be scanned for selection of a particular area on a frame; and it operates under manual control so that the film may be precisely positioned for study and mensuration purposes. The film transport will handle reels containing up to 500 feet of film.

. . . AND THE FUTURE

The field of panoramic aerial photography has made great strides in the past decade, and the future holds promise of dramatic new applications. Recently, the work being done in the mathematical aspects of image displacement has been extended by applying analytical photogrammetric approaches to panoramic photography. This will broaden the application of high-resolution, wide-coverage photography to mapping and charting operations requiring very precise measurements.

The fruits of many other scientific fields are being applied to all aspects of panoramic aerial photography. Inter-disciplinary research is being conducted to combine the potentials of electronics, optics, photography, and other sciences in order to overcome the limitations imposed by each and to increase the over-all information gathering capabilities of the system.

Today, panoramic aerial photography finds its major application in gathering information about the earth; tomorrow it will take its place as a valuable contributor to the exploration of space.

*Seasonal Changes in Light Reflectance from Forest Vegetation**‡

CHARLES E. OLSON, JR., and RALPH E. GOOD,**
Assistant Prof. of Forestry and Graduate Asst. in Botany, respectively,
Univ. of Illinois, Urbana, Ill.

ABSTRACT: *During the 1960 growing season, light reflectance from foliage of nine species of trees was measured weekly with a G.E. recording spectrophotometer. Hardwood foliage reflected more light than pine foliage in almost all wave-lengths during all parts of the growing season. Differences in reflectance between hardwood and pine foliage decreased steadily from May to the beginning of the hardwood color change in September and October. During the fall color change reflectance from hardwood foliage varied erratically by species.*

A PHOTOGRAPH is nothing more nor less than a graphic record of energy intensity. The characteristics of reflected energy strongly influence images recorded in the camera. Despite this fact very little is known about the reflecting characteristics of objects we photograph.

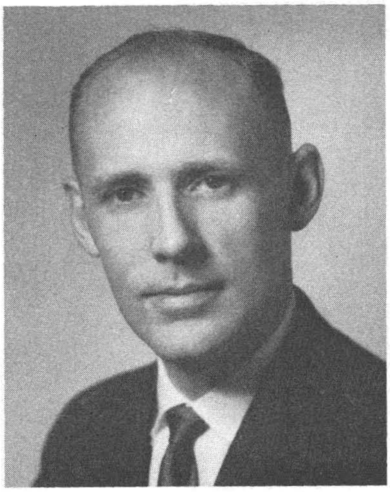
One of the first major works in spectral reflectance from natural formations was completed by E. L. Krinov prior to 1939, although publication of his results was delayed by World War II (Krinov, 1947). Studies of spectral reflectance from natural and man-made objects have been completed at the U. S. National Bureau of Standards (Keegan and O'Neill, 1951; Keegan, Schleter, and Hall, 1955; Keegan *et al.*, 1955, 1956), and several other investigators have reported spectral reflectance studies (Schulte, 1951; Bäckström and Welander, 1953; Colwell, 1954, 1956; Belov and Areybašev, 1957; Hindley and Smith, 1957; Steen and Little, 1959).

In 1959 the University of Illinois initiated studies of spectral reflectance characteristics of forest vegetation. A pilot study was conducted during the fall of 1959 to test equipment and sampling procedures; the sampling design for the 1960 growing season was based on the results of this pilot study. This report summarizes results for the 1960 growing season.

* This report summarizes work supported by the Office of Naval Research, U. S. Navy, as Contract 1834 (31), Project NR 387-025.

‡ A partial revision of paper presented at the 27th Annual Meeting, The Shoreham Hotel, Washington D. C., March 19–23, 1961.

** Mr. Good is now at Botany Dept., Rutgers Univ.



CHARLES E. OLSON, JR.

METHODS

Seven large-crowned trees from each of nine species were selected as project trees. All project trees were located in nine- and ten-year-old forest plantations on one 40-acre plot of ground close to the University of Illinois campus at Urbana. Tree heights ranged from 15 to 35 feet but were nearly constant for any one species.

Sampling was begun as soon as individual leaves were large enough to cover the sample port of the spectrophotometer. This occurred from one to two weeks after the trees had actually "leafed out." Weekly sampling of each species was planned, but weather conditions prevented rigid adherence to any fixed schedule. Samples were collected at four- to ten-day intervals except in mid-summer, when the interval reached 14 to 17 days on two occasions. Sampling was started on May 2, 1960, continued through the fall color change, and terminated when leaf-fall had progressed far enough to make continued sampling impractical.

At each sampling period four of the seven project trees in each species were randomly selected as sample trees. One leaf was picked from the south side of the upper quarter of the crown of each sample tree. (In the case of the conifers, between one and two ounces of needles were picked from the same relative crown position.) All samples were picked between 10 A.M. and 2 P.M. local standard time, and no samples were collected when the foliage surfaces were wet. All foliage was taken to the laboratory, where spectral reflectance for the wave-length range from 400 to 700 millimicrons was measured within one hour of the time the foliage was picked. A General Electric recording spectrophotometer having a slit width of 10 millimicrons was used. Incident energy was normal to the leaf surface, and the specular component was included in the measurements.

The nine species sampled were red pine (*Pinus resinosa*, Ait.), Scots pine (*Pinus sylvestris*, L.), cottonwood (*Populus deltoides*, Bartr.), silver maple (*Acer saccharinum*, L.), white ash (*Fraxinus americana*, L.), basswood (*Tilia americana*, L.), yellow poplar (*Liriodendron tulipifera*, L.), sweet gum (*Liquidambar styraciflua*, L.), and sycamore (*Platanus occidentalis*, L.).

RESULTS

Remarkable correspondence in reflectance from coniferous foliage was observed between and within species. Reflectance measurements for any one date were so nearly identical that the data for the two coniferous species have been combined. Reflectance curves with four replications of both coniferous species averaged together are shown in Figure 1 for four dates during the growing season. Reflectance increased steadily until late in the growing season. The large increase in reflectance between May and July was probably due to the fact that the May measurements were made on one-year-old needles, as the new needles were too small to permit reflectance measurements with available equipment.

Considerably greater variations were found in reflectance from hardwood (broad-leaved) foliage than from coniferous foliage, both within and between species. However, variation within a single species on any one date was not great enough to invalidate average curves prepared by species and date of sampling. A distinct pattern of change with date

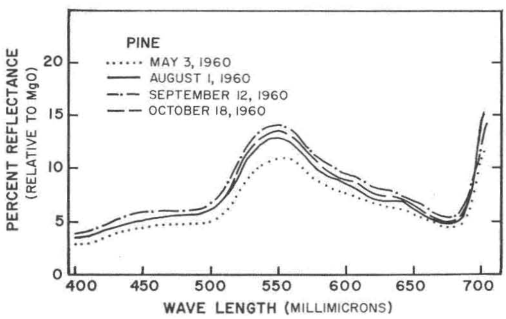


FIG. 1. Spectral reflectance of visible light from pine foliage at Urbana, Illinois, for four dates during the 1960 growing season.

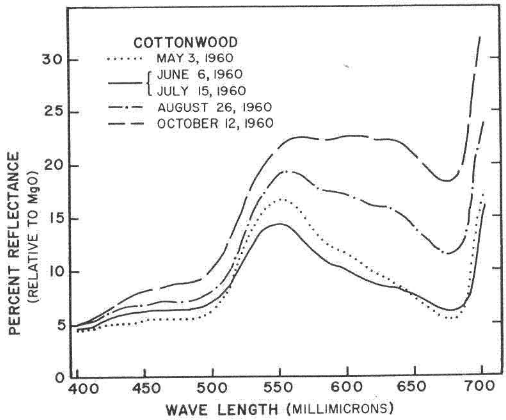


FIG. 2. Spectral reflectance of visible light from the upper surface of cottonwood (*Populus deltoides*, Bartr.) leaves at Urbana, Illinois, for five dates during the 1960 growing season.

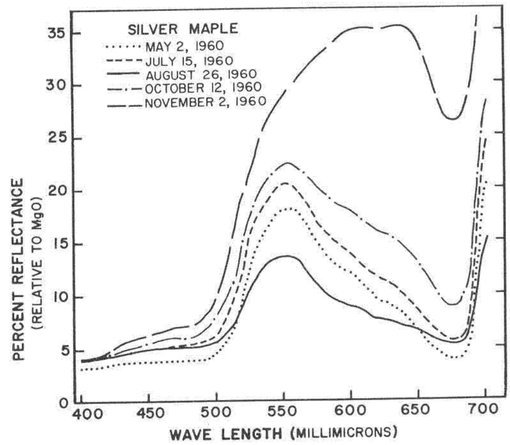


FIG. 3. Spectral reflectance of visible light from the upper surface of silver maple (*Acer saccharinum*, L.) leaves at Urbana, Illinois, for five dates during the 1960 growing season.

was observed in average reflectance curves of each of the seven broad-leaved species studied. The trends are most obvious in cottonwood and silver maple, and this discussion will be confined to these two species.

Average reflectance curves obtained from the upper surface of cottonwood leaves are shown in Figure 2 for several dates during the growing season. The curves for June and July were nearly identical and have been plotted as one curve in this illustration. Reflectance decreased from May to June, remained nearly constant into July, and then began to increase. The late season increase in reflectance continued through October 12, the final sampling date for cottonwood. The steady increase in reflectance with time at approximately 675 millimicrons was characteristic of all species studied.

Seasonal changes in reflectance, similar to those shown for cottonwood, were also noticed in silver maple. Silver maple was one of the first species to leaf out, but characteristics of leaf shape prevented sampling until May 2, approximately two weeks after the leaves first appeared. As shown in Figure 3, reflectance from the upper surface of silver maple leaves seemed to be higher in July than in May. The August curve is lower than any of the others, indicating a downward trend in reflectance during the late summer. As in cottonwood, reflectance showed general increases of considerable magnitude during the

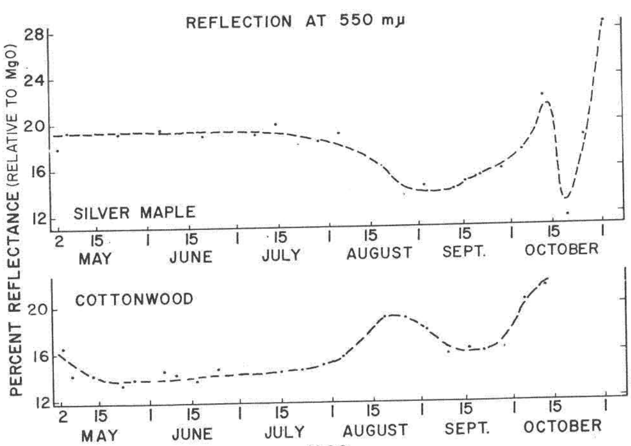


FIG. 4. Seasonal variation in light reflectance at 550 millimicrons from the upper surface of leaves from cottonwood (*Populus deltoides*, Bartr.) and silver maple (*Acer saccharinum*, L.) at Urbana, Illinois.

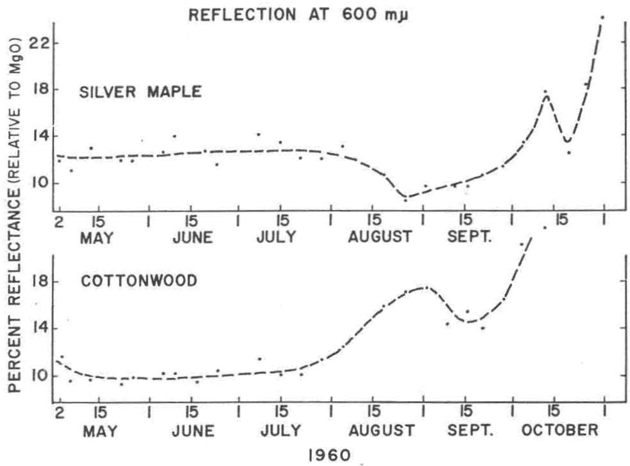


FIG. 5. Seasonal variation in light reflectance at 600 millimicrons from the upper surface of leaves from cottonwood (*Populus deltoides*, Bartr.) and silver maple (*Acer saccharinum*, L.) at Urbana, Illinois.

later part of the growing season. The steady increase in reflectance at approximately 675 millimicrons is also apparent.

Curves shown in Figures 2 and 3 represent average reflectance on the dates of sampling. Variations within species certainly occur, and curves for specific dates, based on only four trees per species, are probably not precise. In many ways a better picture of the changes that took place can be obtained by plotting per cent reflectance over date for a single wave-length. Such a curve would be essentially a transect perpendicular to the horizontal axis of Figures 2 or 3. While data for any one species were not conclusive, inflection points appeared in the curves for all seven broad-leaved species on different dates, but at about the same relative point in the growth cycle, strongly suggesting that an underlying trend was present. The dashed curves in Figures 4 and 5 illustrate the apparent trend. While families of spectral curves are usually compared at wave-lengths of absorption (i.e., absorption bands), the low reflectance of vegetation in the absorption region at 675 millimicrons makes such a comparison of questionable value to the photogrammetrist or photo interpreter. Those interested in aerial photography find the wave-lengths of maximum reflectance of more significance, and for this reason curves of reflectance over date are shown for 550 and 600 rather than 675 millimicrons.

The early season decrease in reflectance noted for cottonwood appears in the trend curves. Aside from this, reflectance from both species at 550 and 600 millimicrons remained essentially constant until mid-summer. Cottonwood is one of the earliest species to start the fall color change, and the beginning of this change is indicated by the rise in reflectance after July 22. As cottonwood began to show increasing reflectance, reflectance from silver maple decreased. A distinct decrease in reflectance in September or October was apparent in all seven broad-leaved species and is shown in the trend curves, even though the change was abrupt and brief in most species. The trend curves at 600 millimicrons (Figure 5) are essentially amplified versions of the trend curves at 550 millimicrons (Figure 4).

In Figure 6 reflectance curves for both cottonwood and silver maple are plotted together for four specific sampling periods. Net area between the curves is directly related to the total difference in reflectance of visible light from the upper surface of the foliage of these two species on the dates indicated. As such the area between the curves is related to the probability that panchromatic photography taken on this date would render the two species in different tones.

Based on limited trials with panchromatic/minus-blue aerial photography, the difference shown for May 2–3, 1960, would not have created distinctly different tones between species. The difference shown for July 15 would probably result in silver maple appearing in lighter tones than cottonwood. On August 26, and again in October, the difference is definitely great enough to result in cottonwood appearing in lighter tones than silver maple when photographed on panchromatic film with a minus-blue filter. This tonal rendition is not limited to new photography and can be seen in photographs taken

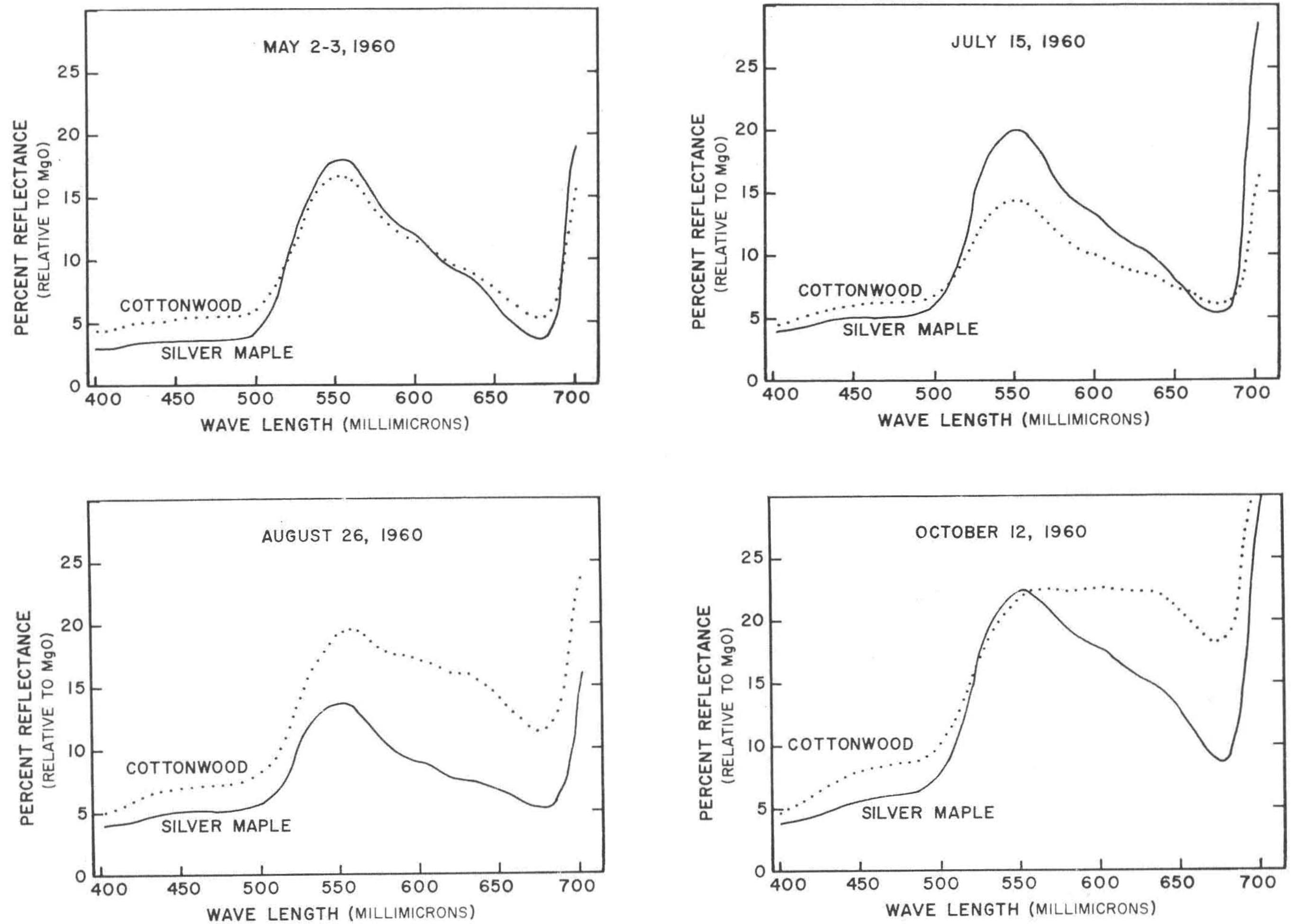


FIG. 6. Comparative spectral reflectance of visible light from the upper surface of leaves from cottonwood (*Populus deltoides*, Bartr.) and silver maple (*Acer saccharinum*, L.) at Urbana, Illinois, for four dates during the 1960 growing season.

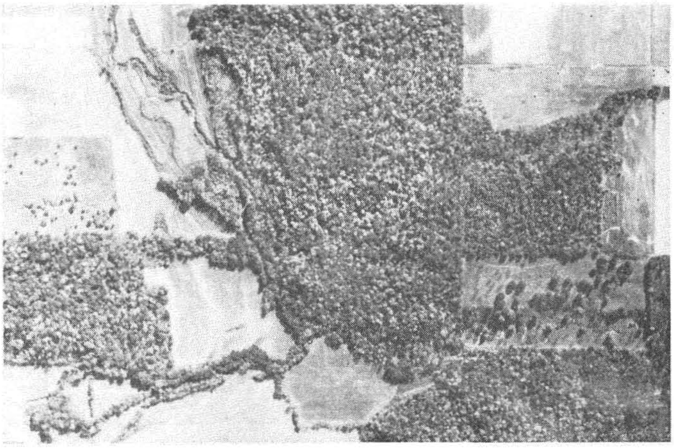


FIG. 7. Tone contrast between tree species resulting from seasonal changes in leaf coloration on October 17, 1938. Light-toned crowns are cottonwood; others largely silver maple and sycamore, (USDA photo)

more than twenty years ago (Figure 7).

Due to the practical importance of distinguishing between hardwoods and conifers from aerial photography, data for the two pine species and the seven hardwood species studied have been averaged for comparison (Figure 8). Differences in area between the hardwood and pine curves for the four dates shown strongly suggest that the probability of obtaining distinct tonal contrast between hardwoods and conifers in panchromatic aerial photography is greater in the early and late stages of the growing season than in mid-summer. Existing aerial photography near Oregon, Illinois, supports this (Figure 9). The area was photographed in September 1951 and May 1958 using panchromatic film in both cases. Tone contrast between hardwoods and conifers was almost nonexistent in the 1951 coverage, but distinct in the 1958 coverage. The hardwoods shown are primarily oak, and oak is one of the last species to begin the fall color change.

DISCUSSION

Light reflectance measurements obtained during this study varied widely from one month to another. Bäckström and Welander (1953) reported similar seasonal variations in trees of northern Europe. It appears that average values for light reflectance from living vegetation are of questionable value when compiled from data collected over a time span of several weeks. Seasonal variations may have contributed to the wide variations in reflectance within species reported by others.

Data obtained during 1960 indicate considerably greater reflectance from coniferous foliage than previously reported (Colwell, 1954), especially at wave-lengths between 520 and 570 millimicrons. Seasonal variations in reflectance, while not as great in conifers as in hardwoods, were important. Needles grown during the current season are lighter in color and reflect much more light than one-year-old needles. As new needles develop, reflectance from the new needles makes up an increasing percentage of the total reflectance from coniferous species, which results in gradually increasing reflectance during the first half of the growing season.

The increasing reflectance of conifers and the accompanying decreasing reflectance of the maturing hardwood foliage observed through the first half of the 1960 growing season may partially explain the difficulty foresters have had in obtaining consistent tone contrast between hardwoods and conifers on panchromatic film. The fact that good contrast has been obtained frequently in early spring, but almost never in mid-summer, seems to confirm the significance of the seasonal variations observed.

Although the data presented indicate significant differences in foliar reflectance between tree species for specific parts of the growing season, these data should be applied with caution. Data such as these, from one site, in one geographic area, and for one growing season, need to be confirmed by further work. Weather conditions, soil properties, and insect activities can alter the timing of changes in spectral reflectance, even if they do not

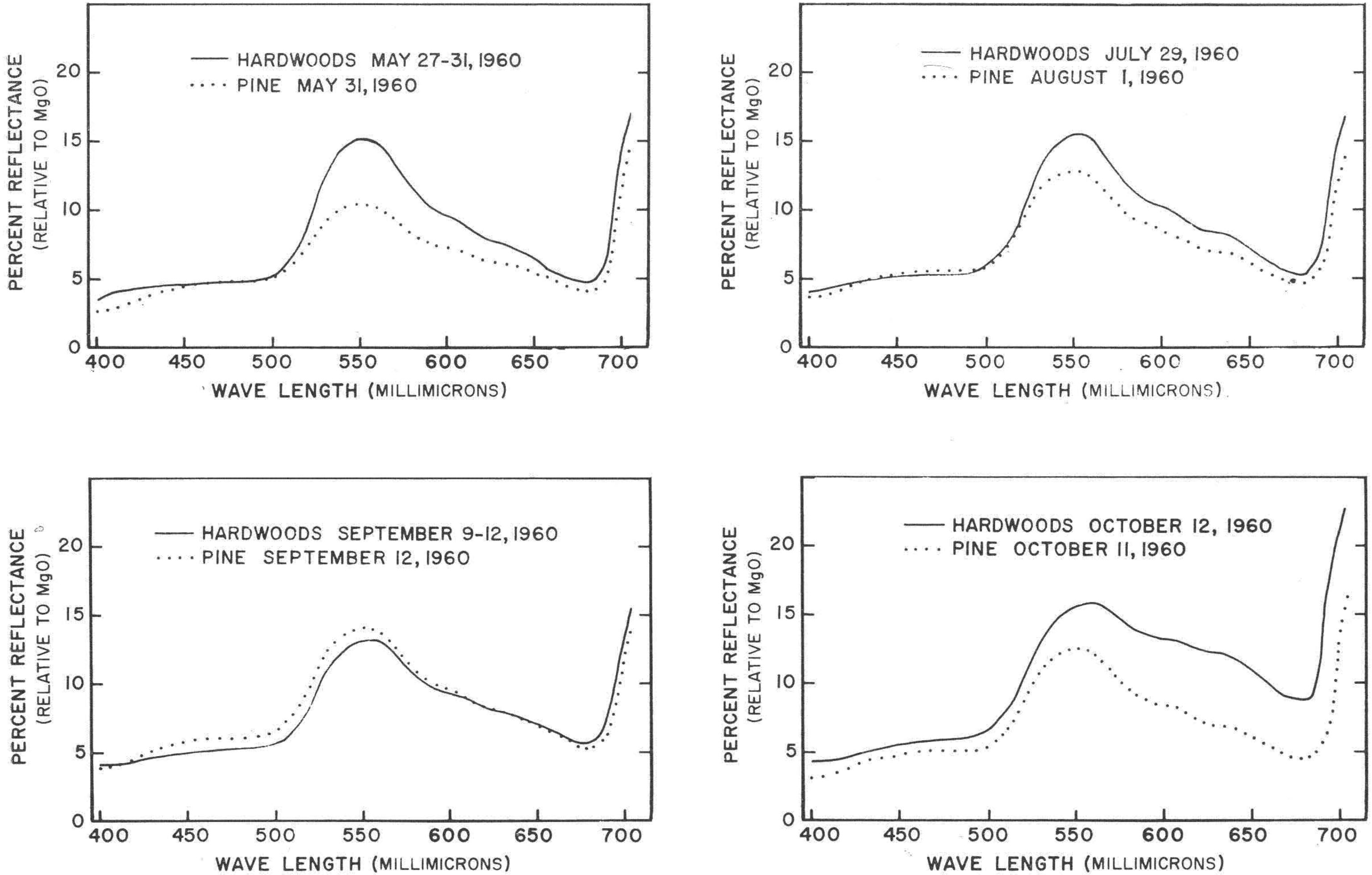


FIG. 8. Average spectral reflectance of visible light from the upper surface of leaves of seven hardwood species compared with average reflectance from two pine species at Urbana, Illinois, for four dates during the 1960 growing season.

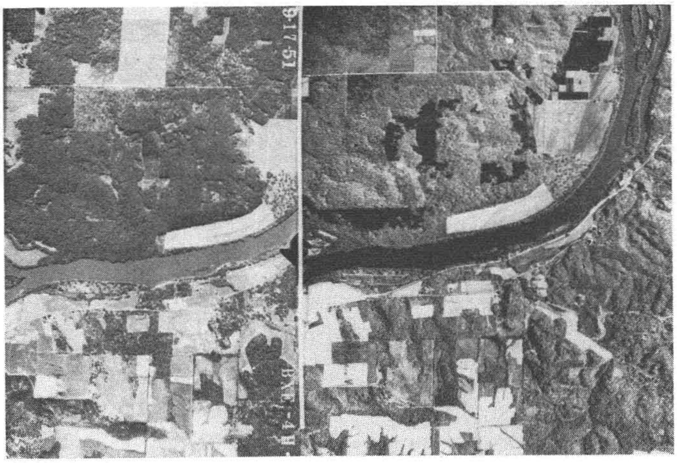


FIG. 9. Differences in tone contrast between hardwoods and conifers at different seasons. Left-hand photograph taken September 17, 1951, and right-hand photograph taken May 6, 1958. (USDA photos)

alter the basic pattern. Data to be collected during 1961 may clarify some of these matters.

REFERENCES

(1) Bäckström, H. and Welander, E. 1953. "En Undersökning av Remissionsförmagan hos Blad ach Barr av Olika Trädslag." (An investigation on the diffuse reflection capacity of leaves and needles of different species.) *Norrlands Skogsförb. Tidskr.* 1953 (1): 141–169.

(2) Belov, S. V. and Areybašev, E. S. 1957. "An Investigation of the Reflectivity of Tree Species in Russia." *Botanicheskii Zhurnal* (Leningrad), Vol. 42: 517–534.

(3) Colwell, R. N. 1954. "A Systematic Analysis of Some Factors Affecting Photographic Interpretation." PHOTOGRAMMETRIC ENGINEERING, Vol. XX: 433–454.

(4) Colwell, R. N. 1956. "Determining the Prevalence of Certain Cereal Crop Diseases by Means of Aerial Photography." *Hilgardia*, Vol. 26 (5): 223–286.

(5) Hindley, E. and Smith, J. H. G. 1957. "Spectrophotometric Analysis of Foliage of Some British Columbia Conifers." PHOTOGRAMMETRIC ENGINEERING, Vol. XXIII: 894–895.

(6) Keegan, H. J. and O'Neill, H. T. 1951. "Spectrophotometric Study of Autumn Leaves." An Abstract in the *Journal of the Optical Society of America*, Vol. 41: 284.

(7) Keegan, H. J., Schleter, J. C., and Hall, W. A., Jr. 1955. "Spectrophotometric and Colorimetric Change in the Leaf of a White Oak Tree Under Conditions of Natural Drying and Excessive Moisture." An NBS Report to the Wright Air Development Center, Wright-Patterson Air Force Base. AD-84922.*

(8) Keegan, H. J., Schleter, J. C., Hall, W. A., Jr., and Haas, G. M. 1955. "Spectrophotometric and Colorimetric Study of Foliage Stored in Covered Metal Containers." An NBS Report to the Wright Air Development Center, Wright-Patterson Air Force Base. AD-84923.*

(9) Keegan, H. J., Schleter, J. C., Hall, W. A., Jr., and Haas, G. M. 1956. "Spectrophotometric and Colorimetric Study of Manually Inoculated and Field Infected Wheat Rust." An NBS Report to the Wright Air Development Center, Wright-Patterson Air Force Base. AD-105799.*

(10) Krinov, E. L. 1957. "Spectral Reflectance Properties of Natural Formations. Academy of Sciences, USSR." Translated into English by G. Belkov in 1953 as Natural Resources Council of Canada Technical Translation TT-439. 267 pp.

(11) Schulte, O. W. 1951. "The Use of Panchromatic, Infrared, and Color Photography in the Study of Plant Distribution." PHOTOGRAMMETRIC ENGINEERING, Vol. XVII: 688–714.

(12) Steen, W. W. and Little, J. C. 1959. "A New Portable Reflectance Spectrophotometer for the Selection of Film Filters for Aerial Photography." PHOTOGRAMMETRIC ENGINEERING, Vol. XXV: 615–618.

* Copies not available from NBS. Qualified requestors may obtain copies from ASTIA.