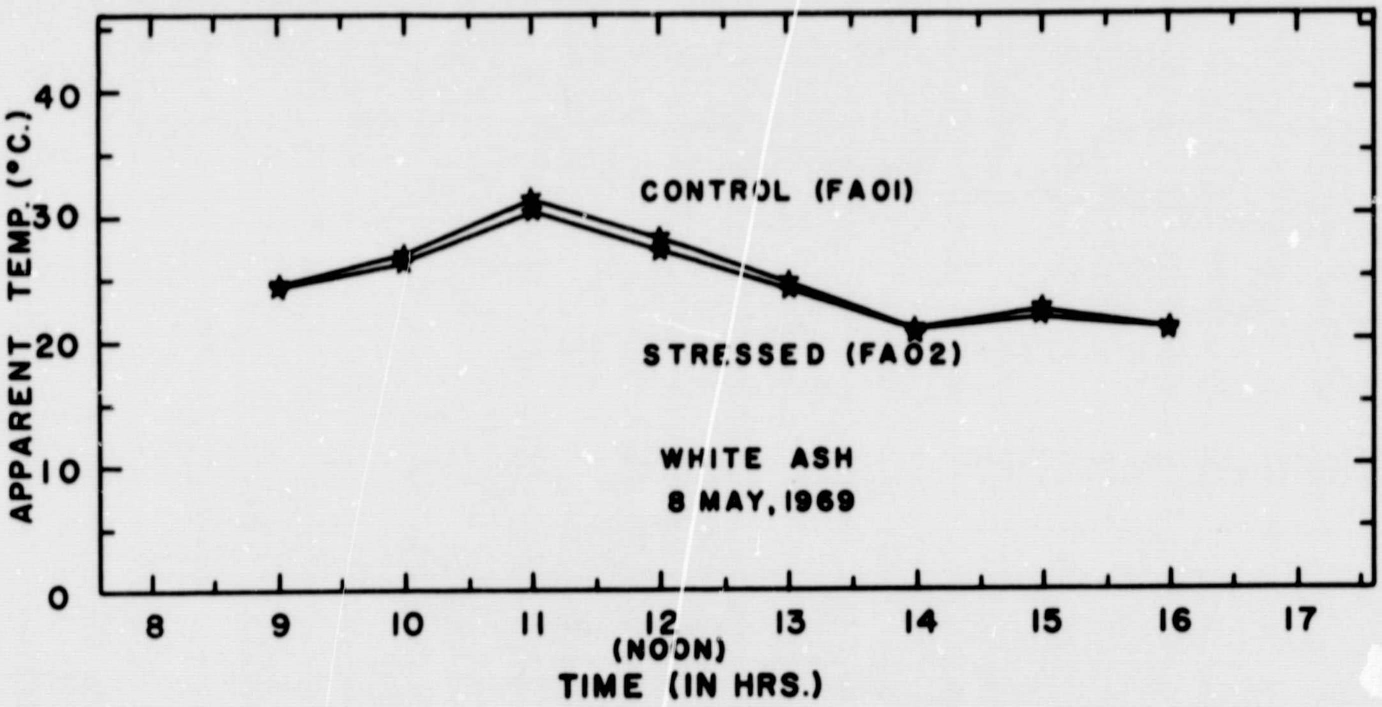


Figure 6. Variation in radiometric temperature of foliage on two red oak seedlings on two different days. Tree QR04 had received no water since 1 February 1969 and was consistently warmer than tree QR01 which had been watered regularly.



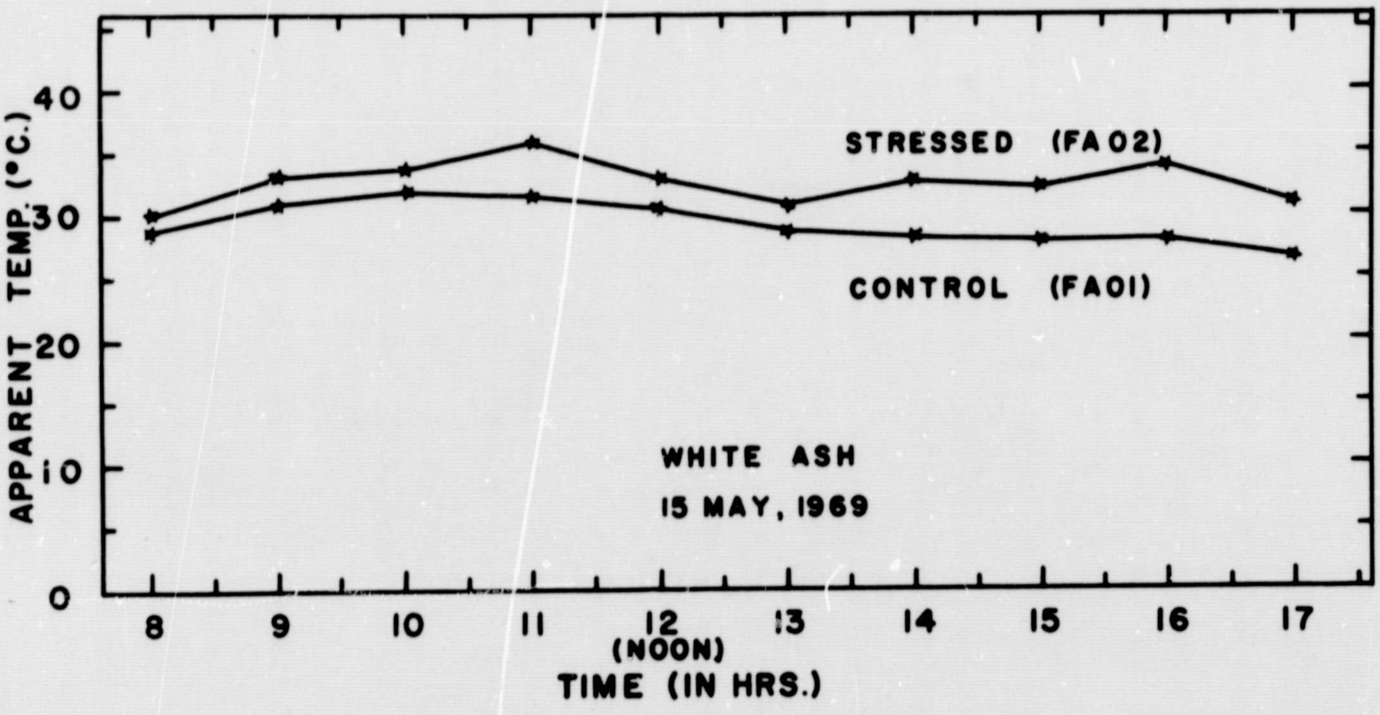
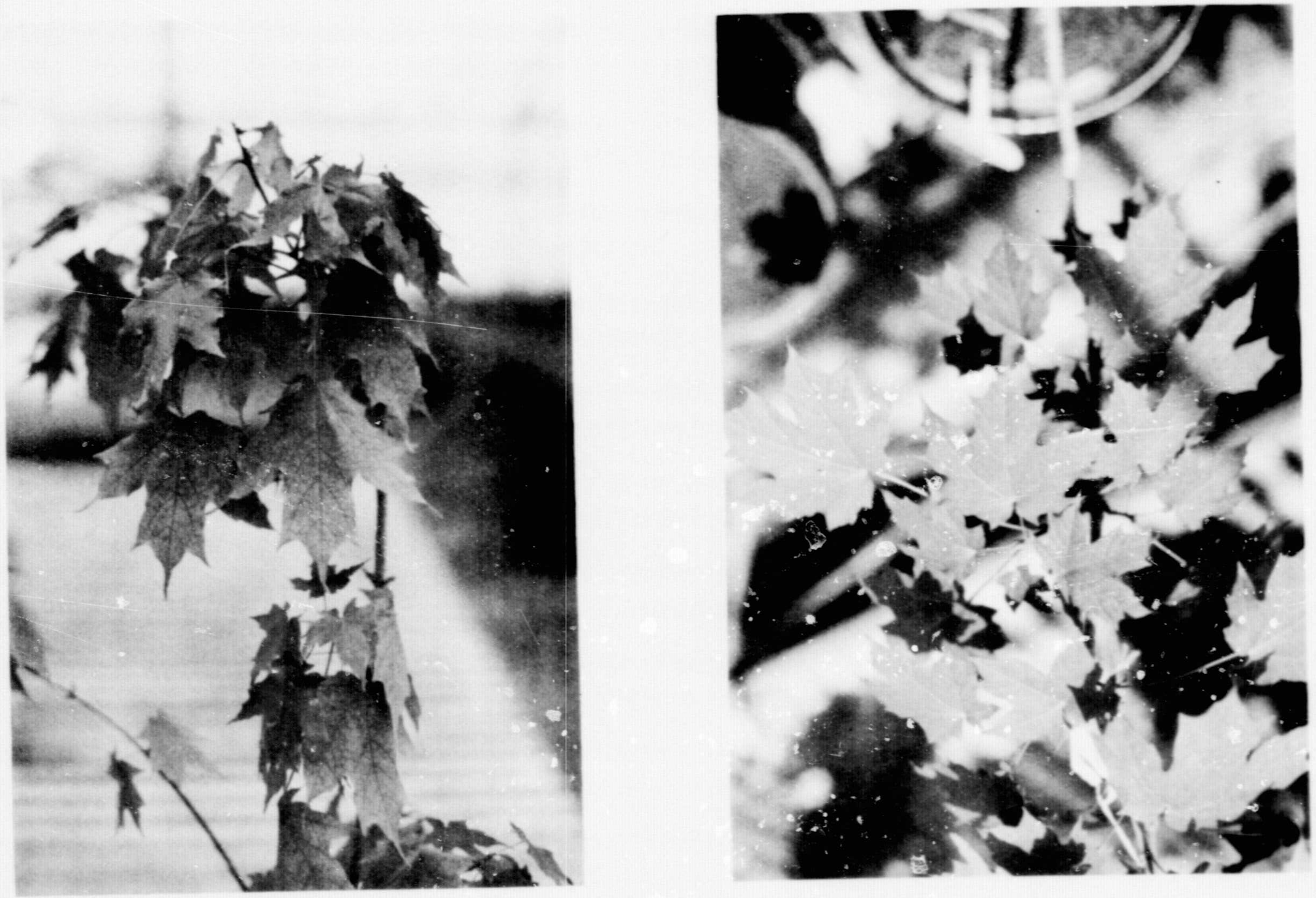


Figure 7. Variation in radiometric temperatures of foliage on two white ash seedlings. Tree FA02 was not watered after 11 May 1969, while tree FA01 was watered regularly. By 15 May the temperature of tree FA02 was 2 to 6°C higher than for tree FA01.



<u>Figure 8.</u> Visual appearance of a sugar maple seedling that had not been watered for sixty days (left) and a sugar maple seedling that was watered regularly (right). The foliage of the unwatered plant was severely wilted but its apparent temperature was only 2°C higher than foliage on the well-watered tree.

Work Currently in Progress

Reduction and analysis of the data gathered during the 1969 growing season are continuing. Selected leaves from each treatment have been prepared for analysis of anatomical changes associated with the reflectance and emittance data. Leaf cross-sections will be obtained with a sliding microtome and will provide the basis for this analysis.

STUDY III. AERIAL DETECTION OF FOMES ANNOSUS IN PINE PLANTATIONS. (Study Leader - W. G. Pohde)

Natural infections of the root-rotting fungus *Fomes annosus* were discovered in pine plantations within the NASA Ann Arbor Test Site in 1968. Reflectance data for infected and healthy trees at the test site, and for seedlings inoculated with the fungus in the greenhouse, indicate that multispectral imagery may provide an early detection capability. The 0.60 to 0.66, 0.78 to 1.0, and 1.2 to 2.6 um bands seem to offer considerable promise.

Overflights of the Ann Arbor Test Site by The University of Michigan C-47 aircraft were scheduled for July, August and September, 1969. The July flight was delayed until August 4 and was followed by a second flight on August 13. The September flight was delayed until October, and further delayed when the aircraft lost an engine.

Analysis of the imagery from the two August flights has been delayed by the lack of imagery. This analysis will begin as soon as the imagery is received from NASA.

DISCUSSION

The results of these studies appear to have distinct implications in remote sensing of the vigor and condition of forest stands.

Data now available indicate that the wavelength band between 1.4 and 2.2 micrometers offers the highest probability for early detection of salt injury in trees. Unfortunately, this band is so strongly influenced by atmospheric moisture that its usefulness from airborne or spacecraft platforms may be limited. There is some hope, however, that meaningful data can be obtained at wavelengths between the strong water absorption bands near 1.43 and 1.94 micrometers.

The continuing work with reflectance from ring- and diffuse-porous trees indicates that basic differences do exist between species in their responses to stress. Because of this, it may be impossible to use a single criterion, or a single discriminant function based on several wavelength bands, to detect similar stresses in different plants.

The work on emissivity of trees suggests that the 8 to 14 micrometer band may provide data permitting detection of trees under moisture stress. Since the available data show no significant change in the difference in radiometric temperatures between stressed and unstressed trees from early morning to late afternoon, time of day may prove a minor factor in planning missions for detection of moisture stress. These data should be used with caution, however, for they are based on greenhouse conditions. Higher wind velocities in the real world may reduce the difference in radiometric temperatures between stressed and unstressed plants below the detection threshold.

Work on early detection of <u>Fomes annosus</u> has not progressed far enough to provide field checks of the laboratory data.

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APPENDIX A

THE SIGNIFICANCE OF CHANGES IN INFRARED REFLECTANCE IN SUGAR MAPLE (ACER SACCHARUM MARSH), INDUCED BY SOIL CONDITIONS OF DROUGHT AND SALINITY

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ABSTRACT

Sugar maple seedlings were subjected to treatments of drought and salinity in the greenhouse, and percent foliar reflectance measurements obtained over the wavelength range from 500 to 2600 nanometers (nm). Analysis of variance of data from nine wavelengths indicated that:

(a) reflectance at wavelengths of 1430, 1940 and 2190 nm was significantly increased by both treatments, even before visible symptoms appeared;

(b) reflectance at wavelengths of 530 and 640 nm was significantly increased only in cases where visible symptoms were obvious;

(c) reflectance at wavelengths of 800, 1000 and 1200 nm was significantly increased by low soil salinity in the presence or absence of visible symptoms, but was unaffected by drought or high salinity, even after visible symptoms had developed.

These results suggest that (1) remote sensors operating at wavelengths of 1430 nm or longer provide the greatest likelihood of previsual detection of plants affected by drought and high or low salinity; and (2) multiband multidate remote sensing systems operating at all of the above-mentioned wavelengths might permit identification of specific agents responsible for stress in plants.

INTRODUCTION

Experiments have been conducted at The University of Michigan to discover whether salinity and drought treatments produce significant changes in reflectance properties of leaves of sugar maple (Acer saccharum Marsh), and to determine at which wavelengths such changes can best be detected.

Methods

Sugar maple seedlings up to 0.5 meter high were grown in the greenhouse under controlled conditions of drought or salinity for two growing seasons (1968 and 1969). Foliar reflectance measurements were made repeatedly, using the upper surface of selected leaves which were not removed from the plants. The instrument used was a Beckman DK-2A spectroreflectometer, operating over the wavelength band from 500 to 2600 nanometers (nm). Data from nine wavelengths (see Figure 1) were subjected to multivariate analysis of variance (anova) to assess the significance of variation in reflectance properties. The nine wavelengths chosen include 530 nm (green); 640 nm (near the strong absorption band of chlorophyll); 800, 1000 and 1200 nm; the water-absorption bands, 1430 and 1940 nm; and 1640 and 2190 nm.

DROUGHT TREATMENT

The 1968 Experiment. A randomised block experiment was designed to ensure that each drought treatment was applied to plants of different vigour, as indicated by their height. Thirty plants were assigned to ten blocks, each block comprising three plants of comparable vigour. In five blocks the plants "leafed out" before treatment began, while in the other five they were leafless before and "leafed out" during treatment. Of the three plants in each block, one was watered daily, one twice weekly and one once weekly with distilled water to produce control, moderate drought and severe drought conditions, respectively. Reflectance measurements were made on the selected leaf on each plant on two occasions, the seventeenth day of treatment, after all plants had "leafed out", and the sixty-fifth day, or before permanent wilting of severely droughted plants. Treatments, blocks and time of "leaf out" were factors in the anova of these data.

The 1969 Experiment. Six plants from the 1968 experiment, three control and three moderately droughted, were subjected to the same treatments for six months in 1969. Treatment began shortly before the plants "leafed out". Six leaves per plant were randomly selected and tagged for identification. Reflectance measurements on these leaves were made weekly in the fourth to sixth months of treatment. Data were analysed from weeks 1-5 and the 10th week of this series of measurements (13th to 17th, and 22nd week after treatments began). Treatments, plants, leaves and weeks, where appropriate, were the factors in the anova.

SALINITY TREATMENT

The 1968 Experiment. 140 sugar maple seedlings, all of which had "leafed out", were assigned to 20 blocks, each block comprising seven plants of comparable vigour. 10 blocks received solutions of sodium chloride (NaCl) and 10 calcium chloride ($CaCl_2$) in distilled water. Seven salt treatments were randomly assigned to the plants in each block: 0.0% (control) 0.05, 0.1, 0.25, 0.5, 1.0 and 2.0% concentration. The soil solution (at the appropriate salt concentration) was maintained at field capacity in each pot to ensure that drought was not a factor in this experiment.

Reflectance measurements were made on one leaf per plant in the sixth week of treatment (or before death in the case of one plant treated with 2.0% NaCl). The data from nine wavelengths were analysed with treatments, salts and blocks as factors in the anova.

The 1969 Experiment. Two NaCl and two $CaCl_2$ blocks were chosen from the 1968 salinity experiment. Three plants in each block were selected and their treatments renewed before they "leafed out". They were 0.0%, 0.25% and 0.5% of the appropriate salt in the soil solution. In the fourth, fifth and sixth months of treatment, reflectance measurements were made weekly on six randomly selected leaves on each plant. Data from weeks 1-5 and the 10th week of measurement, at nine selected wavelengths, were analysed. Treatments, salts, blocks, leaves and weeks, where appropriate were the factors in the anova.

RESULTS AND DISCUSSION

DROUGHT TREATMENT

In 1968, severely droughted plants died during the experiment, between the 17th and 65th days of treatment. As death approached, their leaves became permanently wilted and their colour changed to fawn as they dried. In 1969, drought treatment was less severe and did not result in death during the experiment, nor did it produce permanent wilting or fawn coloration.

The F values and their significance obtained in each drought treatment anova are presented in Tables 1-4. The treatment effects are summarrized in Table 5.

Treatment Effect. In Table 5 it can be seen that in 1969, before there was any significant change in reflectance of visible wavelengths or development of obvious symptoms, the moderately severe drought treatment produced a significant increase in reflectance at wavelengths longer than 1400 nm. No indication of drought was apparent at wavelengths between 800 and 1200 nm.

"Leaf Out" Effect. Tables 1 and 2 indicate that reflectance at some wavelengths is higher if plants "leaf out" before drought treatment. The actual increase in mean reflectance at these wavelengths was 2.0%.

Week Effect. Table 3 shows some significant changes in reflectance at several wavelengths from week to week (Figure 2).

Plant Effect. There was a large amount of random variation between plants in weeks 1-5, but plant effects were less significant in the data from the 10th week (Table 4).

SALINITY TREATMENT

In 1968, plants treated with 2.0% salt (NaCl or $CaCl_2$) developed visible symptoms in the oldest leaves first, before any wilting occurred. The symptoms were changes in colour, from green to yellow, to fawn or reddish brown, beginning at the tips of leaves, spreading to the edges and then towards the base of the midrib. Wilting of a leaf did not occur until almost no green area remained. Lower concentrations of salt induced the same symptoms, but more slowly. Most plants treated with 1.0% or 2.0% salt died, some towards the end of the first growing season, some during over-wintering in an outdoor sunken cold-frame, and others early in the second growing season after treatment was renewed. Plants receiving 0.5% or 0.25% salt "leafed out" normally in the second season after renewal of treatments, and began to show visible symptoms only after ten to twelve weeks of treatment in 1969. By the 22nd week of treatment (tenth week of reflectance measurement), all plants except the controls were showing some symptoms, some more than others. Those treated with 0.5% salt were affected sooner than those with 0.25% and their symptoms were much further advanced by the tenth week of measurement. Plants treated in 1968 and 1969 with 0.1% or less of either salt showed no ill effects beyond slight yellowing of the extreme tips of some leaves at the end of the second growing season.

Thus, sugar maple tolerates low concentrations of NaCl or $CaCl_2$ in the soil solution without ill effect, but higher concentrations of both salts kill the plants, the speed of death being proportional to the concentration of the salt.

Treatment Effect. In 1968, salt concentrations of up to 1.0% in the soil solution produced very little effect, visible or otherwise, on the sugar maples concerned (Table 7), so that the significant increases in reflectance due to treatment, as reported in Table 6, can be attributed to the 2.0% treatment. In 1969, differences in reflectance due to treatment were highly significant at all wavelengths in weeks 1-5 (Table 8), but were less significant in the 10th week (Table 9) even though visible symptoms had appeared by this time in all plants receiving salt. Block effects and interactions during weeks 1-5 were so significant at all wavelengths that no conclusions could be drawn about the effect of treatments. Block effects and interactions were less significant in the 10th week, but still reached a higher level of significance than the treatment effects. Further computations were performed to try to define the source of variation and to eliminate visibly affected plants.

Analysis of all three treatments in the first and second weeks only, when visible symptoms were almost nonexistent, still showed highly significant treatment effects at all wavelengths except in the 1430 and 1940 nm water absorption bands. Only at 800 nm were these effects not equalled or exceeded by random variation, as indicated by block effects (Table 10).

Separate analysis of data from the 0.25% salt treatment vs. controls (Tables 11 and 12) and the 0.5% salt treatment vs. controls (Tables 13 and 14) appears to show a difference in the effect of these two salt treatments upon reflectance. Plants visibly affected by 0.5% salt were significantly different from control plants in their reflectance of visible bands (530, 640 nm) and the wavelengths absorbed by water (1430, 1940 nm), (Tables 13 and 14) while plants showing no visible symptoms of 0.25% salt showed significantly increased reflectance (by 1-2%) at all wavelengths longer than 800 nm (Table 11). Unlike droughted plants or those treated with 0.5% salt, these plants showed increased reflectance at 800, 1000 and 1200 nm even after visible symptoms appeared (Table 12).

Salt Effect. In 1968, plants treated with NaCl showed significantly higher reflectance at 1940 and 2190 nm than those receiving $CaCl_2$ (Tables 6 and 7). In 1969, where 0.5% salt is a factor in the anova, $CaCl_2$ is associated with significantly higher reflectance than NaCl (Tables 8, 9, 12, 13 and 14). Where 0.5% salt is not included the salt effect is very much less significant (Tables 11 and 12). Thus, the highly significant treatment effects in Tables 11 and 12 apply to both salts.

Week Effect. Where weeks were included as a factor in the anova, some increase in reflectance was apparent as time passed. With drought treatment, this was most significant at 1430, 1640 and 1940 nm (Table 4). With salt treatment, the effect of time was most apparent at wavelengths of 1200 nm and less (Tables 8 and 13).

Block Effect. Random variation, as indicated by the significance of the block effect and treatment x block interaction, was considerable in analyses which included 0.5% salt treatment, but was less important when the control and the 0.25% treatment were considered alone (Tables 11 and 12).

CONCLUSIONS

The results of these experiments suggest that some wavelengths are more useful than others for the previsual detection of the effects of drought and salinity in greenhouse-grown sugar maple (*Acer saccharum* Marsh) seedlings. Severe drought and high salinity (0.5 - 2.0%) increased reflectance in the visible and water absorption bands. Wavelengths of 1430, 1640, 1940 and 2190 nm showed significantly increased reflectance by plants treated with moderately severe drought, or low salinity (0.25%) before there was any significant change in reflectance of visible wavelengths. On the other hand, reflectance at 800, 1000 and 1200 nm showed no indication of any of the treatments except 0.25% salt, even after symptoms of the treatments became clearly visible. This suggests that the reflectance properties of the leaves were changed in different ways by (a) drought or high salinity and (b) low salinity.

No conclusions can be drawn from the results of this experiment about the relative effects of $CaCl_2$ and NaCl on sugar maple. In 1968, NaCl was associated with significantly higher reflectance than $CaCl_2$ but in 1969 the reverse was true. However, the data from the 1968 experiment were taken from 10 replicates of each salt, as against only 2 in 1969, so the 1968 result may be more reliable.

REMOTE SENSING IMPLICATIONS

Significant increases in reflectance in the water absorption bands (1430 and 1940 nm) and nearby wavelengths (1640 and 2190 nm) were produced in sugar maples by drought, high salinity and low salinity. Remote sensors operating in the water absorption bands (near 1430 and 1940 nm) have the best chance of detecting sugar maples affected by all three conditions, before or after the appearance of visible symptoms. Since plants affected by low salinity showed increased reflectance at 800, 1000 and 1200 nm, while those suffering from drought or high salinity did not, multiband reconnaissance including this spectral region may provide a means of distinguishing between low salinity and drought or high salinity, as soil factors affecting the reflectance properties of sugar maples.

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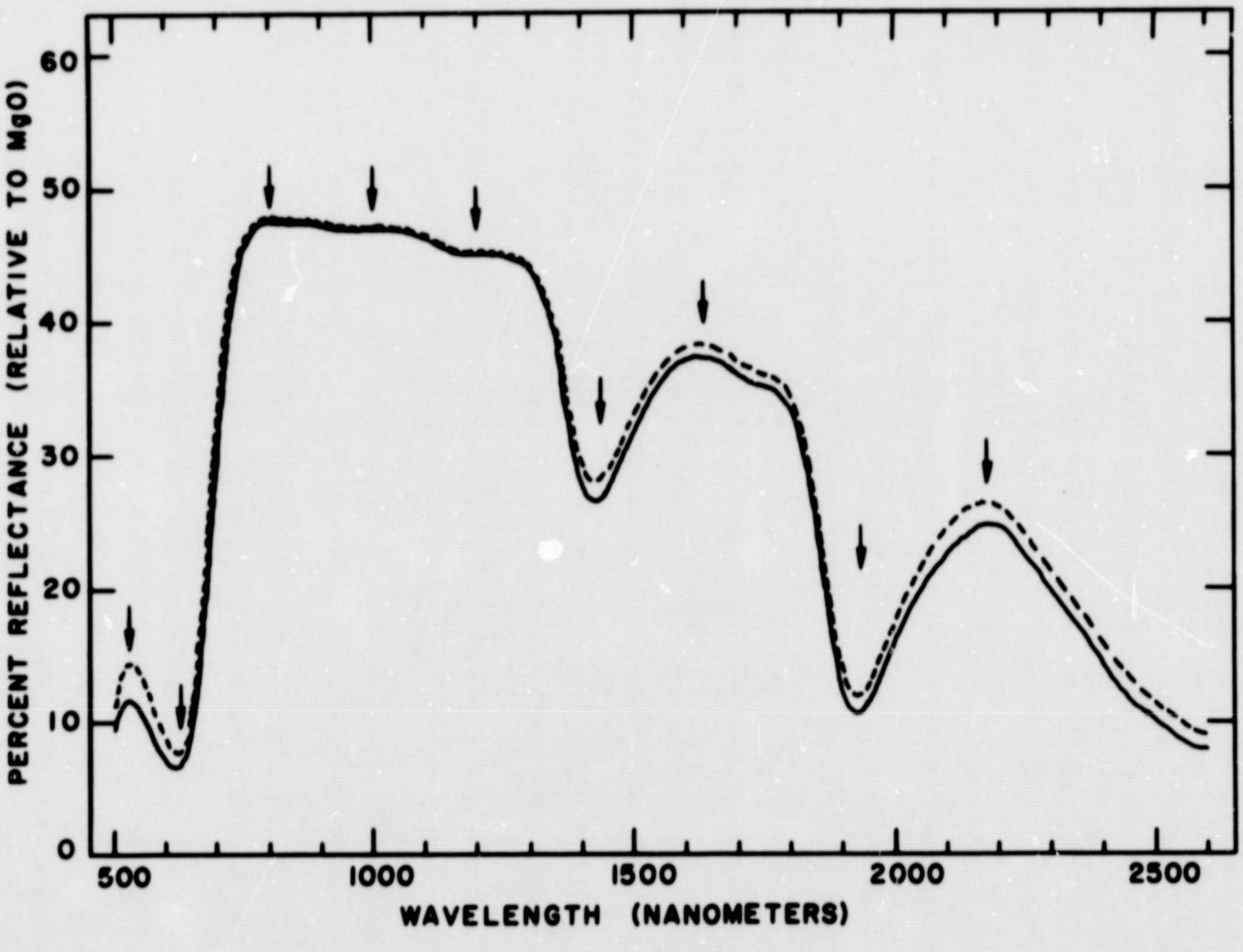

Figure 1. Foliar reflectance of two leaves from one control plant. Arrows indicate the wavelength chosen for analysis of data.

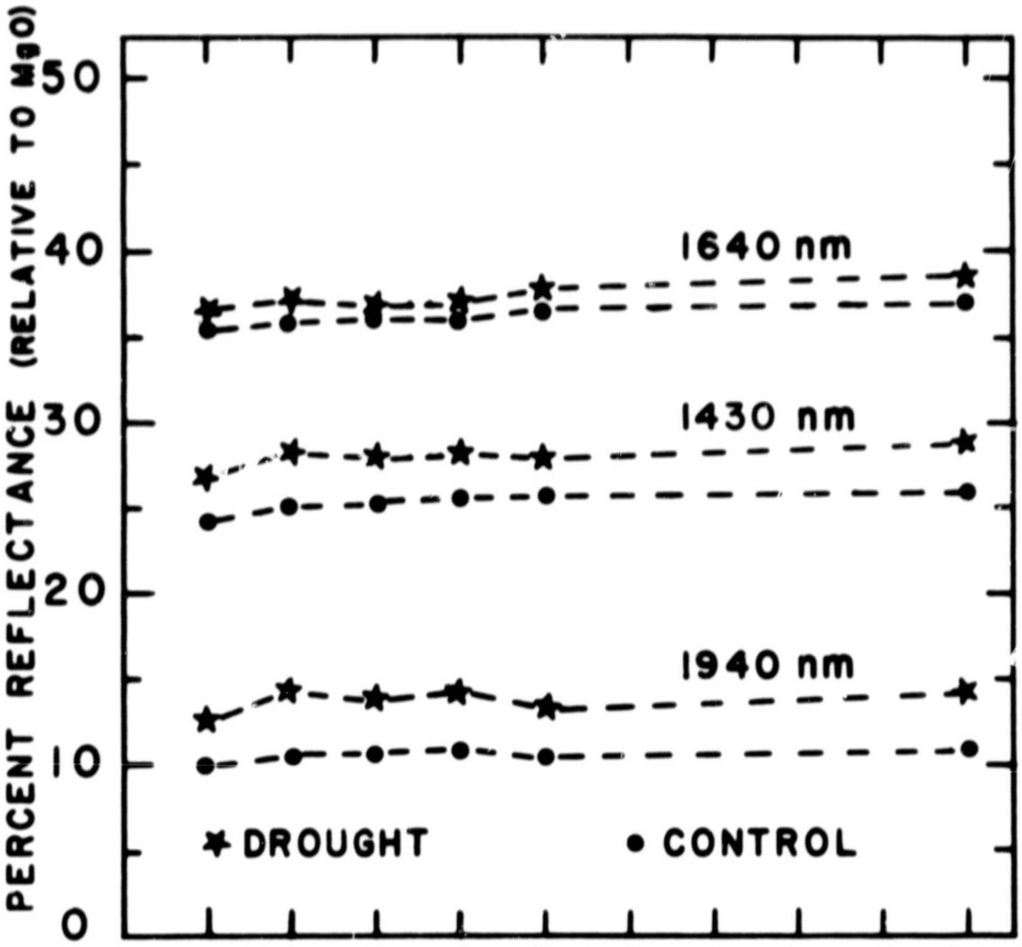

Figure 2. Weekly variation in foliar reflectance. Data taken from droughted and control plants from the 1969 drought experiment.

Table 1. 1968 Drought Experiment. Results of F-tests on mean squares from percent reflectance data for the 17th day.

Wavelength	Factors		Interaction
	Treatment	"Leaf out"	Treatment x "Leaf out"
nm	df 2,16	df 1,8	df 2,16
530	4.72*	<1	<1
640	3.54	1.62	<1
800	1.65	3.67	<1
1000	<1	2.47	<1
1200	<1	6.39*	<1
1430	4.71*	<1	<1
1640	<1	3.26	<1
1940	5.64*	<1	<1
2190	3.38	1.47	<1

* - p = 0.05.

Treatment: Control, moderate and severe drought.

Table 2. 1968 Drought Experiment. Results of F-tests on mean squares from percent reflectance data for the last day.

Wavelength	Factors		Interaction
	Treatment	"Leaf out"	Treatment x "Leaf out"
nm	df 2,16	df 1,8	df 2,16
530	8.8^{**}	6.25^{*}	<1
640	7.82^{**}	10.03^{*}	4.99^{*}
800	<1	<1	3.63^{*}
1000	2.08	<1	5.10^{*}
1200	<1	<1	4.78^{*}
1430	3.52	<1	2.76
1640	1.45	3.64	2.34
1940	13.07^{***}	4.36	2.16
2190	6.57^{**}	6.26^{*}	1.59

* - p = 0.05

** - p = 0.01

*** - p = 0.001

Treatment: Control, moderate and severe drought.

Table 3. 1969 Drought Experiment. Results of F-tests on mean squares from percent reflectance data for "weeks 1-5" (the 13th to 17th weeks after treatments began).

Wavelength	Factors			Interaction
	Treatment	Plant	Week	Week x Treatment
nm	df 1,20	df 20,150	df 4,20	df 4,20
530	1.69	5.09***	<1	<1
640	1.25	5.86***	1.44	<1
800	<1	4.36***	1.34	<1
1000	<1	3.25	1.30	<1
1200	<1	2.66***	1.91	<1
1430	85.1***	2.58***	3.11*	<1
1640	37.3***	1.14	4.49**	<1
1940	192.0***	2.33***	5.14**	<1
2190	70.1***	3.39***	<1	<1

* - p = 0.05

** - p = 0.01

*** - p = 0.001

Treatment: Control and moderately severe drought.

Table 4. 1969 Drought Experiment. Results of F-tests on mean squares from percent reflectance data for the 10th week of measurement (22nd week after treatments began).

Wavelength	Factors	
	Treatment	Plant
nm	df 1,4	df 4,30
530	1.27	4.58**
640	2.05	7.93***
800	<1	4.93**
1000	<1	3.95*
1200	<1	2.77*
1430	35.3**	1.41
1640	31.5**	<1
1940	33.35**	2.54
2190	26.83**	2.12

* - p = 0.05

** - p = 0.01

*** - p = 0.001

Treatment: Control, and moderately severe drought.

Table 5. Summary of Drought Treatment Effects. Results of F-tests on mean squares from percent reflectance data for treatment effects only in the 1968 and 1969 drought treatments.

Wavelength	1968 17th Day	1968 Last Day	1969 Weeks 1-5	1969 10th Week
nm	df 2,16	df 2,16	df 1,20	df 1,4
530	4.72*	8.8**	1.69	1.27
640	3.54	7.82**	1.25	2.05
800	1.65	<1	<1	<1
1000	<1	2.08	<1	<1
1200	<1	<1	<1	<1
1430	4.71*	3.52	85.1***	35.3**
1640	<1	1.45	37.3***	31.5**
1940	5.64*	13.07**	192.0***	33.35**
2190	3.38	6.57*	70.1***	26.83**

* - p = 0.05

** - p = 0.01

*** - p = 0.001

Treatments: 1968 - Control, moderate and severe drought.

1969 - Control, and moderately severe drought.

Table 6. 1968 Salinity Experiment. Results of F-tests on mean squares from percent reflectance data for the 6th week of treatment.

Wavelength	Factors		Interaction
	Salt	Treatment	Salt x Treatment
nm	df 1,126	df 6,126	df 6,126
530	<1	7.66***	<1
640	<1	5.71***	<1
800	<1	<1	1.15
1000	<1	<1	<1
1200	1.54	<1	1.02
1430	3.6	5.74***	1.31
1640	2.58	3.11	<1
194[illegible]	6.95**	8.24***	1.73
2190	4.18*	5.76***	<1

* - p = 0.05

** - p = 0.01

*** - p = 0.001

Treatments: control, 0.05, 0.1, 0.25, 0.50. 1.0 and 2.0% salt.

Salt: NaCl or $CaCl_2$

Table 7. 1968 Salinity Experiment. Results of F-test on mean squares from percent reflectance data for the 6th week of treatment, excluding data for the highest salt concentration.

	Factors		Interaction
Wavelength	Salt	Treatment	Salt x Treatment
nm	df 1,108	df 5,108	df 5,108
530	<1	1.59	<1
640	<1	1.27	<1
800	<1	<1	1.07
1000	1.06	<1	<1
1200	1.85	<1	<1
1430	2.19	<1	1.27
1620	2.47	<1	<1
1940	10.72**	<1	<1
2190	4.00*	1.15	<1

* - $p = 0.05$

** - $p = 0.01$

Treatment: control, 0.05, 0.1, 0.25, 0.5 and 1.0% salt

Salt: NaCl or $CaCl_2$

Table 8. 1968 Salinity Experiment. Results of F-tests on mean squares from percent reflectance data for the first five weekly measurements.

	Factors				Interactions	
Wavelength	Salt	Treatment	Block	Week	Salt x Treatment S x T	Treatment x Block T x B
nm	df 1,300	df 2,300	df 10,300	df 4,300	df 2,300	df 20,300
530	92.90***	60.40***	16.41***	4.09**	67.80***	6.61***
640	82.10***	84.00***	12.62***	9.16***	61.60***	10.65***
800	13.77***	50.36***	1.24	9.55***	10.17***	4.04***
1000	30.58***	34.40***	3.02***	7.22***	21.80***	4.06***
1200	38.99***	32.20***	3.92***	6.40***	26.50***	3.46***
1430	33.43***	11.61***	8.12***	<1	15.85***	2.01**
1640	50.45***	33.41***	5.09***	2.96**	30.40***	1.94**
1940	39.58***	12.63***	10.66***	1.14	19.40***	2.68***
2190	47.45***	36.08***	10.20***	1.77	20.79***	3.33***

** - p = 0.01

*** - p = 0.001

Treatment: control, 0.25 and 0.5% salt

Salt: NaCl or $CaCl_2$

Table 9. 1969 Salinity Experiment. Results of F-tests on mean squares from percent reflectance data for 10th week of measurement.

Wavelength	Factors			Interactions	
	Salt	Treatment	Block	Salt x Treatment	Treatment x Block
nm	df 1,60	df 2,60	df 2,60	df 2,60	df 4,60
530	1.84	5.24*	7.03*	2.20	6.87*
640	24.25***	15.32***	18.77***	10.33***	10.07***
800	1.71	1.71	<1	4.91*	2.63
1000	5.08*	1.94	3.52**	6.93*	4.46**
1200	6.48*	2.45	4.22*	7.38**	4.54**
1430	10.85**	3.22*	11.18***	6.84**	4.05**
1640	6.29*	1.83	7.71**	5.58**	5.45**
1940	11.40**	5.96**	11.67***	8.49***	6.58***
2190	10.82**	2.03	6.14**	5.51**	4.93**

* - p = 0.05

** - p = 0.01

*** - p = 0.001

Treatment: control, 0.25 and 0.5% salt

Salt: NaCl or $CaCl_2$

Table 10. 1969 Salinity Experiment. Results of F-tests on mean squares from percent reflectance data for the first and second weekly measurements.

Wavelength	Factors				Interactions	
	Salt	Treatment	Block	Week	Salt x Treatment S x T	Treatment x Block T x B
nm	df 1,120	df 2,120	df 4,120	df 1,120	df 2,120	df 8,120
530	37.95***	14.07***	19.49	1.89	28.64***	5.78***
640	24.00***	16.89***	7.62***	<1	18.17***	5.90***
800	2.40	19.68***	2.46*	<1	4.70*	2.79**
1000	8.22***	14.11***	5.19***	<1	10.68***	4.16***
1200	12.72***	13.67***	5.95***	<1	13.51***	3.46**
1430	14.09***	3.47*	5.33***	<1	5.59**	1.58
1640	22.81***	16.74***	6.81***	<1	14.55***	2.12*
1940	15.53***	6.49**	10.08***	1.14	6.61**	2.09**

* - p = 0.05

** - p = 0.01

*** - p = 0.001

Treatment: control, 0.25 and 0.5% salt

Salt: $CaCl_2$ or NaCl

Table 11. 1969 Salinity Experiment. Results of F-tests on mean squares from percent reflectance data for the first and second weeks measurement--control and 0.25% salt treatment only.

Wavelength	Factors				Interactions	
	Salt	Treatment	Block	Week	Salt X Treatment S x T	Treatment x Block T x B
nm	df 1,80	df 1,80	df 4,80	df 1,80	df 1,80	df 4,80
530	6.30*	1.70	12.57***	1.08	34.84***	5.47***
640	6.11*	1.96	9.30***	2.50	56.75***	9.06***
800	<1	37.95***	<1	<1	4.14*	2.10
1000	<1	36.45***	<1	<1	4.46*	1.66
1200	<1	39.95***	<1	<1	8.45**	1.58
1430	3.41	7.94**	1.52	<1	6.48*	<1
1640	2.56	79.80***	2.56*	1.41	9.50**	<1
1940	4.75*	33.18***	6.29***	4.51*	7.23**	1.11
2190	3.52	52.80***	4.03**	1.78	3.40	2.50

* - $p = 0.05$

** - $p = 0.01$

*** - $p = 0.001$

Treatment: control and 0.25% salt

Salt: NaCl or $CaCl_2$

Table 12. 1969 Salinity Experiment. Results of F-tests on mean squares from percent reflectance data for the 10th week of measurement --control and 0.25% salt treatment only.

Wavelength	Factors			Interactions	
	Salt	Treatment	Block	Salt x Treatment S x T	Treatment x Block T x B
nm	df 1,40	df 1,40	df 2,40	df 1,40	df 2,40
530	<1	5.16*	11.82***	3.81	3.66*
640	3.37	5.47*	5.86**	<1	3.99*
800	1.34	9.79**	<1	3.14	5.70**
1000	<1	15.98***	<1	3.03	5.61*
1200	<1	22.18***	<1	2.33	4.42*
1430	1.15	10.40**	4.91*	<1	1.39
1640	<1	32.61***	2.33	<1	1.39
1940	1.53	12.41**	5.73**	<1	1.14
2190	1.85	5.63*	<1	<1	1.61

* - p = 0.05

** - p = 0.01

*** - p = 0.001

Treatment: control and 0.25% salt

Salt: NaCl or $CaCl_2$

Table 13. 1969 Salinity Experiment. Results of F-tests on mean squares from percent reflectance data for the first five weekly measurements--control and 0.5% salt treatment only

Wavelength	Factors				Interactions	
	Salt	Treatment	Block	Week	Salt × Treatment	Treatment × Block
nm	df 1,200	df 1,200	df 10,200	df 4,200	df 1,200	df 10,200
530	157.2***	84.0***	4.07***		2.54*	3.53
640	110.7***	96.8***	10.43***	5.35***	26.80***	10.42***
800	27.72***	<1	1.69	6.26***	1.75	4.20***
1000	48.28***	1.96	1.99*	3.94**	11.10***	5.59***
1200	58.90***	2.31	2.23*	3.45**	11.15***	4.91***
1430	41.05***	1.13	6.63***	<1	5.96*	1.61
1640	62.05***	<1	4.35***	2.10	21.61***	1.88*
1940	51.40***	7.46**	10.32***	<1	9.43**	1.85*
2190	52.70***	<1	11.75***	1.07	18.69***	1.47

* - p = 0.05

** - p = 0.01

*** - p = 0.001

Treatment: control and 0.5% salt

Salt: NaCl or $CaCl_2$

Table 14. 1969 Salinity Experiment. Results of F-tests on mean squares from percent reflectance data for the 10th week of measurements--control and 0.5% salt treatment only.

Wavelength	Factors			Interactions	
	Salt	Treatment	Block	Salt x Treatment S x T	Treatment x Block T x B
nm	df 1,40	df 1,40	df 2,40	df 1,40	df 1,40
530	3.58	6.58*	<1	<1	2.88
640	32.71***	30.50***	17.52***	13.08***	16.46***
800	4.40*	<1	<1	3.24	3.74**
1000	7.46	2.32	2.57	5.68*	6.03**
1200	8.26**	3.18	3.30*	6.46*	5.83**
1430	10.0**	4.87	9.13***	9.01**	5.03*
1640	6.03*	2.02	6.88**	5.78*	5.53**
1940	10.58**	7.93**	10.33***	9.05**	6.66**
2190	9.48**	2.67	6.26**	5.40*	4.54*

* - p = 0.05

** - p = 0.01

*** - p = 0.001

Treatment: control and 0.5% salt

Table 15. Summary of Salinity Treatment Effects. Results of F-tests on mean squares from percent reflectance data for treatment effects in the 1968 and 1969 salinity experiments.

Wavelength	1968 6th Week (to 2.0%)	1968 6th Week (to 1.0%)	1969 Weeks 1-5 (0.0%, 0.25% and 0.5%)	10th Week (0.0%, 0.25% and 0.5%)	Weeks 1-2 (0.0%, 0.25% and 0.5%)	Weeks 1-2 (0.0% and 0.25%)	10th Week (0.0% and 0.25%)	Weeks 1-5 (0.0% and 0.5%)	10th Week (0.0% and 0.5%)
nm	df 6,126	df 5,108	df 2,300	df 2,60	df 2,120	df 1,80	df 1,40	df 1,200	df 1,40
530	7.66***	1.59	60.4	5.24*	14.07***	1.70	5.16*	84.0***	6.58*
640	5.71***	1.27	84.0***	15.32***	16.89***	1.96	5.47*	96.8***	30.5***
800	<1	<1	50.36***	1.71	19.68***	37.95***	9.79**	<1	<1
1000	<1	<1	34.4***	1.94	14.11***	36.45***	15.98***	1.96	2.32
1200	<1	<1	32.2***	2.45	13.67***	39.95***	22.18***	2.31	3.18
1430	5.74***	<1	11.61***	3.22*	3.47*	7.34**	10.40**	1.13	4.87*
1640	3.11**	<1	33.41***	1.83	16.74***	79.80***	32.61***	<1	2.02
1940	8.24***	<1	12.63***	5.96**	6.49**	31.18***	12.41**	7.46**	7.93**
2190	5.76***	1.15	36.08***	2.03	16.33**	52.90***	5.63*	<1	2.67
			(s.v.)	(s.v.)			(s.v.)	(s.v.)	(s.v.)

* - p = 0.05

** - p = 0.01

*** - p = 0.001

(s.v.) = symptoms visible

Table 16. Summary of Reflectance Changes Resulting From Drought and Salinity Treatment. Highest significance of F-test of mean squares on percent reflectance data.

Treatment	Visible 530,640nm	Wavelength Bands 800,1000,1200nm	Water-Absorbed 1430,1940nm	2190nm
Drought - severe 1 season, symptoms visible	***	-	**	**
Drought - moderately severe 2 seasons, no visible symptoms	-	-	***	***
Salinity - 2.0% 1 season, symptoms visible	***	-	***	***
Salinity - 0.5% 2 seasons, symptoms visible or advanced	***	-	**	-
Salinity - 0.25% 2 seasons, symptoms visible	*	***	**	*
Salinity - 0.25% 2 seasons, no visible symptoms	-	***	***	***

* - p = 0.05
** - p = 0.01
*** - p = 0.001