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THE DEPENDENCE OF THE SPECTRAL SIGNATURE OF SUGAR BEETS ON THE OBSERVATION LEVEL AND THE REFLECTION GEOMETRY.

PART B: IN SITU MEASUREMENTS WITH SPECTRORADIOMETERS.

Abstract

A joint experiment was carried out in September 1979 in order to determine the spectral reflection characteristics of sugar beets by (nearly) simultaneous measurements with a spectroradiometer and an airborne multispectral scanner in situ and with a spectrophotometer in the laboratory. The measurements with the spectroradiometer were made in the spectral ranges from 0.5 to 1.1 μm and from 1.5 to 2.4 μm at a height of about 15 m and with different zenith angles (0^{o}, 15^{o}, 30^{o}, 45^{o}) and two azimuth directions having 180^{o} difference. The spectral reflectance factors were calculated and compared with the corresponding values determined from the MSS data and the laboratory measurements of leaf reflectance (Part A and C of the joint paper).

Introduction

In the frame of a research project on the detection of vegetation stress by changed reflection characteristics diseased sugar beets were investigated by different instruments and from different observation levels:

- airborne multispectral scanner BENDIX M^2S flown at altitudes of 300 m and 2000 m above ground (see part A of the paper),
- ground-based field spectroradiometers,
- laboratory spectral photometer ZEISS PMQ II/RA3 (see part C of the paper)

This paper reports on the field measurements with spectroradiometers of the type EG&G 555 and BARNES Spectral Master 12-550 operating in the wavelength ranges 0.5 to 1.1 μm and 1.4 to 2.5 μm, respectively. The radiometers were mounted at the top of a turnable jib of 18 m length looking at the same target area and at different zenith angles ϑ_r and fixed azimuth directions $\varphi_r/\varphi_r \pm 180^{o}$ by turning the jib around a horizontal axis (β), see Figures 1 (hatched plane) and 2. The target size had a diameter of about 2.5 m for the EG&G 555 (10^{o} FOV) and about 5 m for the BARNES SM (20^{o} FOV).

Measurements

The field measurements were carried out with the BARNES Spectral Master on September 18, 1979 and on the following day (day of the scanner flight) with the EG&G spectroradiometer. The measuring program consisted of three cycles of observations made in the late morning, at noon, and in the afternoon in order to study the dependence of $R(\lambda)$ on the position of the sun (expressed by the coordinates ϑ_i and φ_i, see Fig. 1).

Each cycle started with a vertical measurement ($\vartheta_r = 0$), followed by the inclination of the jib to the left side in three steps ($\vartheta_r = 15^\circ$, 30° and 45° resp., $\varphi_r < 0^\circ$), a further vertical measurement, three inclined positions ($\vartheta_r = 15^\circ$, 30° and 45° resp., $\varphi_r > 0^\circ$), and a final vertical observation. These nine observations could be performed in about 75 minutes in the case of measurements with the EG&G 555, and in about 50 minutes with the BARNES SM, respectively, including the reference measurements with a reflection standard.

The (ϑ_i, φ_i)-diagram in Figure 3 shows for which solar positions the data with the two spectroradiometers were collected. Starting and end point of each cycle are marked by a symbol and connected by a straight line. The $(\vartheta_r, \varphi_i - \varphi_r)$-diagram in the same Figure indicates the observation geometry with respect to the solar azimuth. The dark sectors of the diagram correspond to more or less front lighting ($|\varphi_i - \varphi_r| \leq 45^\circ$) or back lighting ($|\varphi_i - \varphi_r| \geq 135^\circ$), respectively. The light fields symbolize side lighting conditions.

The output signals of the instruments were converted into values of the object radiance $\bar{L}_{\lambda,r}$ calculated in steps of 5 nm with a spectral resolution of 10 nm in the case of measurements with the EG&G 555, and in steps of 10 nm with a spectral resolution of about 40 nm from the Spectral Master data.

From $\bar{L}_{\lambda,r}$ and corresponding values of the radiance $L_{\lambda,r;w}$ of a reflection standard the spectral reflectance factor

$$R(\lambda) = \frac{\bar{L}_{\lambda,r}}{L_{\lambda,r;w}}$$

has been calculated /1/, /2/.

Results

The Figures 4 to 7 show the spectral reflectance factor versus wavelength in the two spectral ranges covered by the two types of spectroradiometers and determined in the first cycle. The highest values of $R(\lambda)$ were obtained with front lighting and $\vartheta_r \approx \vartheta_i$ (in this case with $\vartheta_r = 45^\circ$). In the opposite viewing direction with back lighting the splitting of the curves for different values of ϑ_r is very small. Results of measurements made at other sugar beet test sites indicate a clearer separation for a higher elevation of the sun with decreasing reflectance factors for increasing values of ϑ_r /3/.

The relative change of $R(\lambda)$ with respect to the variation of ϑ_r for five selected wavelengths λ_k and the three measuring cycles is illustrated in Figure 8. As shown in the two diagrams for the first cycle front and back lighting conditions produce a remarkable difference in the spectral response between wavelength ranges which correspond to processes determining the reflection properties of plants (pigment-absorbing region 0.4 to 0.7 μm, internal-leaf-structure region 0.7 to 1.3 μm, and leaf-moisture-content region 1.3 to 2.5 μm, /4/). Viewed with side lighting the sugar beet canopy shows a reflection behavior approximately like a Lambertian surface.

Due to technical limitations these measurements could only be performed in two opposite azimuth directions $\varphi_r = -30^\circ$ and $\varphi_r = 150^\circ$ (relative to South). In order to study the influence of the azimuth $\varphi_o = 13^\circ$ of the sugar beet rows the relative change of $R(\lambda)$ by variation of the difference between solar and row azimuth has been calculated for the same wavelengths as above and vertical observation of the target. As shown in Figure 9 there is no evidence for an influence of the row azimuth (the rows were visible but without any strong structure). The unexpected increased values in the right part of the diagram for the afternoon measurements could have several causes. Firstly a small slope of the terrain resulted in a diminution of ϑ_i in the afternoon against the values given in the diagram for an ideal horizontal surface. From other measurements on sugar beets and feeding turnips it is known that $R(\lambda)$ increases with a higher solar elevation /3/, /5/. Secondly the sugar beets were stressed by a water deficiency (caused by a gravel ground layer and also by nematodes) leading to slacking leaves after some hours of solar irradiation so that the leaf-arrangement changed during the day. And finally also the wind which blowed strongly with 5 to 9 m/s from South-West could have influenced the reflection properties of the canopy.

As a consequence of the disease the sugar beets did not fully cover the ground. About 20 % of the surface within the field of view of the instrument was uncovered soil which contributed to the reflected radiance. The influence of the soil reflectance on the spectral signatures will be discussed in part C of the joint paper by Mr Sanwald.

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References

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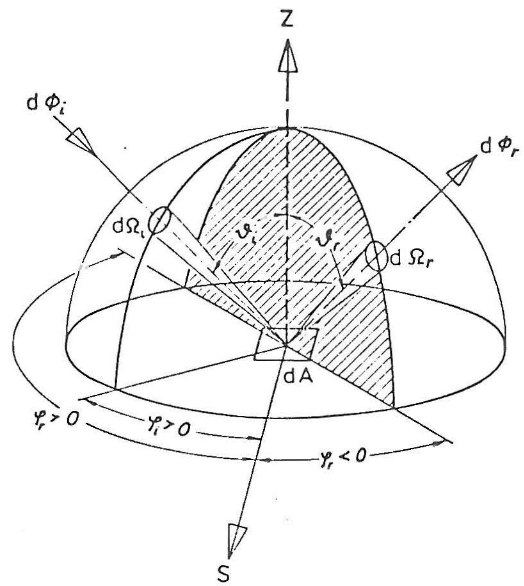


i INDEX FOR INCIDENT RADIATION
r INDEX FOR REFLECTED RADIATION
d Φ ELEMENT OF RADIATION FLUX
d Ω ELEMENT OF SOLID ANGLE
d A ELEMENT OF REFLECTING SURFACE
Z ZENITH
S SOUTH
ϑ ZENITH ANGLE
φ AZIMUTH

FIG. 1

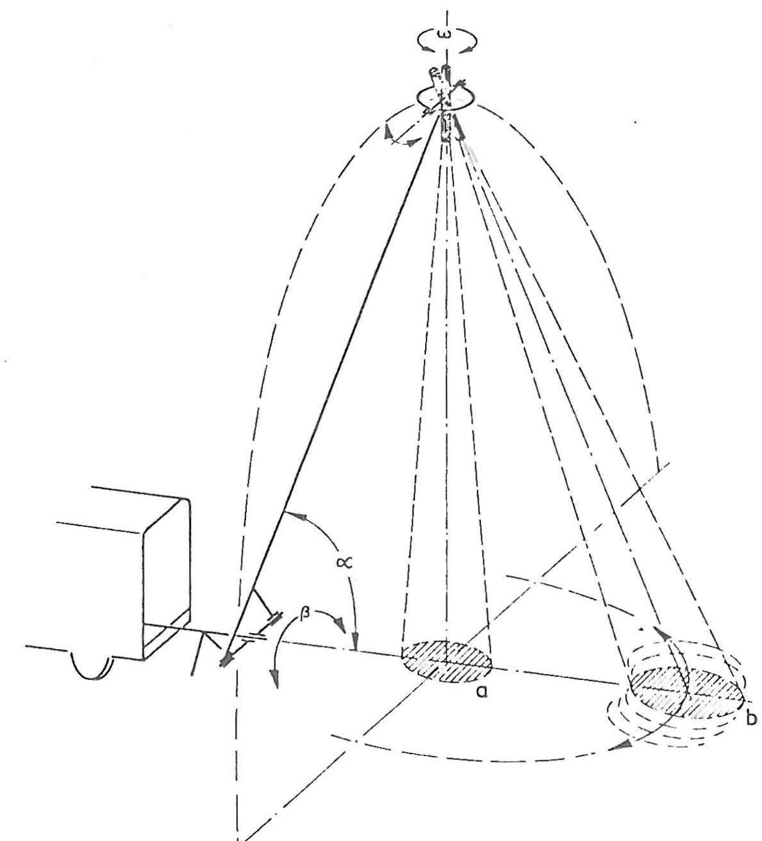
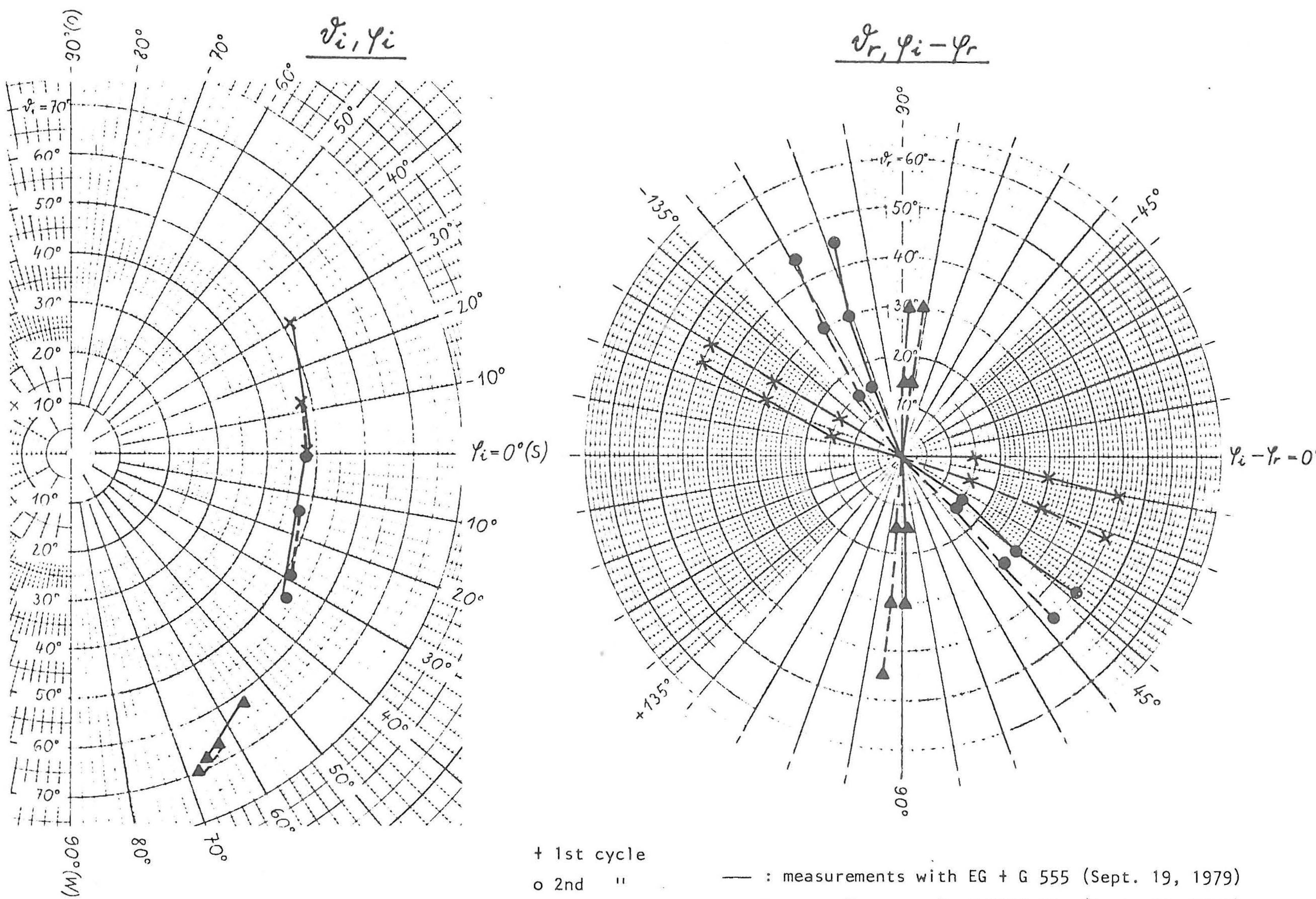


FIG. 2



+ 1st cycle
o 2nd "
Δ 3rd "

—— : measurements with EG + G 555 (Sept. 19, 1979)
--- : " " BARNES SM (Sept. 18, 1979)

FIG. 3

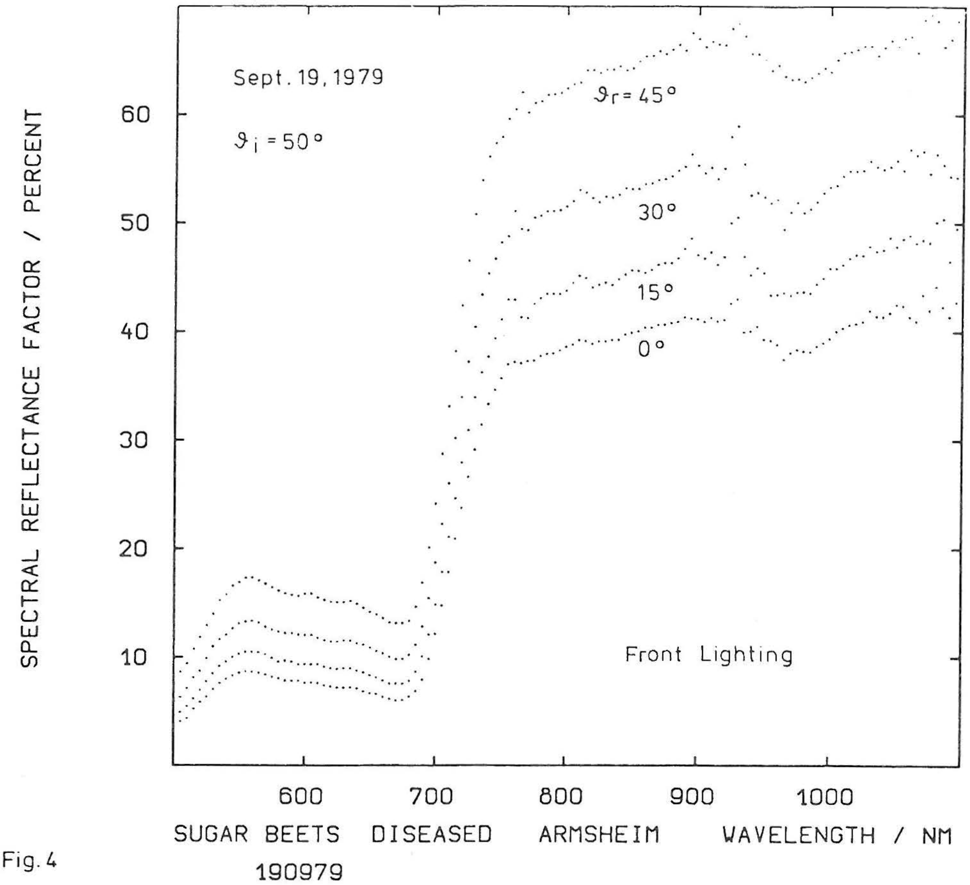

Sept. 19, 1979
ϑi = 50°
ϑr = 45°
30°
15°
0°
Front Lighting
SPECTRAL REFLECTANCE FACTOR / PERCENT
10
20
30
40
50
60
600
700
800
900
1000
SUGAR BEETS DISEASED ARMSHEIM WAVELENGTH / NM
190979

Fig. 4

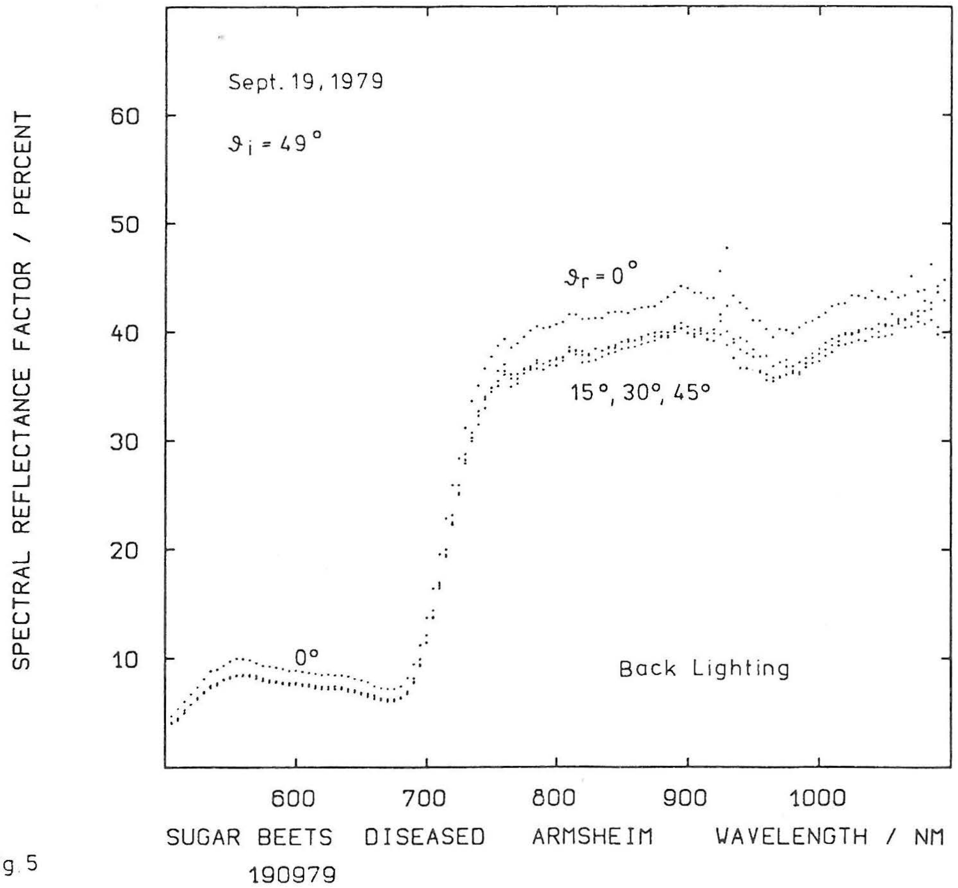

Sept. 19, 1979
ϑi = 49°
ϑr = 0°
15°, 30°, 45°
0°
Back Lighting
SPECTRAL REFLECTANCE FACTOR / PERCENT
10
20
30
40
50
60
600
700
800
900
1000
SUGAR BEETS DISEASED ARMSHEIM WAVELENGTH / NM
190979

Fig. 5

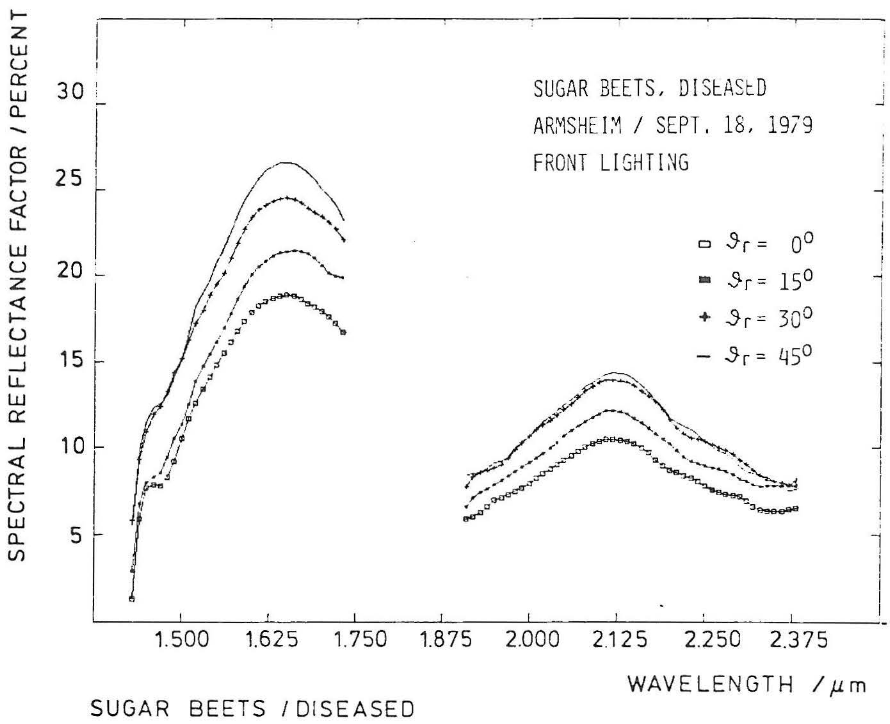

SPECTRAL REFLECTANCE FACTOR / PERCENT
30
25
20
15
10
5
SUGAR BEETS, DISEASED
ARMSHEIM / SEPT. 18, 1979
FRONT LIGHTING
$\vartheta_r = 0^0$
$\vartheta_r = 15^0$
$\vartheta_r = 30^0$
$\vartheta_r = 45^0$
1.500
1.625
1.750
1.875
2.000
2.125
2.250
2.375
WAVELENGTH / μm
SUGAR BEETS / DISEASED

FIG. 6

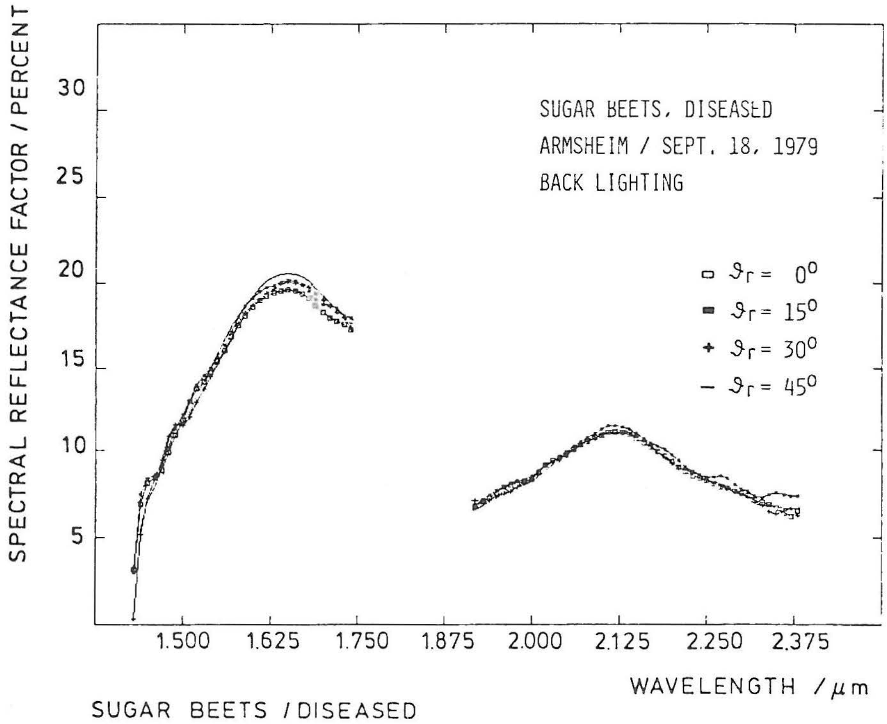

SPECTRAL REFLECTANCE FACTOR / PERCENT
30
25
20
15
10
5
SUGAR BEETS, DISEASED
ARMSHEIM / SEPT. 18, 1979
BACK LIGHTING
$\vartheta_r = 0^0$
$\vartheta_r = 15^0$
$\vartheta_r = 30^0$
$\vartheta_r = 45^0$
1.500
1.625
1.750
1.875
2.000
2.125
2.250
2.375
WAVELENGTH / μm
SUGAR BEETS / DISEASED

FIG. 7

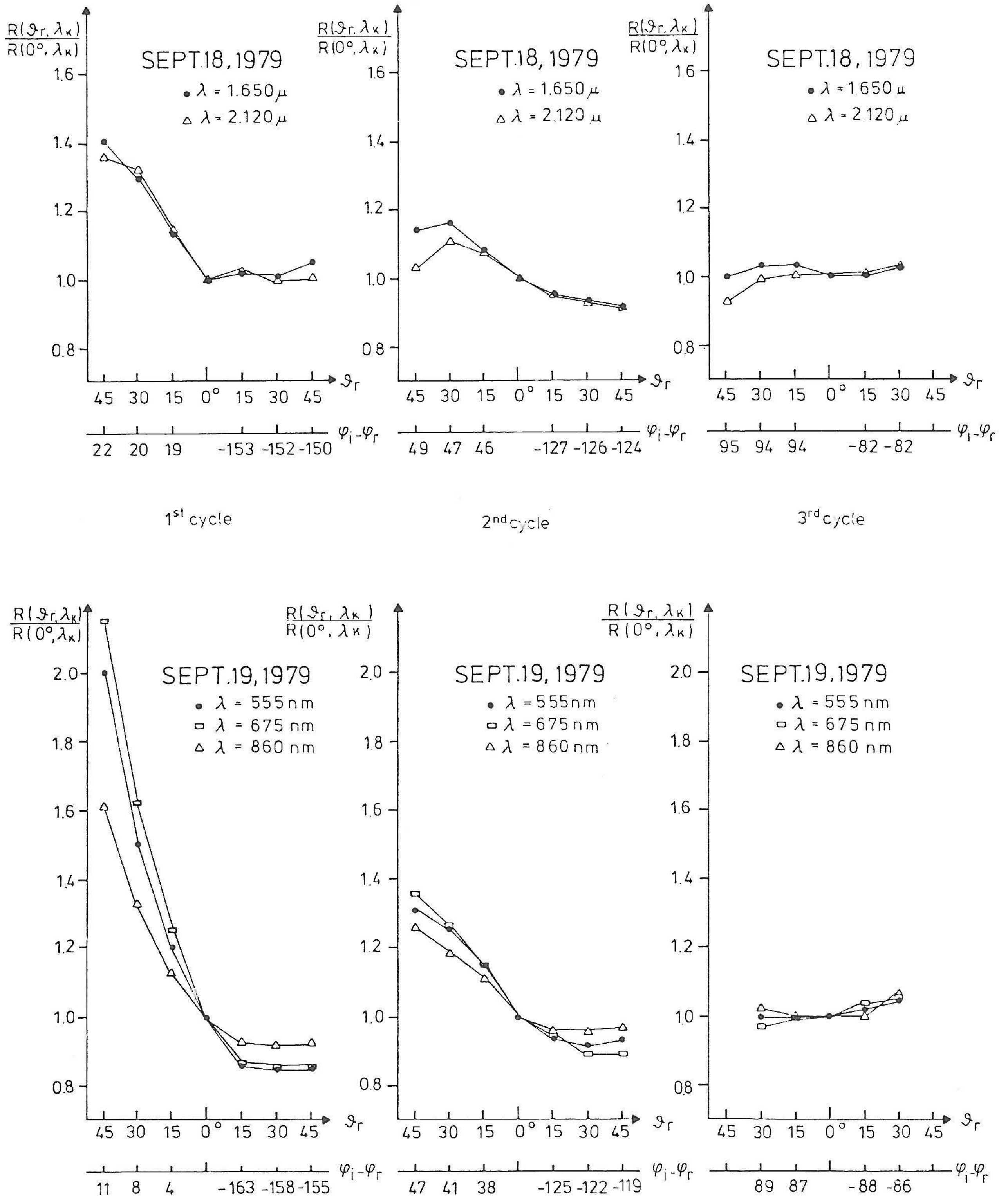
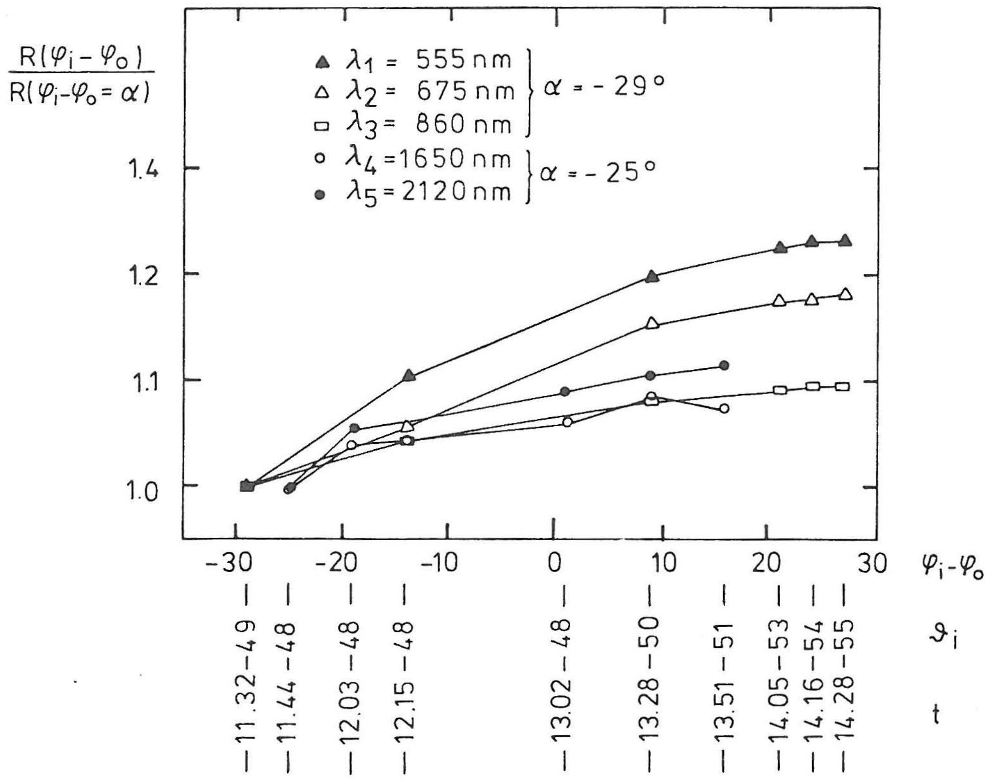

SEPT.18, 1979
• λ = 1.650 μ
△ λ = 2.120 μ
R(ϑr, λκ) / R(0°, λκ)
ϑr
φi - φr
45 30 15 0° 15 30 45
22 20 19 -153 -152 -150
1st cycle
49 47 46 -127 -126 -124
2nd cycle
95 94 94 -82 -82
3rd cycle
SEPT.19, 1979
• λ = 555 nm
□ λ = 675 nm
△ λ = 860 nm
11 8 4 -163 -158 -155
47 41 38 -125 -122 -119
89 87 -88 -86

FIG. 8



R(φi − φo) / R(φi-φo = α)
λ1 = 555 nm
λ2 = 675 nm
λ3 = 860 nm
α = -29°
λ4 = 1650 nm
λ5 = 2120 nm
α = -25°
1.4
1.2
1.1
1.0
-30
-20
-10
0
10
20
30
φi-φo
ϑi
t
11.32-49
11.44-48
12.03-48
12.15-48
13.02-48
13.28-50
13.51-51
14.05-53
14.16-54
14.28-55

FIG. 9