NATIONAL BUREAU OF STANDARDS REPORT

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SPECTROPHOTOMETRIC AND COLORIMETRIC

RECORD OF SOME

LEAVES OF TREES, VEGETATION, AND SOIL.

By

Harry J. Keegan,

John C. Schleter,

Wiley A. Hall, Jr.,

and

Gladys M. Haas.

To

U. S. Department of the Air Force
Aerial Reconnaissance Laboratory
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio.

NBS

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PREFACE

This is one of a series of NBS reports of spectrophotometric and colorimetric work done under NBS Project 0201-20-2325 entitled Color Reconnaissance Studies, financed by the Aerial Reconnaissance Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio; Air Force Contract No. 33 (616) 52-21. It is coordinated with Air Force Contract No. 33 (616) - 262 under Dr. Hugh T. O'Neill, O'Neill Associates, Annapolis, Maryland, who requested the NBS to perform this test of leaves of trees, and who collected and identified the American leaf specimens and grouped and identified the Canadian leaf specimens.

Harry J. Keegan
Project Leader

SPECTROPHOTOMETRIC AND COLORIMETRIC RECORD OF SOME LEAVES OF TREES, VEGETATION, AND SOIL.

Harry J. Keegan, John C. Schleter, Wiley A. Hall, Jr., and Gladys M. Haas.*

Abstract

Visible and near infrared measurements of spectral directional reflectance have been made on some selected leaves of deciduous trees from the Annapolis, Maryland, and Washington, D. C. areas of the United States of America, and from the Ottawa, Ontario, area of the Dominion of Canada on a General Electric recording spectrophotometer for the spectral region 400 to 1080 millimicrons. These recordings have been illustrated and tables of data are included as well as graphs and tables of chromaticity coordinates, daylight reflectances, Munsell renotations, and ISCC-NBS color designations. In addition, color difference determinations in terms of the NBS unit of color difference have been made between similar leaf specimens and between the ventral and the dorsal sides of the same leaf specimens. Similar reductions are reported and illustrated for some natural formations in the USSR as reported in the literature.

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* Miss Gladys M. Haas is at present employed at the Mare Island Naval Shipyard, San Francisco, California.

Contents

I. Introduction

The overall objective of this Air Force investigation is stated as follows: "To develop by visible, near infrared, and near ultraviolet spectrophotometry, methods for the detection of objects from color reconnaissance; to study the colors, tonal contrast, and color separation necessary in aerial photography to yield maximum information; to determine the wavelength region at which the film manufacturer should strive to obtain maximum sensitivity to yield clear separation of an object from its adjacent area rather than to yield true color fidelity; to determine the characteristics required in a sensitized material for the rapid and accurate extraction of this information."

This particular report pertains to the spectrophotometric and colorimetric changes that appear in the background of an aerial scene; namely, the leaves of trees, vegetation, and soil. The leaves studied are from some of the prominent deciduous trees in eastern parts of the United States of America and in eastern parts of the Dominion of Canada. The vegetation and soil are some of those reported by Krinov [1] in Russia from the Eastern part of Europe and the Western part of Asia.

The method of measurement and computation is that requested in the original project proposal and used in three previous reports of this project [2, 3, 4].

The leaves of trees were studied chiefly for other purposes, and the results are recorded here for ready reference as a start toward a collection of the complete information required for reliable interpretation of aerial photographs.

II. Material

With the exception of the seven Russian specimens for which data were taken from Krinov [1] , all of the specimens of this report were supplied by Dr. H. T. O'Neill, O'Neill Associates, Annapolis, Maryland, on five work requests in the fall of 1952 and the spring of 1953. These five work requests were assigned NBS serial numbers 2.1/WADC-4/52, -5/52, -8/52, -19/53, and -20/53. Copies of these original work requests are included in Appendix F of this report. The first four work requests pertain to the leaves of deciduous trees picked in the Eastern part of the United States of America, three of them in the late fall of the year just before and just after the first frost of the season, and one in the early spring of the year. The fifth work request pertained to two shipments of leaves collected on May 10 and 18, 1953 by Dr. J. M. Robinson, Department of Resources and Development, Ottawa, Canada, from deciduous trees near there, and sent to Dr. O'Neill, at his request, who in turn selected certain representative specimens as examples of "early foliage in the

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Numbers in brackets refer to bibliography on page 157 of this report.

subarctic deciduous forest; also dead overwintered leaves on the ground". Detailed designations of these specimens are listed in Tables I, VI, and XI of this report.

III. Spectrophotometric Measurements

Measurements of spectral directional reflectance were made on the NBS General Electric recording spectrophotometer [5, 6] for the American and the Canadian Forest leaves. In most cases these measurements covered the visible and near infrared spectrum, 400 to 1080 millimicrons. However, those leaves picked in the late fall in the United States and most of the Canadian leaves were measured for the visible spectrum only (400 to 750 millimicrons).

In each case the ventral side of the tree leaf was considered to be the side on which the measurements were to be made; however, when differences between the ventral and dorsal side of the specimens seemed to be large, measurements were made on both sides of the specimen. For each measurement, a backing specimen similar to the measured specimen was selected and the measured specimen was placed on top of the backing specimen and both specimens were held firmly against the integrating sphere of the instrument by a wooden block covered with black paper.

The measurements were made for the condition of inclusion of the specular component of the reflected radiant energy. The slit widths used for these measurements were approximately 10 millimicrons of spectrum for the spectral region, 400 to 750 millimicrons (visible spectrum), and 20 millimicrons of spectrum for the spectral region 730 to 1080 millimicrons (near infrared spectrum).

IV. Spectrophotometric Results

The results of the spectrophotometric measurements of this report are shown on the 20 Ozalid prints of the original recordings from the General Electric recording spectrophotometer. These Ozalid prints are a part of Appendices A and C of this report; fifteen of them are for the visible spectrum, 400 to 750 millimicrons, and five of them are for the near infrared spectrum, 730 to 1080 millimicrons. Ten of the graph sheets contain calibration curves for the correction of the wavelength and photometric scale errors [7, 8].

Values of spectral directional reflectances were read at each ten millimicron interval from 400 to 750 millimicrons or from 400 to 1080 millimicrons, whichever was available for each of the 49 spectrophotometric curves of 21 leaf specimens of American trees, and for each of the 48 spectrophotometric curves of 24 leaf specimens of Canadian trees. These 97 sets of spectrophotometric data are listed in Appendices B, D, and E of this report together with the spectrophotometric data published by Krinov for the seven samples of Russian terrain having data reported continuously from 400 to 900 millimicrons.

V. Colorimetric Computations

The spectral-directional-reflectance data of each of these seventy-four specimens listed in Appendices B, D, and E for the visible spectrum (400 to 750 millimicrons) were converted into terms of luminous reflectance, Y, and chromaticity coordinates, x, y of the C.I.E. colorimetric system by integration according to the C.I.E. standard observer [9] for C.I.E. source C, representative of average daylight.

These chromaticity coordinates and daylight reflectances are listed in tables at the end of each of the three classifications of this report, and in illustrations of the C.I.E. chromaticity diagram under each classification; namely, American, Canadian, and Russian.

VI. Munsell Renotations and ISCC-NBS Color Designations

From the above mentioned determinations of C.I.E. chromaticities and daylight reflectances of the seventy-four specimens studied in this report, the Munsell renotations were obtained from graphs of conversion from the C.I.E. system to the Munsell Renotation System [10] . These Munsell renotations then were converted into terms of the ISCC-NBS (Inter-Society Color Council - National Bureau of Standards) color designations [11] . Similarly, these renotations and color designations are listed in tables and illustrated in graphs under the respective country of origin of the specimens.

VII. Color Difference Computations

From the Munsell renotations of the fifty-two determinations of twenty-six of the American and the Canadian leaves, color differences in terms of the NBS unit of color difference (ΔE) were computed by means of the Godlove formula [12] , as follows:

$$\Delta E_{NBS} = 5 \left[\left\{ 2\, C_1\, C_2\, \phi(H) \right\} + (\Delta C)^2 + (4 \Delta V)^2 \right]^{1/2},$$

where, $\phi(H) = 1 - \cos 3.6\,°\Delta H$.

These results are tabulated for the American leaves in Table V for differences between four sets of the ventral sides of similar leaves picked and measured on successive days. Also tabulated are color differences between the ventral and the dorsal sides of ten other pairs of American leaves. Illustrations of these changes are shown in Figures 16, 17, and 18. Similar color differences for the color changes between the ventral and the dorsal sides of twelve sets of Canadian leaves are shown in Table X and illustrated in Figure 36. Color differences between the two grasses and the two soils reported by Krinov were also computed and are listed in Table XIV and illustrated in Figure 43.

VIII. American Forest Leaves.

Table I lists the common name, the Latin name, and the dates of picking and measurement of the twenty-one leaf specimens. This is followed by eighteen illustrations (Figures 1 to 18) showing a record of the thirty-one determinations of these 21 specimens of leaves from deciduous trees or shrubs in the eastern part of the United States of America.

The first seven illustrations show the spectral directional reflectance curves of the specimens designated in the legends of the illustrations, and listed in the index to Appendix A. The data plotted in the illustrations are taken from that listed in Appendix B.

The chromaticity coordinates of the samples of these seven illustrations are shown in segments of the C.I.E. chromaticity diagram for standard source C, Figures 8, 9, and 10. The data used for these illustrations are listed in Table II.

The Munsell renotations of these same specimens are illustrated in the schematic diagrams of the "Ideal Munsell System" in Figures 11 to 15. The data used for these illustrations are listed in Tables III and IV together with the corresponding ISCC-NBS color designation.

Determinations were made of the color differences between separate samples picked from the same tree and between the ventral and the dorsal sides of the same leaf. This information is listed in Table V and illustrated in Figures 16, 17, and 18.

Each specimen, when received, was identified by the common name of the tree, such as "ASPEN", from which it was taken, and by a word, such as "Blackening", descriptive of the phase of color change of which the leaf was judged to be representative. These identifying words are used throughout this report except in the illustrations. When more than one phase in the color change of leaves from one kind of tree was represented, these phases were designated by consecutive numbers on the illustrations to save space. Thus, BEECH, BEECH "Russet Brown", and BEECH "Yellow", are identified in the illustrations as BEECH (1), BEECH (2), and BEECH (3), and the same method is used for DOGWOOD, SPANISH HAZELNUT, MOCKERNUT HICKORY, BLACK OAK, and WHITE OAK. The color names used by the botanist to differentiate one phase of the leaf-color change from another are not to be confused with the more precise ISCC-NBS color designations derived from the Munsell renotation of the specimen.

Table I

Identification of the Leaf Specimens from Trees and Shrubs of the Eastern Part of the United States of America, and the Dates of Picking and Measurement.

Specimen: Common Name	Specimen: Latin Name	Date Picked	Date Measured
ASPEN "Blackening"	Populus grandidentata Michx..	11- 2-52	11- 4-52
BEECH (1)	Fagus grandifolia Ehrh.	10-16-52	10-16-52
BEECH (2) "Russet Brown"	Fagus grandifolia Ehrh.	11- 2-52	11- 4-52
BEECH (3) "Yellow"	Fagus grandifolia Ehrh.	11- 2-52	11- 4-52
DOGWOOD (1)	Cornus florida L.	10-16-52	10-16-52
DOGWOOD (2)	Cornus florida L.	10-17-52	10-17-52
DOGWOOD (3) "Red and Green"	Cornus florida L.	11- 2-52	11- 4-52
SPANISH HAZELNUT (1) "Red"	Corylus avellana L.	4-22-53	4-22-53
SPANISH HAZELNUT (2) "Red and Green"	Corylus avellana L.	4-22-53	4-22-53
SPANISH HAZELNUT (3) "Green Sport"	Corylus avellana L.	4-22-53	4-22-53
MOCKERNUT HICKORY (1)	Carya tomentosa (Lam.) Nutt.	10-16-52	10-16-52
MOCKERNUT HICKORY (2)	Carya tomentosa (Lam.) Nutt.	10-17-52	10-17-52
BLACK OAK (1)	Quercus velutina Lam.	10-16-52	10-16-52
BLACK OAK (2)	Quercus velutina Lam.	10-17-52	10-17-52
SCARLET OAK "Red"	Quercus coccinea Willd.	11- 2-52	11- 4-52
WHITE OAK (1)	Quercus alba L.	10-16-52	10-16-52
WHITE OAK (2) "Green"	Quercus alba L.	10-17-52	10-17-52
WHITE OAK (3) "Red Brown"	Quercus alba L.	11- 2-52	11- 4-52
WHITE OAK (4) "Reddish"	Quercus alba L.	10-17-52	10-17-52
PLUM "Red"	Prunus pissardi Hort.	4-22-53	4-22-53
TULIP POPLAR "Yellow"	Liriodendron tulipifera L.	11- 2-52	11- 4-52

Figure 1.

Visible and near infrared spectral directional reflectance of the ventral side of the leaves of five typical deciduous trees in the Annapolis, Maryland, region of the U.S.A. picked and measured on October 16, 1952. They are Mockernut Hickory (1), Beech (1), Dogwood (1), White Oak (1), and Black Oak (1). For further identification see Table I and the index to Appendix A.

Figure 2.

Visible and near infrared spectral directional reflectance of the ventral side of the leaves of five typical deciduous trees in the Annapolis, Maryland, region of the U.S.A. picked and measured on October 17, 1952. They are Mockernut Hickory (2), Dogwood (2), White Oak (2) "green", White Oak (4) "reddish", and Black Oak (2). For further identification see Table I and the index to Appendix A.

Figure 3.

Visible spectral directional reflectance of the ventral and the dorsal sides of the leaves of two deciduous trees in the Annapolis, Maryland, region of the U.S.A. picked on November 2, 1952 and measured on November 4, 1952. They are Tulip Poplar "yellow" and Dogwood (3) "red and green". For further identification see Table I and the index to Appendix A.

Figure 4.

Visible spectral directional reflectance of the ventral side of the leaves of three typical deciduous trees in the Annapolis, Maryland, region of the U.S.A., and the dorsal side of two of them. Specimens picked on November 2, 1952 and measured on November 4, 1952. They are Aspen "blackening" (ventral side only), White Oak (3) "red brown", and Scarlet Oak "red". For further identification see Table I and the index to Appendix A.

Figure 5.

Visible spectral directional reflectance of the ventral and the dorsal sides of two leaves of a typical deciduous tree in the Annapolis, Maryland, region of the U.S.A. Specimens picked on November 2, 1952 and measured on November 4, 1952. They are: Beech (2) "russet brown" and Beech (3) "yellow". For further identification see Table I and the index to Appendix A.

Figure 6.

Visible and near infrared spectral directional reflectance of the ventral side of three leaves of a shrub, and a leaf of a tree, typical of "spring red leaves", in the Washington, D. C. region of the U.S.A. picked and measured on April 22, 1953. They are Plum "red", Spanish Hazelnut (1) "red", Spanish Hazelnut (3) "green sport", and Spanish Hazelnut (2) "red and green". For further identification see Table I and the index to Appendix A.

Figure 7.

Visible and near infrared spectral directional reflectance of the dorsal side of three leaves of a shrub, and a leaf of a tree, typical of "spring red leaves", in the Washington, D. C. region of the U.S.A. picked and measured on April 22, 1953. They are Plum "red", Spanish Hazelnut (1) "red", Spanish Hazelnut (3) "green sport", and Spanish Hazelnut (2) "red and green". For further identification see Table I and the index to Appendix A.

Figure 8.

Segment of the C.I.E. chromaticity diagram showing dominant wavelength, excitation purity, and chromaticity coordinates for standard source C of the ventral side of the leaves of Figures 1 and 2; from data listed in Table II. For further identification see Table I and the index to Appendix A.

Figure 9.

Segment of the C.I.E. chromaticity diagram showing dominant wavelength, excitation purity, and chromaticity coordinates for standard source C of the ventral (closed circles) and the dorsal (open circles) sides of the leaves of Figures 3, 4, and 5; from data listed in Table II. For further identification see Table I and the index to Appendix A.

Figure 10.

Segment of the C.I.E. chromaticity diagram showing dominant wavelength, excitation purity, and chromaticity coordinates for standard source C of the ventral (closed circles) and the dorsal (open circles) sides of the shrub and tree leaves of Figures 6 and 7; from data listed in Table II. For further identification see Table I and the index to Appendix A.

Figure 11.

Vertical and horizontal projections of the color differences between the ventral sides of two leaves of Mockernut Hickory (1) and (2) (Figures 1, 2, and 8), and between the ventral (closed circle) and the dorsal (open circle) sides of Beech (2) "russet brown" (Figures 5 and 9), and of Beech (3) "yellow" (Figures 5 and 9). The upper diagram shows the Munsell Value of these measurements plotted against the Munsell Hue and Chroma points projected from the lower diagram. The Munsell data are listed in Tables III and IV. For further identification see Table I and the index to Appendix A.

Figure 12.

Vertical and horizontal projections of the colors of the ventral side of Aspen (Figures 4 and 9) and of Black Oak (2) (Figures 2 and 8), and of the color differences between the ventral (closed circle) and the dorsal (open circle) sides of Dogwood (3) "red and green" (Figures 3 and 9) and of White Oak (3) "red brown" (Figures 4 and 9). The upper diagram shows the Munsell Value of these measurements plotted against the Munsell Hue and Chroma points projected from the lower diagram. The Munsell data are listed in Tables III and IV. For further identification see Table I and the index to Appendix A.

Figure 13.

Vertical and horizontal projections of: (1) the colors of the ventral side of Beech (1) (Figures 1 and 8), of Black Oak (1) (Figures 1 and 8), and of White Oak (4) "reddish" (Figures 2 and 8); (2) the color differences between the ventral (closed circle) and the dorsal (open circle) sides of the leaves of Scarlet Oak "red" (Figures 4 and 9) and of Tulip Poplar "yellow" (Figures 3 and 9); and (3) the color differences between the ventral sides of two leaves of Dogwood (1) and (2) (Figures 1, 2, and 8). The upper diagram shows the Munsell Value of these measurements plotted against the Munsell Hue and Chroma points projected from the lower diagram. The Munsell data are listed in Tables III and IV. For further identification see Table I and the index to Appendix A.

Figure 14

Vertical and horizontal projections of the color differences between the ventral (closed circle) and the dorsal (open circle) sides of the leaves of Plum "red" (Figures 6, 7, and 10) and of Spanish Hazelnut (1) "red" (Figures 6, 7, and 10). The upper diagram shows the Munsell Value of these measurements plotted against the Munsell Hue and Chroma points projected from the lower diagram. The Munsell data are listed in Tables III and IV. For further identification see Table I and the index to Appendix A.

Figure 15

Vertical and horizontal projections of: (1) the color differences between the ventral sides of two leaves of White Oak (1) and (2) "green" (Figures 1, 2, and 8); and (2) the color differences between the ventral (closed circle) and the dorsal (open circle) sides of the leaves of Spanish Hazelnut (3) "green sport" (Figures 6, 7, and 10) and of Spanish Hazelnut (2) "red and green" (Figures 6, 7, and 10). The upper diagram shows the Munsell Value of these measurements plotted against the Munsell Hue and Chroma points projected from the lower diagram. The Munsell data are listed in Tables III and IV. For further identification see Table I and the index to Appendix A.

Figure 16

Color differences computed from the Godlove color-difference formula, converted into NBS units, between the ventral sides of sets of "nearly" identical leaf specimens, picked from the same tree on successive days (October 16, 1952 and October 17, 1952). The data are listed in Table V. For further identification see Table I and the index to Appendix A.

Figure 17

Color differences computed from the Godlove color-difference formula, converted into NBS units, between the ventral and the dorsal sides of the same leaf specimens picked in the late fall (November 2, 1952). The data are listed in Table V. For further identification see Table I and the index to Appendix A.

Figure 18.

Color differences computed from the Godlove color-difference formula, converted into NBS units, between the ventral and the dorsal sides of the same leaf specimens picked in early spring (April 22, 1953). The data are listed in Table V. For further identification see Table I and the index to Appendix A.

Table II

American Forest Leaves

Chromaticity Coordinates and Daylight Reflectances for C.I.E. Source C of the Leaves Studied.

Specimen	Ventral Side: Chromaticity Coordinates x	Ventral Side: Chromaticity Coordinates y	Ventral Side: Daylight Reflectance Y(%)	Dorsal Side: Chromaticity Coordinates x	Dorsal Side: Chromaticity Coordinates y	Dorsal Side: Daylight Reflectance Y(%)
ASPEN "Blackening"	0.378	0.362	10.1	---	---	---
BEECH (1)	.446	.379	10.8	---	---	---
BEECH (2) "Russet Brown"	.407	.371	17.4	0.410	0.380	24.4
BEECH (3) "Yellow"	.438	.369	10.2	.420	.382	15.8
DOGWOOD (1)	.430	.317	7.0	---	---	---
DOGWOOD (2)	.402	.321	6.3	---	---	---
DOGWOOD (3) "Red and Green"	.370	.348	8.8	.357	.347	18.4
SPANISH HAZELNUT (1) "Red"	.328	.316	4.2	.370	.321	5.5
SPANISH HAZELNUT (2) "Red and Green"	.338	.368	6.0	.357	.358	10.0
SPANISH HAZELNUT (3) "Green Sport"	.347	.430	9.3	.349	.406	16.6
MOCKERNUT HICKORY (1)	.457	.438	28.6	---	---	---
MOCKERNUT HICKORY (2)	.447	.423	23.0	---	---	---
BLACK OAK (1)	.403	.370	13.6	---	---	---
BLACK OAK (2)	.414	.368	9.3	---	---	---
SCARLET OAK "Red"	.362	.319	4.8	.387	.338	7.9
WHITE OAK (1)	.355	.422	12.2	---	---	---
WHITE OAK (2) "Green"	.364	.423	14.3	---	---	---
WHITE OAK (3) "Red Brown"	.400	.358	7.8	.360	.341	12.5
WHITE OAK (4) "Reddish"	.421	.354	11.1	---	---	---
PLUM "Red"	.366	.354	7.1	.365	.336	10.1
TULIP POPLAR Yellow"	.455	.392	13.8	.440	.402	17.4

Table III

American Forest Leaves

Munsell Renotations and ISCC-NBS Color Designations of the Ventral Sides of the Leaves Studied.

Specimen	Munsell Renotations	ISCC-NBS Color Designations
ASPEN "Blackening"	8.7YR 3.7/2.4	Grayish Yellowish Brown
BEECH (1)	5.2YR 3.8/5.0	Strong Brown
BEECH (2) "Russet Brown"	6.5YR 4.7/4.2	Light Brown
BEECH (3) "Yellow"	4.0YR 3.7/4.7	Moderate Brown
DOGWOOD (1)	4.7R 3.1/5.0	Dark Red
DOGWOOD (2)	5.7R 2.9/3.4	Dark Red
DOGWOOD (3) "Red and Green"	6.0YR 3.5/2.0	Grayish Brown
SPANISH HAZELNUT (1) "Red"	5.8R 2.4/0.7	Dark Grayish Red
SPANISH HAZELNUT (2) "Red and Green"	2.0GY 2.9/1.6	Grayish Olive
SPANISH HAZELNUT (3) "Green Sport"	5.6GY 3.6/3.9	Moderate Olive Green
MOCKERNUT HICKORY (1)	1.7Y 5.9/8.2	Deep Yellow
MOCKERNUT HICKORY (2)	1.0Y 5.3/6.8	Light Olive Brown
BLACK OAK (1)	7.1YR 4.2/3.6	Moderate Brown
BLACK OAK (2)	5.8YR 3.6/3.6	Moderate Brown
SCARLET OAK "Red"	6.1R 2.6/1.8	Grayish Reddish Brown
WHITE OAK (1)	4.3GY 4.0/3.7	Moderate Olive Green
WHITE OAK (2) "Green"	2.8GY 4.3/3.9	Moderate Olive Green
WHITE OAK (3) "Red Brown"	5.1YR 3.3/3.0	Moderate Brown
WHITE OAK (4) "Reddish"	2.2YR 3.9/4.3	Moderate Reddish Brown
PLUM "Red"	9.0YR 3.1/1.8	Dark Grayish Yellowish Brown
TULIP POPLAR "Yellow"	6.4YR 4.3/5.9	Strong Brown

Table IV

American Forest Leaves

Munsell Renotations and ISCC-NBS Color Designations of the Dorsal Sides of the Leaves Studied.

Specimen	Munsell Renotations	ISCC-NBS Color Designations
ASPEN "Blackening"	---	---
BEECH (1)	---	---
BEECH (2) "Russet Brown"	7.8YR 5.5/4.9	Light Brown
BEECH (3) "Yellow"	7.5YR 4.5/4.5	Light Brown
DOGWOOD (1)	---	---
DOGWOOD (2)	---	---
DOGWOOD (3) "Red and Green"	8.1YR 4.8/2.0	Grayish Yellowish Brown
SPANISH HAZELNUT (1) "Red"	6.8R 2.7/1.1	Dark Reddish Gray
SPANISH HAZELNUT (2) "Red and Green"	2.2Y 3.7/1.7	Moderate Olive Brown
SPANISH HAZELNUT (3) "Green Sport"	4.2GY 4.6/3.6	Moderate Yellow Green
MOCKERNUT HICKORY (1)	---	---
MOCKERNUT HICKORY (2)	---	---
BLACK OAK (1)	---	---
BLACK OAK (2)	---	---
SCARLET OAK "Red"	0.9YR 3.3/2.7	Grayish Reddish Brown
WHITE OAK (1)	---	---
WHITE OAK (2) "Green"	---	---
WHITE OAK (3) "Red Brown"	4.9YR 4.1/1.9	Grayish Brown
WHITE OAK (4) "Reddish"	---	---
PLUM "Red"	0.5YR 3.7/2.2	Grayish Reddish Brown
TULIP POPLAR "Yellow"	8.9YR 4.7/5.6	Strong Yellowish Brown

Table V

Color Differences Computed from the Godlove Color-Difference Formula, Converted into NBS Units; (1) Between the Ventral Sides of Sets of Nearly Identical Leaf Specimens (see Figure 16); (2) Between the Ventral and the Dorsal Sides of the Same Leaf Specimens Picked in Late Fall (see Figure 17); and (3) Between the Ventral and the Dorsal Sides of the Same Leaf Specimens Picked in Early Spring (see Figure 18).

Specimen	Color Difference ΔE
(1) Two "Nearly" Identical Leaf Specimens	
DOGWOOD (1) and (2)	9.0
MOCKERNUT HICKORY (1) and (2)	14.0
BLACK OAK (1) and (2)	12.0
WHITE OAK (1) and (2)	6.0
(2) Ventral and Dorsal sides of Specimens Picked in Late Fall	
BEECH (2) "Russet Brown"	16.5
BEECH (3) "Yellow"	16.5
DOGWOOD (3) "Red and Green"	26.0
SCARLET OAK "Red"	15.0
WHITE OAK (3) "Red Brown"	17.0
TULIP POPLAR "Yellow"	9.0
(3) Ventral and Dorsal sides of Specimens Picked in Early Spring	
SPANISH HAZELNUT (1) "Red"	6.5
SPANISH HAZELNUT (2) "Red and Green"	17.0
SPANISH HAZELNUT (3) "Green Sport"	20.0
PLUM "Red"	13.5

Appendix A.

Ozalid prints of the original recordings of the leaf specimens of some American Forest trees and shrubs obtained on a General Electric recording spectrophotometer at the National Bureau of Standards, 400 to 1080 millimicrons.

Index to Appendix A

Specimen	GE Graph Sheet Serial Number: Visible Spectrum	GE Graph Sheet Serial Number: Near Infrared Spectrum	Curve Number: Ventral Side	Curve Number: Dorsal Side
ASPEN "Blackening"	GE II-1076	----	16	--
BEECH (1)	-1063	GE II-1064	5	--
BEECH (2) "Russet Brown"	-1076	----	8	9
BEECH (3) "Yellow"	-1076	----	14	15
DOGWOOD (1)	-1063	-1064	6	--
DOGWOOD (2)	-1065	-1066	4	--
DOGWOOD (3) "Red and Green"	-1076	----	6	7
SPANISH HAZELNUT (1) "Red"	-1192	-1193	3	4
SPANISH HAZELNUT (2) "Red and Green"	-1192	-1193	7	8
SPANISH HAZELNUT (3) "Green Sport"	-1192	-1193	5	6
MOCKERNUT HICKORY (1)	-1063	-1064	4	--
MOCKERNUT HICKORY (2)	-1065	-1066	5	--
BLACK OAK (1)	-1063	-1064	8	--
BLACK OAK (2)	-1065	-1066	8	--
SCARLET OAK "Red"	-1076	----	10	11
WHITE OAK (1)	-1063	-1064	7	--
WHITE OAK (2) "Green"	-1065	-1066	6	--
WHITE OAK (3) "Red Brown"	-1076	----	12	13
WHITE OAK (4) "Reddish"	-1065	-1066	7	--
PLUM "Red"	-1192	-1193	1	2
TULIP POPLAR "Yellow"	-1076	----	4	5

Appendix B

Spectral directional reflectance data obtained by correcting and reading the spectrophotometric curves of leaf specimens of some American Forest trees and shrubs.

American Forest Leaves
(Near Annapolis, Maryland)

Spectral Directional Reflectance of the Ventral, or Ventral and Dorsal Sides of the Leaves of the Indicated Trees for the Visible Spectrum, 400 to 750 Millimicrons. (See Appendix A; GE Graph Sheet Serial No. GE II - 1076.)

Wave Length mμ	ASPEN "Blackening" Ventral	BEECH (2) "Russet Brown" Ventral	Dorsal	BEECH (3) "Yellow" Ventral	Dorsal	DOGWOOD (3) "Red and Green" Ventral	Dorsal
400	0.048	0.059	0.074	0.043	0.055	0.048	0.094
10	.050	.067	.082	.044	.059	.050	.104
20	.053	.073	.091	.044	.062	.053	.115
30	.056	.078	.098	.044	.064	.057	.121
40	.058	.082	.103	.044	.066	.058	.127
450	.060	.085	.109	.044	.067	.061	.131
60	.062	.089	.116	.044	.069	.062	.138
70	.066	.093	.123	.045	.072	.063	.142
80	.068	.098	.130	.046	.074	.063	.145
90	.070	.102	.138	.046	.077	.064	.147
500	.074	.109	.148	.048	.081	.066	.152
10	.077	.116	.161	.052	.094	.071	.159
20	.082	.125	.175	.058	.108	.075	.165
30	.086	.135	.191	.066	.120	.079	.169
40	.092	.146	.208	.075	.133	.080	.172
550	.096	.158	.226	.085	.147	.082	.174
60	.102	.171	.246	.097	.160	.085	.179
70	.107	.184	.264	.110	.174	.089	.185
80	.111	.199	.283	.124	.188	.094	.193
90	.117	.214	.303	.137	.202	.100	.202
600	.122	.229	.321	.151	.215	.108	.214
10	.128	.244	.338	.164	.227	.116	.225
20	.134	.259	.354	.176	.239	.121	.236
30	.139	.274	.370	.188	.249	.127	.248
40	.145	.290	.387	.200	.260	.124	.250
650	.150	.305	.401	.212	.269	.114	.243
60	.155	.321	.416	.220	.276	.104	.236
70	.160	.338	.433	.228	.282	.091	.224
80	.166	.354	.448	.242	.292	.090	.224
90	.173	.375	.467	.264	.313	.139	.277
700	.179	.395	.484	.283	.331	.263	.374
10	.185	.414	.499	.298	.345	.369	.450
20	.191	.435	.515	.312	.357	.446	.505
30	.197	.450	.528	.325	.368	.500	.543
40	.203	.468	.543	.339	.380	.538	.569
750	.209	.483	.555	.356	.389	.558	.585

American Forest Leaves
(Near Annapolis, Maryland)

Spectral Directional Reflectance of the Ventral and Dorsal Sides of the Leaves of the Indicated Trees for the Visible Spectrum, 400 to 750 Millimicrons. (See Appendix A; GE Graph Sheet Serial No. GE II - 1076.)

Wave Length mμ	SCARLET OAK "Red" Ventral	SCARLET OAK "Red" Dorsal	WHITE OAK (3) "Red Brown" Ventral	WHITE OAK (3) "Red Brown" Dorsal	TULIP POPLAR "Yellow" Ventral	TULIP POPLAR "Yellow" Dorsal
400	0.040	0.046	0.040	0.083	0.037	0.040
10	.040	.048	.040	.085	.039	.043
20	.040	.050	.041	.087	.042	.046
30	.041	.051	.043	.089	.043	.049
40	.041	.052	.044	.091	.043	.052
450	.041	.054	.044	.092	.044	.054
60	.041	.056	.045	.093	.045	.058
70	.041	.057	.046	.095	.047	.062
80	.041	.058	.047	.098	.048	.065
90	.041	.059	.048	.099	.049	.070
500	.042	.060	.051	.102	.051	.078
10	.042	.062	.054	.104	.059	.092
20	.042	.063	.058	.108	.074	.109
30	.042	.064	.062	.111	.089	.128
40	.042	.065	.066	.114	.104	.146
550	.042	.067	.070	.116	.122	.163
60	.042	.070	.074	.122	.139	.180
70	.044	.074	.079	.126	.157	.198
80	.046	.081	.086	.132	.175	.214
90	.050	.090	.094	.139	.194	.230
600	.054	.100	.100	.146	.210	.244
10	.060	.112	.110	.154	.223	.257
20	.068	.125	.120	.162	.233	.266
30	.080	.139	.130	.172	.243	.276
40	.096	.156	.141	.182	.250	.285
650	.110	.171	.152	.190	.254	.287
60	.126	.183	.161	.196	.249	.284
70	.140	.193	.168	.200	.240	.275
80	.157	.207	.181	.213	.249	.284
90	.180	.231	.200	.235	.291	.328
700	.201	.252	.219	.254	.333	.365
10	.220	.269	.235	.269	.356	.386
20	.237	.283	.250	.283	.373	.402
30	.253	.297	.264	.295	.386	.414
40	.268	.310	.278	.307	.400	.428
750	.281	.321	.291	.320	.413	.439

American Forest Leaves
(Near Annapolis, Maryland)

Spectral Directional Reflectance of the Ventral Side of the Leaves of the Indicated Trees for the Visible and Near Infrared Spectrum, 400 to 1080 Millimicrons. (See Appendix A; GE Graph Sheets Serial No. GE II-1063, -1064, -1065, -1066.)

BEECH (1)				DOGWOOD (1)				DOGWOOD (2)			
Ventral Side				Ventral Side				Ventral Side			
Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ
400	0.039	750	0.433	400	0.039	750	0.570	400	0.039	750	0.511
10	.040	60	.449	10	.041	60	.591	10	.041	60	.534
20	.040	70	.467	20	.043	70	.604	20	.042	70	.553
30	.041	80	.483	30	.045	80	.617	30	.044	80	.571
40	.041	90	.499	40	.047	90	.628	40	.045	90	.587
450	.041	800	.516	450	.048	800	.635	450	.046	800	.602
60	.042	10	.533	60	.048	10	.642	60	.047	10	.616
70	.042	20	.548	70	.049	20	.649	70	.048	20	.628
80	.043	30	.563	80	.049	30	.656	80	.048	30	.639
90	.043	40	.577	90	.049	40	.662	90	.048	40	.649
500	.046	850	.590	500	.049	850	.666	500	.048	850	.658
10	.051	60	.602	10	.049	60	.671	10	.048	60	.667
20	.060	70	.614	20	.049	70	.676	20	.048	70	.675
30	.072	80	.624	30	.049	80	.679	30	.048	80	.681
40	.082	90	.633	40	.049	90	.683	40	.048	90	.688
550	.094	900	.641	550	.049	900	.687	550	.049	900	.694
60	.106	10	.648	60	.049	10	.689	60	.049	10	.699
70	.119	20	.652	70	.051	20	.691	70	.051	20	.703
80	.131	30	.658	80	.056	30	.693	80	.056	30	.708
90	.145	40	.660	90	.066	40	.694	90	.063	40	.711
600	.159	950	.661	600	.084	950	.694	600	.074	950	.714
10	.173	60	.662	10	.114	60	.694	10	.089	60	.716
20	.184	70	.662	20	.152	70	.692	20	.112	70	.716
30	.199	80	.662	30	.199	80	.692	30	.140	80	.718
40	.213	90	.662	40	.246	90	.691	40	.174	90	.718
650	.223	1000	.661	650	.289	1000	.690	650	.207	1000	.717
60	.227	10	.660	60	.318	10	.690	60	.237	10	.716
70	.225	20	.660	70	.335	20	.689	70	.261	20	.715
80	.242	30	.660	80	.361	30	.688	80	.294	30	.714
90	.282	40	.660	90	.419	40	.688	90	.340	40	.714
700	.324	1050	.659	700	.464	1050	.687	700	.381	1050	.713
10	.354	60	.659	10	.494	60	.687	10	.413	60	.713
20	.379	70	.658	20	.518	70	.686	20	.444	70	.712
30	.398	80	.658	30	.538	80	.686	30	.468	80	.712
40	.410			40	.556			40	.491		

American Forest Leaves
(Near Annapolis, Maryland)

Spectral Directional Reflectance of the Ventral Side of the Leaves of the Indicated Trees for the Visible and Near Infrared Spectrum, 400 to 1080 Millimicrons. (See Appendix A; GE Graph Sheets Serial No. GE II-1063, -1064, -1065, -1066.)

MOCKERNUT HICKORY (1)				MOCKERNUT HICKORY (2)				BLACK OAK (1)			
Ventral Side				Ventral Side				Ventral Side			
Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ
400	0.042	750	0.553	400	0.042	750	0.481	400	0.048	750	0.411
10	.046	60	.561	10	.046	60	.492	10	.055	60	.438
20	.049	70	.567	20	.048	70	.505	20	.060	70	.454
30	.051	80	.574	30	.050	80	.518	30	.063	80	.470
40	.052	90	.581	40	.053	90	.532	40	.066	90	.487
450	.053	800	.587	450	.054	800	.542	450	.069	800	.504
60	.055	10	.592	60	.058	10	.555	60	.072	10	.520
70	.058	20	.598	70	.063	20	.566	70	.074	20	.536
80	.059	30	.598	80	.068	30	.577	80	.077	30	.552
90	.063	40	.607	90	.072	40	.587	90	.081	40	.565
500	.077	850	.611	500	.087	850	.597	500	.086	850	.579
10	.117	60	.615	10	.118	60	.606	10	.092	60	.593
20	.177	70	.619	20	.154	70	.613	20	.099	70	.606
30	.233	80	.622	30	.182	80	.621	30	.107	80	.618
40	.271	90	.625	40	.206	90	.626	40	.115	90	.629
550	.300	900	.627	550	.227	900	.633	550	.124	900	.641
60	.323	10	.629	60	.249	10	.637	60	.134	10	.648
70	.343	20	.631	70	.267	20	.640	70	.145	20	.656
80	.359	30	.631	80	.284	30	.645	80	.155	30	.664
90	.374	40	.632	90	.299	40	.647	90	.166	40	.671
600	.386	950	.631	600	.313	950	.648	600	.177	950	.676
10	.398	60	.631	10	.325	60	.649	10	.189	60	.680
20	.406	70	.630	20	.336	70	.648	20	.200	70	.682
30	.415	80	.630	30	.347	80	.648	30	.210	80	.685
40	.414	90	.629	40	.352	90	.648	40	.221	90	.686
650	.406	1000	.628	650	.352	1000	.648	650	.230	1000	.686
60	.400	10	.627	60	.354	10	.647	60	.239	10	.686
70	.390	20	.627	70	.352	20	.646	70	.248	20	.686
80	.404	30	.626	80	.366	30	.645	80	.263	30	.685
90	.464	40	.626	90	.401	40	.645	90	.288	40	.685
700	.504	1050	.625	700	.428	1050	.645	700	.313	1050	.684
10	.523	60	.625	10	.442	60	.645	10	.334	60	.684
20	.533	70	.624	20	.455	70	.644	20	.353	70	.683
30	.539	80	.624	30	.460	80	.644	30	.379	80	.683
40	.547			40	.461			40	.395		

American Forest Leaves
(Near Annapolis, Maryland)

Spectral Directional Reflectance of the Ventral Side of the Leaves of the Indicated Trees for the Visible and Near Infrared Spectrum, 400 to 1080 Millimicrons. (See Appendix A; GE Graph Sheets Serial No. GE II-1063, -1064, -1065, -1066.)

BLACK OAK (2)				WHITE OAK (1)				WHITE OAK (2)			
Ventral Side				Ventral Side				"Green" Ventral Side			
Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ
400	0.039	750	0.323	400	0.042	750	0.584	400	0.042	750	0.594
10	.041	60	.339	10	.046	60	.603	10	.046	60	.612
20	.042	70	.353	20	.048	70	.612	20	.051	70	.622
30	.044	80	.369	30	.050	80	.617	30	.054	80	.628
40	.045	90	.384	40	.052	90	.621	40	.057	90	.633
450	.046	800	.399	450	.053	800	.624	450	.058	800	.637
60	.047	10	.416	60	.055	10	.627	60	.062	10	.641
70	.048	20	.431	70	.055	20	.629	70	.063	20	.643
80	.048	30	.447	80	.057	30	.631	80	.066	30	.647
90	.050	40	.461	90	.058	40	.633	90	.067	40	.650
500	.053	850	.476	500	.063	850	.634	500	.069	850	.653
10	.057	60	.491	10	.079	60	.637	10	.094	60	.655
20	.063	70	.506	20	.110	70	.638	20	.127	70	.658
30	.069	80	.520	30	.139	80	.640	30	.157	80	.660
40	.075	90	.532	40	.154	90	.641	40	.174	90	.662
550	.083	900	.546	550	.162	900	.642	550	.183	900	.664
60	.092	10	.558	60	.158	10	.643	60	.181	10	.666
70	.100	20	.567	70	.144	20	.644	70	.168	20	.666
80	.109	30	.576	80	.126	30	.645	80	.152	30	.667
90	.118	40	.585	90	.116	40	.645	90	.144	40	.668
600	.128	950	.592	600	.113	950	.644	600	.140	950	.668
10	.135	60	.598	10	.105	60	.644	10	.130	60	.668
20	.144	70	.603	20	.096	70	.643	20	.120	70	.667
30	.154	80	.607	30	.092	80	.642	30	.117	80	.667
40	.163	90	.610	40	.087	90	.642	40	.110	90	.667
650	.169	1000	.612	650	.075	1000	.641	650	.096	1000	.666
60	.174	10	.613	60	.067	10	.640	60	.084	10	.665
70	.178	20	.614	70	.059	20	.640	70	.071	20	.664
80	.189	30	.613	80	.057	30	.639	80	.069	30	.664
90	.217	40	.613	90	.084	40	.639	90	.105	40	.664
700	.244	1050	.612	700	.187	1050	.638	700	.223	1050	.663
10	.263	60	.612	10	.310	60	.638	10	.346	60	.663
20	.280	70	.612	20	.423	70	.637	20	.454	70	.662
30	.294	80	.612	30	.509	80	.637	30	.522	80	.662
40	.309			40	.558			40	.568		

American Forest Leaves
(Near Annapolis, Maryland)

Spectral Directional Reflectance of the Ventral Side of a Leaf of the Tree Indicated for the Visible and Near Infrared Spectrum, 400 to 1080 Millimicrons. (See Appendix A; GE Graph Sheets Serial No. GE II-1065, -1066.)

WHITE OAK (4) "Reddish" Ventral Side			
Wave Length mμ	R_λ	Wave Length mμ	R_λ
400	0.042	750	0.417
10	.046	60	.431
20	.051	70	.445
30	.054	80	.460
40	.057	90	.475
450	.058	800	.491
60	.062	10	.506
70	.063	20	.521
80	.066	30	.536
90	.068	40	.548
500	.071	850	.563
10	.075	60	.575
20	.079	70	.587
30	.082	80	.598
40	.085	90	.609
550	.089	900	.619
60	.095	10	.627
70	.105	20	.635
80	.118	30	.640
90	.135	40	.646
600	.155	950	.648
10	.176	60	.651
20	.199	70	.652
30	.223	80	.655
40	.245	90	.656
650	.264	1000	.656
60	.281	10	.657
70	.294	20	.658
80	.309	30	.658
90	.329	40	.657
700	.348	1050	.657
10	.363	60	.657
20	.379	70	.656
30	.390	80	.656
40	.401		

American Forest Leaves
(Washington, D.C.)

Spectral Directional Reflectance of the Ventral and Dorsal Sides of a Leaf of the Indicated Tree for the Visible and Near Infrared Spectrum, 400 to 1080 Millimicrons. (See Appendix A; GE Graph Sheets Serial No. GE II-1192, -1193.)

SPANISH HAZELNUT (1)
"Red"

Ventral Side				Dorsal Side			
Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ
400	0.039	750	0.578	400	0.039	750	0.564
10	.040	60	.618	10	.040	60	.586
20	.040	70	.630	20	.042	70	.599
30	.040	80	.634	30	.045	80	.605
40	.040	90	.639	40	.045	90	.609
450	.040	800	.642	450	.045	800	.612
60	.040	10	.644	60	.045	10	.616
70	.040	20	.646	70	.044	20	.618
80	.040	30	.648	80	.044	30	.619
90	.040	40	.650	90	.044	40	.620
500	.040	850	.650	500	.044	850	.622
10	.039	60	.652	10	.044	60	.622
20	.040	70	.653	20	.044	70	.624
30	.040	80	.654	30	.044	80	.625
40	.040	90	.656	40	.045	90	.627
550	.040	900	.658	550	.046	900	.628
60	.040	10	.658	60	.048	10	.629
70	.040	20	.658	70	.050	20	.630
80	.040	30	.659	80	.054	30	.630
90	.042	40	.659	90	.061	40	.630
600	.046	950	.658	600	.070	950	.629
10	.050	60	.655	10	.080	60	.626
20	.052	70	.651	20	.089	70	.622
30	.054	80	.650	30	.098	80	.621
40	.054	90	.651	40	.101	90	.622
650	.049	1000	.654	650	.099	1000	.624
60	.045	10	.658	60	.095	10	.626
70	.042	20	.661	70	.088	20	.631
80	.042	30	.665	80	.086	30	.635
90	.050	40	.669	90	.115	40	.637
700	.122	1050	.671	700	.188	1050	.642
10	.246	60	.672	10	.290	60	.644
20	.375	70	.676	20	.375	70	.646
30	.476	80	.676	30	.476	80	.648
40	.542			40	.530		

American Forest Leaves
(Washington, D.C.)

Spectral Directional Reflectance of the Ventral and Dorsal Sides of a Leaf of the Indicated Tree for the Visible and Near Infrared Spectrum, 400 to 1080 Millimicrons. (See Appendix A; GE Graph Sheets Serial No. GE II-1192, -1193.)

SPANISH HAZELNUT (2)

"Red and Green"

Ventral Side				Dorsal Side			
Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ
400	0.039	750	0.615	400	0.064	750	0.598
10	.040	60	.635	10	.065	60	.618
20	.040	70	.646	20	.065	70	.630
30	.040	80	.651	30	.065	80	.634
40	.040	90	.654	40	.066	90	.636
450	.040	800	.656	450	.068	800	.639
60	.040	10	.659	60	.069	10	.640
70	.040	20	.660	70	.068	20	.640
80	.040	30	.660	80	.068	30	.642
90	.040	40	.662	90	.068	40	.644
500	.040	850	.663	500	.070	850	.644
10	.044	60	.664	10	.077	60	.645
20	.055	70	.665	20	.086	70	.646
30	.065	80	.666	30	.094	80	.646
40	.069	90	.667	40	.099	90	.648
550	.070	900	.668	550	.102	900	.649
60	.069	10	.668	60	.106	10	.650
70	.064	20	.670	70	.108	20	.650
80	.060	30	.670	80	.109	30	.650
90	.059	40	.670	90	.112	40	.650
600	.060	950	.669	600	.118	950	.648
10	.060	60	.666	10	.120	60	.644
20	.056	70	.664	20	.117	70	.642
30	.054	80	.662	30	.116	80	.642
40	.050	90	.664	40	.112	90	.642
650	.044	1000	.666	650	.101	1000	.644
60	.040	10	.669	60	.095	10	.649
70	.036	20	.673	70	.084	20	.652
80	.036	30	.676	80	.081	30	.656
90	.048	40	.680	90	.105	40	.660
700	.120	1050	.684	700	.190	1050	.665
10	.245	60	.687	10	.290	60	.666
20	.385	70	.688	20	.385	70	.668
30	.487	80	.688	30	.491	80	.671
40	.572			40	.560		

American Forest Leaves
(Washington, D.C.)

Spectral Directional Reflectance of the Ventral and Dorsal Sides of a Leaf of the Indicated Tree for the Visible and Near Infrared Spectrum, 400 to 1080 Millimicrons. (See Appendix A; GE Graph Sheets Serial No. GE II-1192, -1193.)

SPANISH HAZELNUT (3)
"Green Sport"

Ventral Side				Dorsal Side			
Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ
400	0.039	750	0.594	400	0.061	750	0.578
10	.040	60	.610	10	.069	60	.596
20	.040	70	.621	20	.074	70	.605
30	.040	80	.628	30	.076	80	.610
40	.040	90	.630	40	.079	90	.612
450	.040	800	.632	450	.084	800	.614
60	.040	10	.634	60	.086	10	.616
70	.040	20	.636	70	.088	20	.618
80	.040	30	.636	80	.089	30	.619
90	.041	40	.638	90	.092	40	.620
500	.044	850	.639	500	.101	850	.621
10	.051	60	.640	10	.124	60	.622
20	.076	70	.642	20	.156	70	.624
30	.110	80	.642	30	.186	80	.624
40	.129	90	.644	40	.201	90	.626
550	.136	900	.644	550	.206	900	.626
60	.132	10	.645	60	.202	10	.626
70	.112	20	.646	70	.186	20	.628
80	.092	30	.646	80	.170	30	.628
90	.081	40	.646	90	.160	40	.627
600	.076	950	.644	600	.155	950	.626
10	.070	60	.642	10	.148	60	.624
20	.062	70	.639	20	.139	70	.619
30	.058	80	.638	30	.134	80	.618
40	.054	90	.639	40	.129	90	.618
650	.048	1000	.641	650	.115	1000	.621
60	.045	10	.644	60	.106	10	.624
70	.042	20	.646	70	.094	20	.628
80	.040	30	.650	80	.090	30	.633
90	.050	40	.654	90	.116	40	.636
700	.122	1050	.656	700	.190	1050	.638
10	.246	60	.660	10	.290	60	.641
20	.390	70	.664	20	.390	70	.644
30	.483	80	.666	30	.490	80	.648
40	.554			40	.546		

American Forest Leaves
(Washington, D.C.)

Spectral Directional Reflectance of the Ventral and Dorsal Side of a Leaf of the Indicated Tree for the Visible and Near Infrared Spectrum, 400 to 1080 Millimicrons. (See Appendix A; GE Graph Sheets Serial No. GE II-1192, -1193.)

PLUM
"Red"

Ventral Side				Dorsal Side			
Wave Length mµ	R_λ	Wave Length mµ	R_λ	Wave Length mµ	R_λ	Wave Length mµ	R_λ
400	0.044	750	0.634	400	0.061	750	0.631
10	.045	60	.650	10	.069	60	.640
20	.046	70	.658	20	.075	70	.646
30	.047	80	.661	30	.076	80	.650
40	.047	90	.664	40	.077	90	.651
450	.048	800	.665	450	.079	800	.652
60	.048	10	.666	60	.080	10	.654
70	.048	20	.668	70	.079	20	.654
80	.048	30	.668	80	.078	30	.655
90	.048	40	.668	90	.077	40	.655
500	.050	850	.669	500	.078	850	.655
10	.054	60	.670	10	.080	60	.656
20	.059	70	.670	20	.083	70	.656
30	.062	80	.670	30	.084	80	.656
40	.064	90	.670	40	.084	90	.658
550	.066	900	.671	550	.086	900	.658
60	.071	10	.672	60	.091	10	.658
70	.076	20	.672	70	.098	20	.659
80	.082	30	.671	80	.110	30	.659
90	.090	40	.670	90	.125	40	.656
600	.096	950	.668	600	.140	950	.654
10	.096	60	.664	10	.146	60	.650
20	.089	70	.659	20	.146	70	.644
30	.086	80	.656	30	.147	80	.642
40	.080	90	.657	40	.141	90	.642
650	.066	1000	.660	650	.125	1000	.644
60	.058	10	.664	60	.114	10	.649
70	.050	20	.668	70	.099	20	.652
80	.048	30	.674	80	.094	30	.656
90	.068	40	.676	90	.129	40	.660
700	.174	1050	.680	700	.235	1050	.665
10	.316	60	.682	10	.355	60	.666
20	.452	70	.684	20	.468	70	.672
30	.550	80	.688	30	.550	80	.675
40	.607			40	.605		

IX. Canadian Forest Leaves

Table VI lists the common name, the Latin name, and the dates of collection and measurement of the twenty-four leaf specimens. This is followed by eighteen illustrations (Figures 19 to 36) showing a record of the forty-eight determinations on these twenty-four specimens of leaves picked from trees or gathered from the ground near Ottawa, Ontario, by Dr. J. M. Robinson of the Department of Resource and Development, on May 10 and May 18, 1953, and delivered to the NBS by Dr. H. T. O'Neill on May 14 and 25, 1953.

These two shipments were made in large cardboard boxes. The samples were wrapped in newspapers and these were surrounded with many leaves picked from trees and off of the ground.

The first nine illustrations, Figures 19 to 27, show the spectral directional reflectance curves of the specimens designated in the legends of the illustrations, and listed in Table VI and in the index to Appendix C. The data plotted in the illustrations are taken from the tables of reduced spectrophotometric readings listed in Appendix D.

The chromaticity coordinates of the samples of these nine illustrations are shown in the segments of the three C.I.E. chromaticity diagrams for standard source C, Figures 28, 29, and 30. The data used for these three illustrations are listed in Table VII.

The Munsell renotations of these same specimens are illustrated in the five schematic diagrams of the "ideal" Munsell System in Figures 31 to 35. The data used for these illustrations are listed in Tables VIII and IX together with the corresponding ISCC-NBS color designation.

Color-difference determinations by means of the Godlove color-difference formula were computed between the ventral and the dorsal sides of twelve of these leaves. These differences are listed in Table X and illustrated in Figure 36.

Table VI

Identification of the Leaf Specimens from Trees of the Eastern Part of the Dominion of Canada, near Ottawa, and the Date of Gathering and Measurement.

Specimen		Date	Date
Common Name	Latin Name	Gathered	Measured
TREMBLING ASPEN	Populus tremuloides Michx.	5-18-53	5-25-53
BASSWOOD	Tilia americana L.	5-10-53	5-14-53
BEECH (1)	Fagus grandifolia Ehrh.	5-10-53	5-14-53
BEECH (2) "Brown"	Fagus grandifolia Ehrh.	5-18-53	5-25-53
BEECH (3) "Green"	Fagus grandifolia Ehrh.	5-18-53	5-25-53
WHITE BIRCH	Betula alba L.	5-10-53	5-14-53
YELLOW BIRCH	Betula lutea Michx.	5-10-53	5-14-53
PIN CHERRY	Prunus pennsylvanica L.	5-10-53	5-14-53
*WHITE ELM (1)	Ulmus americana L.	5-10-53	5-14-53
WHITE ELM (2)	Ulmus americana L.	5-18-53	5-29-53
HORNBEAM	Carpinus betulus L.	5-10-53	5-14-53
IRONWOOD	Carpinus caroliniana Walt.	5-18-53	5-29-53
JUNEBERRY	Amelanchier arborea (Michx.f.) Fern.	5-18-53	5-29-53
RED MAPLE	Acer rubrum L.	5-18-53	5-25-53
SUGAR MAPLE (1)	Acer saccharum Marsh.	5-10-53	5-14-53
SUGAR MAPLE (2)	Acer saccharum Marsh.	5-18-53	5-29-53
*SUGAR MAPLE (3) "Light Brown"	Acer saccharum Marsh.	5-10-53	5-14-53
*SUGAR MAPLE (4) "Medium Brown"	Acer saccharum Marsh.	5-10-53	5-14-53
*SUGAR MAPLE (5) "Dark Brown"	Acer saccharum Marsh.	5-10-53	5-14-53
BALSAM POPLAR (1)	Populus balsamifera L.	5-10-53	5-14-53
BALSAM POPLAR (2) "Black"	Populus balsamifera L.	5-18-53	5-29-53
BALSAM POPLAR (3) "Green"	Populus balsamifera L.	5-18-53	5-29-53
LARGE TOOTH POPLAR(1) "Green"	Populus grandidentata Michx.	5-18-53	5-29-53
LARGE TOOTH POPLAR(2) "White"	Populus grandidentata Michx.	5-18-53	5-29-53

*Overwintered leaves gathered from ground.

Figure 19.

Visible and near infrared spectral directional reflectance of the ventral side of the leaves of four typical deciduous trees in the Ottawa, Ontario, region of the Dominion of Canada, picked on May 10, 1953. They are Hornbeam, White Birch, Beech (1), and Balsam Poplar (1). For further identification see Table VI and the index to Appendix C.

Figure 20.

Visible and near infrared spectral directional reflectance of the ventral side of the leaves of four typical deciduous trees in the Ottawa, Ontario, region of the Dominion of Canada, picked on May 10, 1953. They are Sugar Maple (1), Yellow Birch, Basswood, and Pin Cherry. For further identification see Table VI and the index to Appendix C.

Figure 21.

Visible and near infrared spectral directional reflectance of the ventral side of overwintered leaves from two typical deciduous trees in the Ottawa, Ontario, region of the Dominion of Canada, collected on May 10, 1953. They are White Elm (1), and a "light-", "medium-", and "dark-brown" specimen of Sugar Maple (3), (4), and (5), respectively. For further identification see Table VI and the index to Appendix C.

Figure 22.

Visible spectral directional reflectance of the ventral side of the leaves of three typical deciduous trees in the Ottawa, Ontario, region of the Dominion of Canada, picked on May 18, 1953. They are White Elm (2), Red Maple, and Sugar Maple (2). For further identification see Table VI and the index to Appendix C. (The spectrophotometric curves of the dorsal side of these same leaves are shown in Figure 23.)

Figure 23.

Visible spectral directional reflectance of the dorsal side of the leaves of Figure 22, picked on May 18, 1953 in the Ottawa, Ontario, region of the Dominion of Canada. They are White Elm (2), Red Maple, and Sugar Maple (2). For further identification see Table VI and the index to Appendix C.

Figure 24.

Visible spectral directional reflectance of the ventral side of the leaves of three typical deciduous trees in the Ottawa, Ontario, region of the Dominion of Canada, picked on May 18, 1953. They are a "brown" and a "green" Beech (2) and (3), a "green" and a "black" Balsam Poplar (3) and (2), and a "green" and a "white" Large Tooth Poplar (1) and (2). For further identification see Table VI and the index to Appendix C. (The spectrophotometric curves of the dorsal sides of these same leaves are shown in Figure 25.)

Figure 25.

Visible spectral directional reflectance of the dorsal side of the leaves of Figure 24, picked on May 18, 1953 in the Ottawa, Ontario, region of the Dominion of Canada. They are a "green" and a "brown" Beech (3) and (2), a "green" and a "black" Balsam Poplar (3) and (2), and a "green" and a "white" Large Tooth Poplar (1) and (2). For further identification see Table VI and the index to Appendix C.

Figure 26.

Visible spectral directional reflectance of the ventral side of the leaves of three typical deciduous trees in the Ottawa, Ontario, region of the Dominion of Canada, picked on May 18, 1953. They are Juneberry, Trembling Aspen, and Ironwood. For further identification see Table VI and the index to Appendix C. (The spectrophotometric curves of the dorsal sides of these same leaves are shown in Figure 27.)

Figure 27.

Visible spectral directional reflectance of the dorsal side of the leaves of Figure 26, picked on May 18, 1953 in the Ottawa, Ontario, region of the Dominion of Canada. They are Juneberry, Trembling Aspen, and Ironwood. For further identification see Table VI and the index to Appendix C.

Figure 28.

Segment of the C.I.E. chromaticity diagram showing dominant wavelength, excitation purity, and chromaticity coordinates for standard source C of the ventral sides of Hornbeam, Pin Cherry, and Balsam Poplar (1), and the ventral and dorsal sides of Balsam Poplar (3) "green", Balsam Poplar (2) "black", Ironwood, and Beech (2) "brown"; from data listed in Table VII. For further identification see Table VI and the index to Appendix C. Note ventral side of specimens are illustrated with closed circles and the dorsal side of the specimens by open circles.

Figure 29.

Segment of the C.I.E. chromaticity diagram showing dominant wavelength, excitation purity, and chromaticity coordinates for standard source C of the ventral sides of "light-", "medium-", and "dark-brown" Sugar Maple (3), (4), and (5), and the ventral and the dorsal sides of Trembling Aspen, Red Maple, and Large Tooth Poplar (2) "white"; from data listed in Table VII. For further identification see Table VI and the index to Appendix C. The sugar maple specimens were "dead overwintered leaves on the ground". Note ventral side of specimens are illustrated with closed circles and the dorsal side of the specimens by open circles.

Figure 30.

Segment of the C.I.E. chromaticity diagram showing dominant wavelength, excitation purity, and chromaticity coordinates for standard source C of the ventral sides of Sugar Maple (1), White Birch, Basswood, Beech (1), Yellow Birch, and White Elm (1); and the ventral and the dorsal sides of Beech (3) "green", Sugar Maple (2), Juneberry, and White Elm (2); from data listed in Table VII. For further identification see Table VI and the index to Appendix C. The White Elm (1) specimen was a "dead overwintered leaf on the ground". Note ventral side of specimens are illustrated with closed circles and the dorsal side of the specimens by open circles.

Figure 31.

Vertical and horizontal projections of the colors of the ventral sides (closed circle) of Basswood, Balsam Poplar (1), Pin Cherry, and Hornbeam; and of the color differences between the ventral (closed circle) and the dorsal (open circle) sides of Balsam Poplar (2) "black". The upper diagram shows the Munsell Value of these measurements plotted against the Munsell Hue and Chroma points projected from the lower diagram. The Munsell data are listed in Tables VIII and IX. For further identification see Table VI and the index to Appendix C.

Figure 32.

Vertical and horizontal projections of the colors of the ventral sides (closed circle) of Beech (1), and White Elm (1); and of the color differences between the ventral (closed circle) and dorsal (open circle) sides of Beech (2) "brown", Beech (3) "green", and White Elm (2). The upper diagram shows the Munsell Value plotted against the Munsell Hue and Chroma points projected from the lower diagram. The Munsell data are listed in Tables VIII and IX. For further identification see Table VI and the index to Appendix C.

Figure 33.

Vertical and horizontal projections of the colors of the ventral sides (closed circle) of Yellow Birch and White Birch; and of the color differences between the ventral (closed circle) and dorsal (open circle) sides of Trembling Aspen, Ironwood, and Juneberry. The upper diagram shows the Munsell Value plotted against the Munsell Hue and Chroma points projected from the lower diagram. The Munsell data are listed in Tables VIII and IX. For further identification see Table VI and the index to Appendix C.

Figure 34.

Vertical and horizontal projections of the colors of the ventral sides (closed circle) of "light-", "medium-", and "dark-brown" Sugar Maple (3), (4), and (5); and of the ventral (closed circle) and dorsal (open circle) sides of Sugar Maple (2), and Red Maple. The upper diagram shows the Munsell Value plotted against the Munsell Hue and Chroma points projected from the lower diagram. The Munsell data are listed in Tables VIII and IX. For further identification see Table VI and the index to Appendix C.

Figure 35.

Vertical and horizontal projections of the color differences between the ventral (closed circle) and the dorsal (open circle) sides of Large Tooth Poplar (2) "white", Large Tooth Poplar (1) "green", and Balsam Poplar (3) "green". The upper diagram shows the Munsell Value plotted against the Munsell Hue and Chroma points projected from the lower diagram. The Munsell data are listed in Tables VIII and IX. For further identification see Table VI and the index to Appendix C.

Figure 36.

Color differences computed from the Godlove color-difference formula, converted into NBS units, between the ventral and the dorsal sides of the same leaf specimens picked in the spring (May 18, 1953) in the Ottawa, Ontario, region of the Dominion of Canada.

Table VII

Canadian Forest Leaves

Chromaticity Coordinates and Daylight Reflectances for C.I.E. Source C of the Leaves Studied.

Specimen	Ventral Side			Dorsal Side		
	Chromaticity Coordinates		Daylight Reflectance	Chromaticity Coordinates		Daylight Reflectance
	x	y	Y(%)	x	y	Y(%)
TREMBLING ASPEN	0.337	0.429	9.3	0.341	0.404	18.8
BASSWOOD	.361	.448	12.8	---	---	---
BEECH (1)	.376	.442	16.7	---	---	---
BEECH (2) "Brown"	.409	.391	13.2	.384	.378	15.6
BEECH (3) "Green"	.360	.446	7.9	.348	.401	15.5
WHITE BIRCH	.359	.454	13.2	---	---	---
YELLOW BIRCH	.340	.382	6.9	---	---	---
PIN CHERRY	.335	.418	8.6	---	---	---
WHITE ELM (1)	.373	.352	13.3	---	---	---
WHITE ELM (2)	.363	.440	12.4	.349	.399	18.8
HORNBEAM	.354	.432	6.8	---	---	---
IRONWOOD	.374	.434	10.8	.358	.384	14.3
JUNEBERRY	.384	.450	14.1	.369	.408	22.5
RED MAPLE	.354	.432	11.6	.356	.423	13.5
SUGAR MAPLE (1)	.366	.464	14.5	---	---	---
SUGAR MAPLE (2)	.372	.457	14.3	.351	.407	21.3
SUGAR MAPLE (3) "Light Brown"	.418	.390	17.8	---	---	---
SUGAR MAPLE (4) "Medium Brown"	.390	.358	12.6	---	---	---
SUGAR MAPLE (5) "Dark Brown"	.360	.346	8.1	---	---	---
BALSAM POPLAR (1)	.339	.402	10.4	---	---	---
BALSAM POPLAR (2) "Black"	.340	.334	4.8	.365	.356	11.3
BALSAM POPLAR (3) "Green"	.362	.430	15.3	.341	.377	29.7
LARGE TOOTH POPLAR (1) "Green"	.369	.437	18.8	.338	.372	31.4
LARGE TOOTH POPLAR (2) "White"	.329	.338	15.4	.331	.342	32.8

Table VIII

Canadian Forest Leaves

Munsell Renotations and ISCC-NBS Color Designations of the Ventral Side of the Leaves Studied.

Specimen	Munsell Renotations	ISCC-NBS Color Designations
TREMBLING ASPEN	6.6GY 3.6/4.1	Moderate Olive Green
BASSWOOD	4.8GY 4.1/4.7	Moderate Olive Green
BEECH (1)	2.5GY 4.6/4.8	Moderate Yellow Green
BEECH (2) "Brown"	0.4Y 4.2/3.8	Moderate Yellowish Brown
BEECH (3) "Green"	4.7GY 3.3/4.2	Moderate Olive Green
WHITE BIRCH	5.3GY 4.2/5.0	Moderate Olive Green
YELLOW BIRCH	3.4GY 3.1/2.2	Grayish Olive Green
PIN CHERRY	6.5GY 3.4/3.6	Moderate Olive Green
WHITE ELM (1)	7.0YR 4.2/2.4	Grayish Brown
WHITE ELM (2)	4.2GY 4.1/4.4	Moderate Olive Green
HORNBEAM	4.8GY 3.0/3.7	Moderate Olive Green
IRONWOOD	2.0GY 3.8/4.0	Moderate Olive
JUNEBERRY	1.8GY 4.3/4.9	Moderate Olive
RED MAPLE	5.1GY 3.9/4.0	Moderate Olive Green
SUGAR MAPLE (1)	5.4GY 4.4/5.5	Moderate Olive Green
SUGAR MAPLE (2)	3.8GY 4.3/5.2	Moderate Olive Green
SUGAR MAPLE (3) "Light Brown"	8.9YR 4.8/4.6	Moderate Yellowish Brown
SUGAR MAPLE (4) "Medium Brown"	5.5YR 4.1/3.0	Moderate Brown
SUGAR MAPLE (5) "Dark Brown"	7.5YR 3.3/1.6	Grayish Brown
BALSAM POPLAR (1)	5.6GY 3.7/3.1	Moderate Olive Green
BALSAM POPLAR (2) "Black"	7.7Y 2.6/0.9	Olive Gray
BALSAM POPLAR (3) "Green"	3.7GY 4.5/4.3	Moderate Olive Green
LARGE TOOTH POPLAR (1) "Green"	3.2GY 4.9/4.8	Moderate Yellow Green
LARGE TOOTH POPLAR (2) "White"	5.0Y 4.5/0.8	Olive Gray

Table IX

Canadian Forest Leaves

Munsell Renotations and ISCC-NBS Color Designations of the Dorsal Sides of the Leaves Studied.

Specimen	Munsell Renotations	ISCC-NBS Color Designations
TREMBLING ASPEN	5.7GY 4.9/3.7	Moderate Yellow Green
BASSWOOD	---	----
BEECH (1)	---	----
BEECH (2) "Brown"	1.5Y 4.5/3.1	Light Olive Brown
BEECH (3) "Green"	4.0GY 4.5/3.2	Moderate Olive Green
WHITE BIRCH	---	----
YELLOW BIRCH	---	----
PIN CHERRY	---	----
WHITE ELM (1)	---	----
WHITE ELM (2)	3.8GY 4.9/3.4	Moderate Yellow Green
HORNBEAM	---	----
IRONWOOD	9.0Y 4.3/2.5	Grayish Olive
JUNEBERRY	0.4GY 5.3/3.8	Light Olive
RED MAPLE	4.1GY 4.2/3.9	Moderate Olive Green
SUGAR MAPLE (1)	---	----
SUGAR MAPLE (2)	4.0GY 5.2/3.9	Moderate Yellow Green
SUGAR MAPLE (3) "Light Brown"	---	----
SUGAR MAPLE (4) "Medium Brown"	---	----
SUGAR MAPLE (5) "Dark Brown"	---	----
BALSAM POPLAR (1)	---	----
BALSAM POPLAR (2) "Black"	9.5YR 3.9/2.0	Grayish Yellowish Brown
BALSAM POPLAR (3) "Green"	3.1GY 6.0/2.7	Grayish Yellow Green
LARGE TOOTH POPLAR (1) "Green"	3.4GY 6.1/2.5	Grayish Yellow Green
LARGE TOOTH POPLAR (2) "White"	5.8Y 6.2/1.5	Light Olive Gray

Table X

Color Differences Computed from the Godlove Color-Difference Formula, Converted into NBS Units, Between the Ventral and Dorsal Sides of the Same Leaf Specimen of the Canadian Forest Trees.

Specimen	Color Difference ΔE
TREMBLING ASPEN	26.0
BEECH (2) "Brown"	7.5
BEECH (3) "Green"	24.5
WHITE ELM (2)	17.0
IRONWOOD	13.0
JUNEBERRY	20.5
RED MAPLE	6.0
SUGAR MAPLE (2)	19.0
BALSAM POPLAR (2) "Black"	27.0
BALSAM POPLAR (3) "Green"	31.0
LARGE TOOTH POPLAR (1) "Green"	26.5
LARGE TOOTH POPLAR (2) "White"	34.0

Appendix C.

Ozalid prints of the original recordings of the leaf specimens of the Canadian Forest Trees obtained on a General Electric recording spectrophotometer at the National Bureau of Standards, 400 to 1080 millimicrons.

Index to Appendix C.

Specimen	GE Graph Sheet Serial Number: Visible Spectrum	GE Graph Sheet Serial Number: Near Infrared Spectrum	Curve Number: Ventral Side	Curve Number: Dorsal Side
TREMBLING ASPEN	GE II-1216	----	1	2
BASSWOOD	-1207	GE II-1208	9	--
BEECH (1)	-1207	-1208	7	--
BEECH (2) "Brown"	-1217	----	1	2
BEECH (3) "Green"	-1217	----	3	4
WHITE BIRCH	-1207	-1208	5	--
YELLOW BIRCH	-1207	-1208	8	--
PIN CHERRY	-1207	-1208	11	--
WHITE ELM (1)	-1210	-1209	4	--
WHITE ELM (2)	-1224	----	1	2
HORNBEAM	-1207	-1208	4	--
IRONWOOD	-1221	----	1	2
JUNEBERRY	-1222	----	1	2
RED MAPLE	-1215	----	1	2
SUGAR MAPLE (1)	-1207	-1208	6	--
SUGAR MAPLE (2)	-1223	----	1	2
SUGAR MAPLE (3) "Light Brown"	-1210	-1209	5	--
SUGAR MAPLE (4) "Medium Brown"	-1210	-1209	6	--
SUGAR MAPLE (5) "Dark Brown"	-1210	-1209	7	--
BALSAM POPLAR (1)	-1207	-1208	10	--
BALSAM POPLAR (2) "Black"	-1219	----	3	4
BALSAM POPLAR (3) "Green"	-1219	----	1	2
LARGE TOOTH POPLAR (1) "Green"	-1220	----	1	2
LARGE TOOTH POPLAR (2) "White"	-1220	----	3	4

Appendix D

Spectral directional reflectance data obtained from correcting and reading the spectrophotometric curves of leaf specimens of Canadian Forest Trees.

Canadian Forest Leaves
(Near Ottawa, Ontario)

Spectral Directional Reflectance of the Ventral and Dorsal Sides of the Leaves of the Trees Indicated for the Visible Spectrum, 400 to 750 Millimicrons. (See Appendix C, GE Graph Sheets Serial No. GE II-1216, -1217, 1224.)

Wave Length mμ	TREMBLING ASPEN		BEECH (2) "Brown"		BEECH (3) "Green"		WHITE ELM (2)	
	Ventral	Dorsal	Ventral	Dorsal	Ventral	Dorsal	Ventral	Dorsal
400	0.029	0.040	0.040	0.060	0.021	0.054	0.028	0.068
10	.030	.050	.044	.065	.024	.064	.032	.078
20	.033	.066	.046	.069	.025	.069	.038	.086
30	.036	.080	.050	.073	.026	.074	.041	.090
40	.040	.096	.052	.076	.028	.076	.044	.093
450	.044	.101	.054	.080	.028	.081	.046	.099
60	.045	.108	.058	.084	.029	.084	.048	.102
70	.045	.108	.061	.089	.030	.086	.049	.104
80	.045	.109	.064	.094	.030	.087	.050	.106
90	.046	.113	.070	.099	.030	.090	.050	.109
500	.050	.126	.076	.106	.034	.100	.058	.121
10	.062	.150	.086	.116	.044	.120	.075	.144
20	.087	.188	.098	.126	.066	.148	.106	.176
30	.116	.217	.108	.136	.091	.171	.142	.206
40	.129	.229	.116	.144	.105	.184	.160	.220
550	.132	.232	.126	.152	.111	.188	.168	.226
60	.125	.226	.137	.162	.110	.186	.168	.226
70	.106	.208	.148	.171	.096	.174	.150	.211
80	.088	.189	.159	.180	.081	.161	.130	.195
90	.078	.178	.170	.188	.078	.152	.119	.186
600	.074	.171	.174	.192	.068	.148	.114	.180
10	.068	.164	.176	.194	.062	.141	.105	.174
20	.060	.152	.181	.198	.054	.134	.095	.164
30	.056	.148	.190	.205	.050	.129	.090	.159
40	.051	.139	.192	.204	.046	.122	.084	.153
650	.044	.124	.180	.196	.038	.109	.071	.136
60	.039	.110	.158	.174	.032	.098	.061	.126
70	.034	.096	.137	.155	.026	.085	.050	.110
80	.032	.092	.147	.163	.024	.080	.048	.104
90	.050	.129	.198	.211	.038	.106	.067	.135
700	.124	.219	.259	.274	.101	.184	.150	.220
10	.242	.320	.322	.336	.200	.266	.264	.314
20	.380	.425	.360	.376	.298	.338	.380	.401
30	.511	.511	.384	.396	.374	.395	.476	.476
40	.585	.581	.400	.410	.418	.429	.541	.522
750	.626	.612	.414	.420	.438	.444	.578	.550

Canadian Forest Leaves
(Near Ottawa, Ontario)

Spectral Directional Reflectance of the Ventral and Dorsal Sides of the Leaves of the Trees Indicated for the Visible Spectrum, 400 to 750 Millimicrons. (See Appendix C; GE Graph Sheets Serial No. GE II-1215, -1221, -1222, -1223.)

Wave Length mμ	IRONWOOD		JUNEBERRY		RED MAPLE		SUGAR MAPLE (2)	
	Ventral	Dorsal	Ventral	Dorsal	Ventral	Dorsal	Ventral	Dorsal
400	0.029	0.060	0.030	0.062	0.040	0.040	0.034	0.088
10	.031	.066	.034	.078	.044	.048	.036	.091
20	.034	.071	.037	.090	.045	.052	.038	.094
30	.036	.074	.039	.094	.046	.054	.040	.096
40	.038	.076	.040	.096	.046	.054	.041	.098
450	.039	.080	.041	.100	.047	.058	.043	.104
60	.041	.084	.044	.106	.048	.060	.044	.109
70	.042	.085	.045	.108	.048	.061	.046	.110
80	.042	.086	.045	.109	.049	.062	.046	.111
90	.044	.090	.049	.114	.050	.066	.049	.116
500	.049	.099	.059	.129	.057	.075	.057	.131
10	.064	.112	.082	.156	.075	.097	.081	.160
20	.090	.129	.116	.195	.106	.126	.124	.200
30	.118	.143	.150	.231	.138	.155	.166	.237
40	.131	.150	.171	.252	.150	.168	.186	.254
550	.139	.158	.181	.264	.156	.171	.196	.261
60	.140	.162	.184	.269	.152	.169	.195	.259
70	.131	.160	.176	.261	.136	.154	.176	.242
80	.118	.156	.158	.249	.119	.140	.152	.222
90	.110	.154	.148	.240	.109	.131	.139	.209
600	.106	.154	.141	.236	.104	.126	.131	.202
10	.100	.151	.134	.229	.096	.119	.121	.192
20	.096	.148	.120	.216	.086	.110	.106	.180
30	.086	.146	.114	.209	.084	.106	.100	.174
40	.081	.142	.109	.206	.075	.099	.094	.165
650	.068	.130	.094	.188	.063	.086	.074	.144
60	.058	.121	.076	.164	.054	.075	.061	.129
70	.048	.107	.056	.135	.046	.064	.049	.110
80	.045	.102	.050	.124	.046	.062	.044	.104
90	.068	.134	.072	.158	.074	.100	.072	.139
700	.151	.215	.160	.260	.165	.185	.185	.247
10	.279	.292	.264	.357	.270	.270	.320	.360
20	.374	.354	.352	.433	.348	.348	.434	.454
30	.445	.400	.416	.486	.414	.400	.524	.525
40	.490	.434	.459	.520	.452	.436	.575	.575
750	.518	.456	.481	.539	.472	.456	.609	.604

Canadian Forest Leaves
(Near Ottawa, Ontario)

Spectral Directional Reflectance of the Ventral and Dorsal Sides of the Leaves of the Trees Indicated for the Visible Spectrum, 400 to 750 Millimicrons. (See Appendix C; GE Graph Sheets Serial No. GE II-1219, -1220.)

Wave Length	BALSAM POPLAR(2) "Black"		BALSAM POPLAR(3) "Green"		LARGE TOOTH POPLAR(1) "Green"		LARGE TOOTH POPLAR(2) "White"	
mμ	Ventral	Dorsal	Ventral	Dorsal	Ventral	Dorsal	Ventral	Dorsal
400	0.037	0.052	0.052	0.096	0.050	0.136	0.090	0.146
10	.038	.059	.054	.116	.055	.160	.104	.184
20	.038	.064	.056	.138	.060	.179	.114	.212
30	.039	.068	.058	.156	.064	.191	.120	.235
40	.040	.071	.060	.174	.066	.200	.125	.252
450	.040	.074	.062	.189	.069	.206	.129	.266
60	.040	.077	.063	.200	.071	.212	.132	.277
70	.040	.080	.064	.206	.072	.214	.134	.286
80	.041	.082	.064	.210	.072	.216	.135	.292
90	.041	.084	.064	.216	.074	.219	.136	.298
500	.042	.086	.070	.230	.084	.229	.138	.302
10	.042	.090	.086	.252	.109	.254	.141	.308
20	.044	.095	.124	.282	.158	.294	.146	.314
30	.044	.100	.169	.311	.211	.332	.150	.320
40	.046	.104	.195	.326	.238	.354	.154	.325
550	.046	.109	.206	.335	.248	.360	.158	.329
60	.049	.114	.206	.335	.246	.359	.160	.333
70	.050	.119	.189	.324	.226	.344	.160	.336
80	.051	.124	.164	.308	.202	.326	.160	.338
90	.052	.129	.149	.299	.186	.314	.160	.340
600	.054	.134	.140	.292	.178	.307	.160	.343
10	.055	.137	.131	.286	.169	.300	.161	.345
20	.056	.141	.119	.277	.156	.292	.160	.346
30	.058	.146	.113	.272	.150	.286	.160	.348
40	.059	.150	.104	.265	.136	.276	.159	.348
650	.059	.151	.087	.250	.111	.256	.154	.346
60	.058	.152	.078	.239	.100	.246	.152	.345
70	.056	.152	.068	.222	.084	.232	.150	.342
80	.057	.157	.064	.215	.076	.228	.150	.342
90	.064	.166	.082	.244	.114	.260	.160	.354
700	.072	.176	.186	.326	.250	.374	.204	.364
10	.078	.184	.330	.422	.399	.492	.249	.411
20	.082	.190	.471	.515	.504	.574	.275	.428
30	.086	.195	.576	.592	.566	.624	.294	.440
40	.090	.200	.639	.639	.600	.646	.305	.448
750	.094	.204	.672	.664	.616	.659	.315	.454

Canadian Forest Leaves
(Near Ottawa, Ontario)

Spectral Directional Reflectance of the Ventral Side of the Leaves of the Trees Indicated for the Visible and Near Infrared Spectrum, 400 to 1080 Millimicrons. (See Appendix C; GE Graph Sheets Serial No. GE II-1207, -1208.)

BASSWOOD				BEECH (1)				WHITE BIRCH			
Ventral Side				Ventral Side				Ventral Side			
Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ
400	0.043	750	0.556	400	0.047	750	0.568	400	0.039	750	0.570
10	.044	60	.578	10	.048	60	.578	10	.042	60	.581
20	.043	70	.585	20	.050	70	.585	20	.043	70	.585
30	.043	80	.590	30	.050	80	.592	30	.043	80	.588
40	.043	90	.593	40	.052	90	.597	40	.043	90	.590
450	.043	800	.595	450	.055	800	.602	450	.043	800	.591
60	.044	10	.598	60	.058	10	.607	60	.044	10	.593
70	.046	20	.600	70	.059	20	.611	70	.046	20	.594
80	.047	30	.603	80	.062	30	.615	80	.047	30	.595
90	.048	40	.602	90	.066	40	.618	90	.048	40	.594
500	.057	850	.604	500	.081	850	.622	500	.057	850	.598
10	.079	60	.606	10	.109	60	.625	10	.079	60	.598
20	.122	70	.607	20	.152	70	.628	20	.122	70	.600
30	.154	80	.608	30	.186	80	.630	30	.164	80	.602
40	.170	90	.608	40	.203	90	.632	40	.182	90	.602
550	.174	900	.610	550	.212	900	.637	550	.187	900	.604
60	.168	10	.610	60	.212	10	.638	60	.180	10	.605
70	.150	20	.608	70	.196	20	.641	70	.155	20	.605
80	.130	30	.607	80	.180	30	.642	80	.131	30	.606
90	.118	40	.601	90	.169	40	.643	90	.118	40	.606
600	.112	950	.591	600	.164	950	.640	600	.111	950	.603
10	.103	60	.579	10	.156	60	.638	10	.103	60	.602
20	.093	70	.570	20	.146	70	.637	20	.093	70	.600
30	.089	80	.569	30	.141	80	.637	30	.089	80	.601
40	.080	90	.571	40	.128	90	.640	40	.080	90	.602
650	.066	1000	.576	650	.108	1000	.644	650	.066	1000	.605
60	.057	10	.583	60	.095	10	.648	60	.058	10	.608
70	.047	20	.589	70	.079	20	.650	70	.050	20	.610
80	.045	30	.590	80	.077	30	.652	80	.049	30	.613
90	.075	40	.593	90	.121	40	.654	90	.078	40	.615
700	.189	1050	.596	700	.249	1050	.655	700	.194	1050	.617
10	.292	60	.597	10	.376	60	.658	10	.313	60	.619
20	.402	70	.596	20	.458	70	.660	20	.432	70	.621
30	.482	80	.596	30	.515	80	.662	30	.507	80	.623
40	.530			40	.550			40	.551		

Canadian Forest Leaves
(Near Ottawa, Ontario)

Spectral Directional Reflectance of the Ventral Side of the Leaves of the Trees Indicated for the Visible and Near Infrared Spectrum, 400 to 1080 Millimicrons. (See Appendix C; GE Graph Sheets Serial No. GE II-1207, -1208, -1209, -1210.)

YELLOW BIRCH				PIN CHERRY				WHITE ELM(1)			
Ventral Side				Ventral Side				Ventral Side			
Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ
400	0.039	750	0.296	400	0.037	750	0.626	400	0.073	750	0.309
10	.039	60	.301	10	.038	60	.648	10	.076	60	.329
20	.040	70	.311	20	.039	70	.660	20	.078	70	.339
30	.041	80	.321	30	.041	80	.667	30	.082	80	.351
40	.042	90	.331	40	.042	90	.670	40	.084	90	.362
450	.042	800	.342	450	.043	800	.674	450	.087	800	.372
60	.042	10	.354	60	.043	10	.677	60	.089	10	.382
70	.042	20	.366	70	.043	20	.679	70	.092	20	.392
80	.042	30	.377	80	.043	30	.682	80	.095	30	.402
90	.043	40	.389	90	.043	40	.681	90	.098	40	.411
500	.044	850	.401	500	.044	850	.685	500	.100	850	.420
10	.049	60	.414	10	.056	60	.686	10	.104	60	.430
20	.062	70	.426	20	.079	70	.688	20	.109	70	.437
30	.074	80	.439	30	.106	80	.689	30	.113	80	.445
40	.081	90	.450	40	.118	90	.691	40	.118	90	.451
550	.084	900	.465	550	.122	900	.693	550	.125	900	.459
60	.084	10	.476	60	.115	10	.693	60	.131	10	.465
70	.078	20	.488	70	.098	20	.692	70	.138	20	.470
80	.071	30	.498	80	.081	30	.692	80	.145	30	.475
90	.067	40	.507	90	.073	40	.691	90	.154	40	.481
600	.065	950	.512	600	.068	950	.686	600	.161	950	.484
10	.063	60	.518	10	.063	60	.682	10	.169	60	.489
20	.058	70	.523	20	.056	70	.678	20	.178	70	.493
30	.058	80	.531	30	.054	80	.677	30	.185	80	.495
40	.054	90	.538	40	.050	90	.679	40	.195	90	.500
650	.049	1000	.548	650	.045	1000	.680	650	.203	1000	.502
60	.046	10	.556	60	.041	10	.684	60	.211	10	.503
70	.043	20	.565	70	.039	20	.685	70	.220	20	.504
80	.043	30	.571	80	.039	30	.685	80	.229	30	.504
90	.054	40	.576	90	.049	40	.685	90	.240	40	.503
700	.110	1050	.578	700	.112	1050	.683	700	.251	1050	.501
10	.172	60	.582	10	.226	60	.683	10	.262	60	.500
20	.228	70	.586	20	.361	70	.682	20	.272	70	.497
30	.259	80	.586	30	.495	80	.682	30	.290	80	.496
40	.281			40	.578			40	.300		

Canadian Forest Leaves
(Near Ottawa, Ontario)

Spectral Directional Reflectance of the Ventral Side of the Leaves of the Trees Indicated for the Visible and Near Infrared Spectrum, 400 to 1080 Millimicrons. (See Appendix C; GE Graph Sheets Serial No. GE-II-1207, -1208, -1209, -1210.)

HORNBEAM				SUGAR MAPLE(1)				SUGAR MAPLE(3)			
Ventral Side				Ventral Side				"Light Brown" Ventral Side			
Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ
400	0.025	750	0.394	400	0.036	750	0.624	400	0.051	750	0.442
10	.026	60	.420	10	.038	60	.634	10	.055	60	.454
20	.026	70	.432	20	.039	70	.642	20	.058	70	.462
30	.027	80	.441	30	.041	80	.645	30	.062	80	.471
40	.028	90	.449	40	.042	90	.648	40	.064	90	.480
450	.028	800	.457	450	.043	800	.650	450	.068	800	.487
60	.028	10	.465	60	.043	10	.653	60	.074	10	.494
70	.028	20	.473	70	.044	20	.654	70	.082	20	.499
80	.028	30	.480	80	.046	30	.657	80	.090	30	.505
90	.028	40	.487	90	.048	40	.656	90	.098	40	.510
500	.032	850	.494	500	.057	850	.658	500	.107	850	.515
10	.042	60	.500	10	.088	60	.659	10	.118	60	.519
20	.062	70	.506	20	.137	70	.662	20	.129	70	.524
30	.080	80	.513	30	.179	80	.663	30	.140	80	.527
40	.089	90	.518	40	.196	90	.663	40	.153	90	.530
550	.092	900	.524	550	.201	900	.667	550	.166	900	.534
60	.090	10	.528	60	.195	10	.668	60	.179	10	.537
70	.079	20	.532	70	.173	20	.667	70	.190	20	.539
80	.068	30	.536	80	.149	30	.667	80	.206	30	.542
90	.062	40	.539	90	.135	40	.667	90	.220	40	.544
600	.059	950	.543	600	.127	950	.665	600	.234	950	.545
10	.055	60	.546	10	.115	60	.662	10	.246	60	.549
20	.049	70	.548	20	.100	70	.660	20	.260	70	.550
30	.048	80	.552	30	.095	80	.660	30	.275	80	.552
40	.044	90	.556	40	.085	90	.662	40	.288	90	.554
650	.038	1000	.558	650	.066	1000	.664	650	.298	1000	.554
60	.034	10	.561	60	.054	10	.666	60	.300	10	.553
70	.030	20	.565	70	.040	20	.668	70	.303	20	.552
80	.030	30	.568	80	.040	30	.672	80	.325	30	.551
90	.043	40	.571	90	.077	40	.674	90	.357	40	.548
700	.113	1050	.574	700	.204	1050	.676	700	.378	1050	.545
10	.192	60	.578	10	.337	60	.680	10	.394	60	.543
20	.268	70	.580	20	.451	70	.681	20	.409	70	.542
30	.332	80	.583	30	.539	80	.685	30	.421	80	.541
40	.371			40	.593			40	.432		

Canadian Forest Leaves
(Near Ottawa, Ontario)

Spectral Directional Reflectance of the Ventral Side of the Leaves of the Trees Indicated for the Visible and Near Infrared Spectrum, 400 to 1080 Millimicrons. (See Appendix C; GE Graph Sheets Serial No. GE II-1207, -1208, -1209, -1210.)

SUGAR MAPLE (4) "Medium Brown" Ventral Side				SUGAR MAPLE (5) "Dark Brown" Ventral Side				BALSAM POPLAR (1) Ventral Side			
Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ
400	0.055	750	0.335	400	0.051	750	0.223	400	0.052	750	0.647
10	.061	60	.347	10	.053	60	.242	10	.053	60	.670
20	.066	70	.358	20	.054	70	.254	20	.054	70	.682
30	.069	80	.371	30	.055	80	.268	30	.054	80	.689
40	.072	90	.380	40	.057	90	.281	40	.055	90	.694
450	.074	800	.388	450	.057	800	.292	450	.056	800	.699
60	.076	10	.397	60	.058	10	.306	60	.056	10	.704
70	.077	20	.404	70	.060	20	.316	70	.057	20	.707
80	.080	30	.410	80	.060	30	.327	80	.056	30	.709
90	.082	40	.417	90	.062	40	.337	90	.057	40	.711
500	.085	850	.422	500	.064	850	.346	500	.058	850	.714
10	.090	60	.428	10	.067	60	.355	10	.067	60	.716
20	.095	70	.432	20	.069	70	.365	20	.090	70	.718
30	.100	80	.436	30	.072	80	.372	30	.118	80	.720
40	.108	90	.440	40	.075	90	.380	40	.133	90	.721
550	.116	900	.445	550	.077	900	.388	550	.140	900	.724
60	.124	10	.447	60	.080	10	.394	60	.137	10	.724
70	.131	20	.450	70	.084	20	.400	70	.120	20	.723
80	.140	30	.454	80	.086	30	.406	80	.104	30	.722
90	.149	40	.455	90	.090	40	.410	90	.095	40	.717
600	.159	950	.458	600	.093	950	.415	600	.090	950	.709
10	.169	60	.461	10	.098	60	.421	10	.084	60	.700
20	.180	70	.461	20	.101	70	.425	20	.077	70	.691
30	.190	80	.463	30	.106	80	.429	30	.074	80	.690
40	.201	90	.465	40	.112	90	.432	40	.070	90	.690
650	.213	1000	.466	650	.117	1000	.436	650	.063	1000	.694
60	.225	10	.466	60	.124	10	.436	60	.058	10	.698
70	.236	20	.467	70	.132	20	.437	70	.055	20	.703
80	.248	30	.467	80	.140	30	.436	80	.055	30	.704
90	.261	40	.463	90	.150	40	.435	90	.069	40	.704
700	.275	1050	.459	700	.160	1050	.434	700	.147	1050	.707
10	.288	60	.457	10	.171	60	.434	10	.269	60	.707
20	.301	70	.456	20	.184	70	.433	20	.402	70	.709
30	.313	80	.456	30	.200	80	.433	30	.531	80	.710
40	.325			40	.212			40	.605		

X. Russian Vegetation and Soil

Dr. E. L. Krinov [1] reported spectrophotometric data on 370 samples of Russian terrain, nine of which extended over the whole visible spectrum (400 to 750 millimicrons). The following 8 illustrations relate to 7 of these 9 samples, 5 samples of vegetation and 2 of soils. Figures 37 and 40 show reflectance plotted against wavelength. Figures 38 and 41 are segments of the CIE chromaticity diagram showing the chromaticities of the 7 samples of Russian terrain, and Figures 39 and 42 are plots of the Munsell renotations of the corresponding colors. The data used for these illustrations are listed in Tables XII and XIII and refer to the samples indexed in Table XI and in Appendix E.

Color differences between the two grasses and the two soils were evaluated by means of the Godlove color-difference formula, and are shown in Table XIV and Figure 43 in terms of NBS units.

Krinov published approximately 10,000 spectrograms from the remaining 361 specimens, but these spectrograms all omit the orange-red part of the spectrum (600 to 650 millimicrons), and many of them also omit the red and infrared parts of the spectrum (wavelengths greater than 700 millimicrons). For the present study only seven of the nine samples for which no interpolation or extrapolation of the data was necessary were used. The two specimens not used were the two "snows" (Krinov's object Nos. 337 and 354). It was considered that these spectrograms were photographed with some shadows included and that they did not represent the true nature of the spectral directional reflectance of snow.

Recently, Penndorf [13] reduced the eleven generalized types that Krinov had assembled as representative of his measurements of spectral directional reflectance, using C.I.E. Standard Source B, representative of noon sunlight. These eleven types consisted of four "bare areas and soils", of four "vegetative formations", and three "water surfaces, water bodies, and snow". These are described, tabulated, and illustrated in Belkov's translation of Krinov (pages 70-72; page 97, Table XI; and page 115, Figure 24) [1].

Table XI

Identification of the natural formations in Russia reported by Krinov [1].

Specimen	Characteristics	Object Number
	VEGETATION	
BIRCH	Mature Forest, winter stage	6
PLANTAIN	Individual Leaf (top surface)	147
GRASS	Near Road, dusty	161
GRASS	Summer Green	164
FALLOW, Green	Flowering	166
	SOIL	
SOIL, Grey Podsol	Ploughed, dry	302
EARTH ROAD	Grey Podsol	322

Figure 37.

Visible and near infrared spectral directional reflectance of the five types of vegetation reported by Krinov [1] .

Figure 38.

Segment of the C.I.E. chromaticity diagram showing dominant wavelength, excitation purity, and chromaticity coordinates for standard source C of the five types of Russian vegetation computed from the data illustrated in Figure 37, and listed in Appendix E. The chromaticity coordinates together with the daylight reflectances are listed in Table XII.

Figure 39.

Vertical and horizontal projections of the colors of the five types of Russian vegetation illustrated in Figures 37 and 38. The upper diagram shows Munsell Value plotted against the Munsell Hue and Chroma points projected from the lower diagram. The Munsell data are listed in Table XIII.

Figure 40.

Visible and near infrared spectral directional reflectance of the two samples of Russian soil reported by Krinov [1] .

Figure 41.

Segment of the C.I.E. chromaticity diagram showing dominant wavelength, excitation purity, and chromaticity coordinates for standard source C of the two types of Russian soil computed from the data illustrated in Figure 40 and listed in Table Appendix E. The chromaticity coordinates together with the daylight reflectances are listed in Table XII.

Figure 42.

Vertical and horizontal projections of the colors of the two types of Russian soil illustrated in Figures 40 and 41. The upper diagram shows Munsell Value plotted against the Munsell Hue and Chroma points projected from the lower diagram. The Munsell data are listed in Table XIII.

Figure 43.

Color differences computed from the Godlove color-difference formula, converted into NBS units, between the types of grass and soil reported for Russia by Krinov [1] .

Table XII

Russian Vegetation and Soil

Chromaticity Coordinates and Daylight Reflectances for C.I.E. Source C of the Vegetation and Soil Studied.

Specimen	Chromaticity Coordinates x	y	Daylight Reflectance Y(%)
Russian Vegetation			
BIRCH, MATURE FOREST Winter Stage Object #6*	0.341	0.333	8.8
PLANTAIN, INDIVIDUAL LEAF Top Surface Object #147*	.336	.400	10.5
GRASS, NEAR ROAD Dusty Object #161*	.353	.377	7.3
GRASS Summer Green Object #164*	.333	.498	8.0
FALLOW Green, Flowering Object #166*	.374	.409	6.1
Russian Soil			
SOIL, GREY PODSOL Ploughed, Dry Object #302*	.350	.347	5.2
EARTH ROAD Grey Podsol Object #322*	.342	.345	10.1

* See Reference [1]

Table XIII

Russian Vegetation and Soil

Munsell Renotations and ISCC-NBS Color Designations of the Vegetation and Soil Studied,

Specimen	Munsell Renotations	ISCC-NBS Color Designations
	Russian Vegetation	
BIRCH, MATURE FOREST Winter Stage Object #6*	6.3YR 3.4/1.0	Brownish Gray
PLANTAIN, INDIVIDUAL LEAF Top Surface Object #147*	5.9GY 3.8/3.2	Moderate Olive Green
GRASS, NEAR ROAD Dusty Object #161*	9.1Y 3.2/2.0	Grayish Olive
GRASS Summer Green Object #164*	7.6GY 3.3/6.3	Moderate Olive Green
FALLOW Green, Flowering Object #166*	9.5Y 2.9/2.8	Grayish Olive
	Russian Soil	
SOIL, GREY PODSOL Ploughed, Dry Object #302*	0.7Y 2.7/1.2	Dark Grayish Yellowish Brown
EARTH ROAD Grey Podsol Object #322*	2.4Y 3.7/1.2	Brownish Gray

* See Reference [1]

Table XIV

Color Difference Computed from the Godlove Color-Difference Formula, Converted into NBS Units, Between (1) the Two Types of Grass, and (2) the Two Types of Soil, Computed from Data Published by Krinov [1] .

Specimen	Color Difference ΔE
(1) Two Sets of Grass	
GRASS	23.5
(2) Two Sets of Soil	
SOIL	20.0

Appendix E

Spectral directional reflectance data of Russian vegetation and soil obtained from published data of Krinov [1] .

Russian Vegetation

Spectral Directional Reflectance of Three Types of Vegetation given by Krinov [1] for the Spectral Region 400 to 900 Millimicrons.

BIRCH, MATURE FOREST Winter Stage Object #6*				PLANTAIN, INDIVIDUAL LEAF Top Surface Object #147*				GRASS, NEAR ROAD Dusty Object #161*			
Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ
400	0.072	750	0.100	400	0.060	750	0.452	400	0.031	750	0.380
10	.073	60	.100	10	.060	60	.464	10	.035	60	.385
20	.074	70	.100	20	.060	70	.472	20	.036	70	.390
30	.074	80	.101	30	.060	80	.478	30	.045	80	.391
40	.074	90	.102	40	.060	90	.482	40	.045	90	.392
450	.073	800	.103	450	.058	800	.485	450	.044	800	.392
60	.072	10	.104	60	.057	10	-	60	.043	10	.391
70	.071	20	.105	70	.056	20	-	70	.044	20	.391
80	.070	30	.106	80	.054	30	-	80	.043	30	.390
90	.070	40	.107	90	.053	40	-	90	.045	40	.390
500	.071	850	.108	500	.054	850	-	500	.049	850	.384
10	.073	60	.109	10	.060	60	-	10	.054	60	.376
20	.077	70	.110	20	.096	70	-	20	.058	70	.364
30	.080	80	.110	30	.122	80	-	30	.075	80	.355
40	.082	90	.110	40	.136	90	-	40	.083	90	-
550	.087	900	.110	550	.142	900	-	550	.081	900	-
60	.090			60	.140			60	.081		
70	.091			70	.126			70	.083		
80	.095			80	.105			80	.082		
90	.098			90	.093			90	.074		
600	.100			600	.087			600	.071		
10	.101			10	.082			10	.072		
20	.101			20	.076			20	.074		
30	.102			30	.070			30	.070		
40	.102			40	.064			40	.069		
650	.101			650	.056			650	.068		
60	.100			60	.052			60	.070		
70	.100			70	.052			70	.076		
80	.100			80	.056			80	.090		
90	.100			90	.070			90	.118		
700	.100			700	.132			700	.150		
10	.100			10	.300			10	.218		
20	.100			20	.344			20	.320		
30	.100			30	.400			30	.360		
40	.100			40	.424			40	.371		

* See Reference [1]

Russian Vegetation

Spectral Directional Reflectance of Two Types of Vegetation given by Krinov [1] for the Spectral Region 400 to 900 Millimicrons.

GRASS				FALLOW			
Summer Green Object #164*				Green, Flowering Object #166*			
Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ
400	0.010	750	0.495	400	0.021	750	0.156
10	.013	60	.630	10	.014	60	.156
20	.014	70	.740	20	.019	70	-
30	.014	80	.798	30	.021	80	-
40	.018	90	-	40	.025	90	-
450	.020	800	-	450	.027	800	-
60	.022	10	-	60	.028	10	-
70	.024	20	-	70	.032	20	-
80	.026	30	-	80	.031	30	-
90	.037	40	-	90	.033	40	-
500	.053	850	-	500	.036	850	-
10	.078	60	-	10	.047	60	-
20	.097	70	-	20	.050	70	-
30	.107	80	-	30	.063	80	-
40	.114	90	-	40	.070	90	-
550	.115	900	-	550	.072	900	-
60	.110			60	.070		
70	.096			70	.068		
80	.073			80	.066		
90	.053			90	.062		
600	.045			600	.062		
10	.047			10	.060		
20	.048			20	.061		
30	.040			30	.058		
40	.025			40	.060		
650	.007			650	.060		
60	.000			60	.072		
70	.013			70	.095		
80	.028			80	.123		
90	.052			90	.148		
700	.088			700	.152		
10	.150			10	.154		
20	.245			20	.157		
30	.347			30	.156		
40	.420			40	.156		

* See Reference [1]

Russian Soil

Spectral Directional Reflectance of Two Types of Soil given by Krinov [1] for the Spectral Region 400 to 900 Millimicrons.

SOIL, GREY PODSOL Ploughed, Dry Object #302*				EARTH ROAD Grey Podsol Object #322*			
Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ	Wave Length mμ	R_λ
400	0.037	750	0.122	400	0.081	750	0.167
10	.040	60	.155	10	.079	60	.180
20	.041	70	.192	20	.078	70	.191
30	.043	80	.212	30	.077	80	.202
40	.041	90	.222	40	.076	90	.213
450	.037	800	.228	450	.076	800	.223
60	.035	10	.230	60	.076	10	.233
70	.035	20	.230	70	.077	20	.242
80	.038	30	.229	80	.080	30	.250
90	.040	40	.225	90	.083	40	.257
500	.043	850	.220	500	.087	850	.263
10	.047	60	-	10	.090	60	-
20	.049	70	-	20	.093	70	-
30	.050	80	-	30	.098	80	-
40	.049	90	-	40	.099	90	-
550	.049	900	-	550	.100	900	-
60	.050			60	.101		
70	.055			70	.105		
80	.059			80	.108		
90	.060			90	.110		
600	.060			600	.111		
10	.060			10	.112		
20	.060			20	.112		
30	.060			30	.111		
40	.060			40	.110		
650	.060			650	.113		
60	.061			60	.124		
70	.065			70	.139		
80	.069			80	.149		
90	.074			90	.157		
700	.079			700	.161		
10	.083			10	.162		
20	.089			20	.161		
30	.094			30	.157		
40	.103			40	.156		

* See Reference [1]

XI. Summary

Visible and near infrared measurements of spectral directional reflectance have been made on some selected leaves of trees in the Annapolis, Maryland, and Washington, D. C., areas in the United States of America and in the Ottawa, Ontario, area of the Dominion of Canada on a General Electric recording spectrophotometer at the National Bureau of Standards for the spectral region 400 to 1080 millimicrons. These recordings have been illustrated and tables of data are included as well as graphs and tables of chromaticity coordinates, daylight reflectances, Munsell renotations, and ISCC-NBS color designations. In addition, color differences in terms of the NBS unit of color difference have been computed between similar leaf specimens and between the ventral and the dorsal sides of the same leaf specimens. Similar reductions are reported and illustrated for some natural formations in the USSR as determined and reported by Krinov [1] .

Some of the leaves of this report were studied directly for other purposes, and the results are recorded here for ready reference as a start towards collection of the complete information required for reliable interpretation of aerial photographs.

XII. Bibliography

[1] E. L. Krinov, Spectral reflectance properties of natural formations, Aero Methods Laboratory, Academy of Sciences, USSR, translated by G. Belkov, Nat. Res. Council of Canada, Tech. Trans., TT-439 Ottawa, 1953.

[2] H. J. Keegan, J. C. Schleter, and W. A. Hall, Jr., Spectrophotometric and colorimetric change in the leaf of a white oak tree under conditions of natural drying and excessive moisture, NBS Report No. 4322 to WADC, Sept., 1955.

[3] H. J. Keegan, J. C. Schleter, W. A. Hall, Jr., and G. M. Haas, Spectrophotometric and colorimetric study of foliage stored in covered metal containers, NBS Report No. 4370 to WADC, November, 1955.

[4] H. J. Keegan, J. C. Schleter, W. A. Hall, Jr., and G. M. Haas, Spectrophotometric and colorimetric study of the fading of dyed papers and cardboards under natural daylight, NBS Report No. 4438 to WADC, December, 1955.

[5] A. C. Hardy, A new recording spectrophotometer, J. Opt. Soc. Am. 25, 305 (1935); also A. C. Hardy, History of the design of the recording spectrophotometer, J. Opt. Soc. Am., 28, 360 (1938).

[6] J. L. Michaelson, Construction of the General Electric recording spectrophotometer, J. Opt. Soc. Am. 28, 365 (1938).

[7] K. S. Gibson and H. J. Keegan, Calibration and operation of the General Electric recording spectrophotometer of the National Bureau of Standards, J. Opt. Soc. Am. 28, 372 (1938).

[8] H. J. Keegan and K. S. Gibson, On the use of working standards of didymium and Vitrolite glasses for spectrophotometric measurements, J. Opt. Soc. Am. 34, 770 (1944).

[9] Proceedings, Eighth Session, Commission Internationale de l'Eclairage, Cambridge, England, pp 19 to 29, Sept. 1931.

[10] S. M. Newhall, D. Nickerson, and D. B. Judd, Final report of the OSA subcommittee on the spacing of the Munsell colors, J. Opt. Soc. Am. 33, 385 (1943).

[11] K. L. Kelly and D. B. Judd, The ISCC-NBS method of designating colors and a dictionary of color names, NBS Circular C553, November, 1955.

[12] I. H. Godlove, Improved color-difference formula with applications to the perceptibility and acceptability of fading, J. Opt. Soc. Am. 41, 760 (1951).

[13] R. Penndorf, Colors of natural objects, J. Opt. Soc. Am. 46, 180 (1956).

Appendix F.

Copies of the five work requests authorizing the studies on American and Canadian leaves herein reported are included in this appendix together with some notes by Dr. O'Neill on the specimens. It will be noted that the first two of these work requests also authorize measurements of photographs of these leaves and the final request authorizes measurements of some additional leaves, but these measurements for one reason or another were not made. It has been deemed desirable on this account to make a single report of the completed parts of the work authorized by all five requests.

The following are copies of the original work requests which resulted in the present report. Also included are some notes by Dr. O'Neill accompanying the work requests.

* * * * *

Serial Number 2.1 WADC-4/52. October 16, 1952

"Determine spectrophotometric curves of leaves to match with or compare with color fidelity and gray tones of the same leaves as registered on Ansco, Magenta, and Cyan by overcast sky-light:

1. Green white oak leaves (Quercus alba L.) cf. exposures 83, 84, and 85, i.e. as registered on tricolor, magenta, and cyan films.

2. Red dogwood leaves (Cornus florida L.) cf. exposures 86, 87, and 88.

3. Brown glossy black oak leaves (Quercus velutina Lam.) typical of thick, deciduous, coriaceous leaves when browned. cf. exposures 89, 90, and 91.

4. Bright yellow hickory leaves (Carya tomentosa (Lam.) Nutt.) cf. exposures 92, 93, and 94.

5. Russet beech leaves (Fagus grandifolia Ehrh.) cf. exposures 95, 96, and 97."

"To enable us to set up a standard objective procedure for judging films for intelligence and reconnaissance. One factor and a fundamental factor is color fidelity. The series of photographs mentioned above 83 - 97 shows the field entirely taken up by a single or a very few leaves of as uniform a color as could be found at this time. The curve of each leaf can be compared with that curve shown on the film. Preceding this set of photographs are numbers 50 to 82 which also show the performance of the same films on this cloudy day when registering our standard color patches."

* * * * *

Serial Number 2.1 WADC-5/52. October 17, 1952

"Determine spectrophotometric curves of Red Dogwood leaves corresponding to photographs 131 tricolor, 132 magenta in emulsion, and 133 cyan in emulsion, taken in direct sunlight at 8-inch focus so as to show only the leaves in the entire field. Similarly Yellow hickory leaves in the same series comparable in every detail, Nos. 134, 135, and 136. Also Green white oak leaves photographed on exposures 137, 138, and 139. Also Reddish white oak leaves photographed on exposures 140, 141, and 142. Also glossy black oak leaves photographed on exposures 143, 144, and 145. These are the leaves actually photographed so that this affords a means of testing color fidelity on Ansco Daylight (tricolor or three-dye) emulsion, and special emulsion with magenta only and special emulsion with cyan only."

"This will enable us not only to check or estimate color fidelity as to

leaves but also by comparison with photographs, of the series 98 to 132 to fit in with data on the color patches set up as standards for judging any future films to be tested in this or any other similar research. Yesterday's studies enable the whole series to be compared with similar series made with overcast sky. In this way comparisons as to effect of skylight and of sunlight can be made at numerous points. A table showing all the data of the films, etc. will be supplied separately as soon as the films have been processed."

* * * * *

Serial Number 2.1 WADC-8/52 November 3, 1952

"Spectrophotometric study (400 to 1080 mμ) of colored leaves. These leaves are the "last leaves of Autumn" and were picked after there was a killing frost." (The leaves were given the following color names by Dr. O'Neill to denote the fall coloration: Tulip tree "yellow", Dogwood "red and green", Beech "russet brown", Beech "yellow", Scarlet Oak "red", White Oak "red brown", and Aspen "blackening".)

* * * * *

Serial Number 2.1 WADC-19/53 April 22, 1953

"Spectrophotometric study of Spring red leaves. Measure the spectral directional reflectance of leaves of Spanish Hazelnut and Purpleleaf Plum (including 'green sport' and intermediate leaves of the Hazelnut)."

* * * * *

Serial Number 2.1 WADC-20/53 May 14, 1953

"Study of early foliage in the subarctic deciduous forest, also dead overwintered leaves on the ground". "Shipment of leaves received from J. M. Robinson, 451 Riverdale Avenue, Ottawa, Ontario, on May 14, 1953. Mailed in Ottawa on May 11, 1953. Delayed in Customs which passed them free. They arrived in fairly good condition. We unpacked, sorted, and flattened them out as soon as received. May 10, 1953 9 A.M. Ottawa.
Green leaves: Betula lenta, yellow birch; Fagus sylvatica, beech; Tilia americana, basswood; Populus tremuloides, quaking asp; Quercus borealis, red oak; Acer rubrum L., red maple; Populus balsamifera L., balsam poplar ("cottonwood"); Acer saccharum, sugar maple; Prunus pennsylvanica, pin cherry; Betula papyrifera March, white birch (canoe birch); Acer saccharum, sugar maple; and Ostrya virginiana, hornbeam.
Autumn Dead Leaves (used for packing, showing the brown shades of the leaves on the ground at this time): Acer saccharum, sugar maple; and Ulmus americana, elm."

* * * * *

"Leaves picked 11:00 near Ottawa, May 18, 1953 by Robinson. Record

of leaves received from J, M. Robinson, 451 Riverside Avenue, Ottawa, Ontario. Received 11:00 Saturday May 23, 1953 (placed in refrigerator at noon. Taken to NBS on Monday, 9:30 May 25, 1953)."

"Balsam poplar or cottonwood. Populus balsamifera L. (erroneously P. tacamahaca Mill. of authors). Black leaves show that these turn black when clipped off and used for camouflage at this season of the year. Spectrophotometric curves of pale green under (dorsal) side of leaves, and green top (ventral) side of leaves requested. Blackened leaves are superficially similar to the blackened leaves of pear trees, as they normally turn in fall or when attacked in spring by pear-blight. (Result of tannin and iron)."

"Bitternut hickory. Carya cordiformis. Hopelessly wilted. Turned very dark brown. State of these leaves shows that this species leafs out later than preceding species."

"Large-tooth aspen. Populus grandidentata Michx. Leaves densely white tomentose dorsally (canescent-lanate), bright green ventrally. Catkins showing "cotton" on ripening fruit."

"Quaking or tembling asp or aspen. (Populus tremuloides L. (commonest tree in North America). Leaves only relatively paler green dorsally than ventrally. Apparently this and P. balsamifera leaf out a few days earlier than P. grandidentata)."

"Butternut. Juglans cinerea L. Catkins had turned black. Like the bitternut, this tree leafs out later than the poplars."

"Staghorn sumac. Rhus typhina L. Leaflets very young. Paler green but only slightly paler on ventral than dorsal side. Probably leafs out a little sooner than bitternut and butternut, but later than poplars."

"White or american elm. Ulmus americana L. Now in full leaf but these nearly all fallen off."

"Red maple. Leaves fully out. Note that these leaves are not densely chalky white as are those of the Maryland red maple. They are only slightly paler green dorsally."

"Juneberry. Amelanchier. Leaves fully out. Only slightly paler dorsally. A bush, "Saskatoon"."

"Ironwood. Hop-hornbeam. Ostrya virgiana. Leaves not quite fully out. Slightly paler green dorsally."

"Sugar maple fully out. Acer saccharum."

"Quercus borealis only one quarter leafed out, hopelessly wilted and dark."

"Q. macrocarpa. Same as above in all respects, hopeless and dark."

"Tilia americana. Basswood. Fully out, equally green on both sides."

"Betula papyrifera Marshall. White or canoe birch. Fully out. Slightly paler ventrally. Fully leafed out."

"Betula lutea. Fully leafed out, badly wilted and darkened."

"Ulmus rubra. (Slippery elm ? not with us. U. cinerea is ours). About half leafed out. Later than U. americana. Badly wilted and leaves all fallen off."

"Pin cherry. Prunus pennsylvanica. Hopelessly wilted, past blooming, leaves fully out."

"Fraxinus americana. White ash. Badly wilted; like the other cpd leaves, these leaflets appear relatively late."

"Sent to Bureau of Standards. Many of these were too badly wilted to be of use. May 25, 1953."

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Supplementary Identification. June 2, 1954

"Spanish hazelnut, Corylus avellana L.; Hornbeam, Carpinus betulus L.; Balsam poplar, Populus balsamifera L.; Basswood, Tilia americana L.; Pin cherry, Prunus pennsylvanica L.; Large tooth poplar, Populus grandidentata Michx.; Sugar maple, Acer saccharum Marsh.; Trembling aspen, Populus tremuloides Michx. (Quaking aspen is more common than trembling aspen); Yellow birch, Betula lutea Michx."

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Supplementary Identification. March 2, 1956

"Aspen, Populus grandidentata Michx.; Plum, Prunus Pissardi Hort."

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THE NATIONAL BUREAU OF STANDARDS

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The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

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