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DIFFERENCES IN THE SPECTRAL CHARACTERISTICS BETWEEN HEALTHY AND DISEASED CROPS DETERMINED FOR SUGAR BEETS AND WINTER BARLEY.

PART B: IN SITU MEASUREMENTS WITH SPECTRORADIOMETERS.

Abstract

Radiometric measurements from 0.5 to 1.1 um and from 1.5 to 2.4 um were conducted on sugar beets during two campaigns in July and September 1979 at three controlled test sites in Italy showing infestations by nematodes, virus (rizomania), and fungus (cercospora leaf spot), respectively. Additional measurements could be performed at a common farmland in Germany at which the sugar beets were partly stressed by water deficiency and nematodes. Measurements of barley from 0.5 to 1.1 µm were carried out in 1979 at a German test site consisting of a field plot treated against mildew, fungus, etc. and a non-treated reference plot at intervals of two weeks during the last two months before harvest. The spectral reflectance factors were calculated and compared with the corresponding values determined from measurements in the laboratory and with a multispectral scanner (Parts A and C of the joint paper).

Introduction

Measurements with ground-based spectroradiometers on sugar beets and barley as described in the abstract were carried out in the frame of a research project on the detection of vegetation stress by changed reflection characteristics. The selection of the sugar beet test sites in Rovigo, San Pietro and Anzola (near Bologna) and the field work in Italy were performed in cooperation with the Joint Research Centre/Ispra, the University of Milan and an agricultural institute (Istituto sperimentale per le colture industriali) of Bologna. The measurements on barley could be conducted at selected test plots of 10 x 10 m^2 within a large field of the Landwirtschaftliche Versuchsstation Limburgerhof of the BASF. One of these plots was growth-regulated and treated against mildew, fungus, etc. whereas at the reference plot only some treatment against weeds has been applied. The instrumentation, the methodology and the calculation of the spectral reflectance factor R(λ) as a quantity for the characterization of the reflection properties of vegetated surfaces are described in another paper and will not be presented here /1/.

Results of the measurements on sugar beets

The diagrams of $R(\lambda)$ versus λ of healthy sugar beets show the characteristic response of vital vegetation (Figures 1 and 2). Observation at different zenith angles ϑ_r leads generally to a splitting of the $R(\lambda)$-curves corresponding to ϑ_r which depends on the azimuth difference between the incident solar radiation and the observation direction (and also the zenith angles of the sun and the instrument). This splitting is higher for front lighting/back lighting conditions than for side lighting. Figure 10 illustrates the effect of front lighting (i.e. sun at the back of the observer). The highest values of $R(\lambda)$ were obtained for $\vartheta_r \approx \vartheta_i$. This is true for the whole spectral range from 0.5 to 2.5 µm. Back lighting results in decreased values compared to the result for $\vartheta_r = 0^o$. A further advantage of side lighting with respect to remote sensing applications is the symmetry of the resulting reflectance factors for both azimuth directions perpendicular to the solar azimuth. The following discussions are related to side lighting conditions and to comparable geometrical parameters for those measurements which have been directly compared.

The spectral differences between healthy and diseased sugar beets are now discussed in detail. The reflection properties of diseased sugar beets are determined by changes of morphology and leaf positions as well as reduced soil coverage. Examples of the reflectance factor curves of soil are shown in Figures 1 and 7. The spectral response of diseased sugar beets compared to the healthy test samples is different in the visible and the middle infrared, where $R(\lambda)$ is higher for the diseased beets, and also in the near infrared with higher values of $R(\lambda)$ for the healthy beets. This corresponds to different types of processes which determine the reflection properties of plants in the pigment-absorbing region (0.4-0.7 µm), the internal-leaf-structure region (0.7-1.3 µm), and the leaf-moisture-content region (1.3-2.5 µm) /2/. In all investigated cases a clear distinction is possible between both of them. The highest sensitivity for the spectral change occurs at the 675 nm minimum and at the 2.120 µm maximum. The increased splitting of the curves corresponding to the variation of ϑ_r for the diseased sugar beets can be seen very clearly in Figures 3,7 and 9.

Infestation by nematodes (ROVIGO and ARMSHEIM):

As illustrated in Figures 1,2 and 3 for Rovigo there occurs a remarkable difference between diseased and healthy sugar beets. $R(\lambda)$ of the diseased canopy is about 100 % higher at 675 nm and 2.120 µm than the corresponding values of healthy beets (for vertical observation). This could be explained by the superposition of two effects. Firstly the soil reflectance causes an intensification in the visible and the middle infrared but a decrease in the near infrared. Secondly this type of disease affects the turgor of the leaves which become slacky so that large petiole areas are exposed. Petiole reflectance is higher (about 100 %) in the visible and lower (about 30 %) in the near infrared than that of leaves /3/. The loss of turgor is obviously also associated with an increased reflectance factor in the leaf-moisture-content region. Sugar beets at Armsheim also stressed by water deficiency because of nematodes and a subsurface gravel ground layer showed a similar behavior.

Infestation by rizomania and cercospora leaf spot (SAN PIETRO)

Figure 4 illustrates the difference in the spectral response between the Rovigo and the San Pietro test site in the wavelength range 0.5 to 1.1 µm. In San Pietro the soil coverage by the plants was somewhat higher. The lower reflectance of the beets at this site at 675 nm is probably due to the smaller portion of soil in the field of view and the lower contribution of the petioles to the signal since the slacking of the leaves seemed to be not so strong as in Rovigo. The higher values at the green maximum could be caused by the beginning discoloration of the leaves by light-brown leaf spots (a similar effect as for yellow mosaic virus /3/).

In September the ratio of $R(\lambda)$ between the diseased and the healthy canopy amounted to a factor of about 3 at 675 nm and 2.120 µm (as shown in Figures 5,6 and 7) due to the strongly reduced soil coverage of the diseased plants.

Infestation by cercospora leaf spot (ANZOLA)

In the whole investigated wavelength range lower values of $R(\lambda)$ of healthy sugar beets were obtained in Anzola compared to San Pietro. This is shown in Figure 5 for the visible and the near infrared. The same Figure indicates differences in the spectral response of the diseased beets at both test sites only in the infrared with higher values for San Pietro (see also Figures 7 and 8). This is probably due to different soil properties since the soil coverage by the plants was less than 50 % in both cases.

Results of the measurements on winter barley

Similar to the measurements on sugar beets the $R(\lambda)$ curves are split for different observational zenith angles ϑ_r. Also the influence of the azimuth difference between the sun and the instrument has the same effect as described above. Contrary to the sugar beets the splitting of the curves (for side lighting) is clearly stronger for the healthy field and only significant in the near infrared as illustrated in Fig. 11.

Measurements in the middle of May, shortly before the appearance of the ears, showed no remarkable spectral difference between the treated and the untreated field although the plant height was not equal but 75 and 90 cm, respectively.

Two weeks later after the appearance of the ears the spectral reflectance factor of the diseased barley was about 20 % higher in the green at 555 nm and in the near infrared at 860 nm, but practically equal in the red minimum (675 nm) as shown in Fig. 12. The Figure represents the average of all the measurements carried out with $\vartheta_r = 0^{\circ}$ between the late morning and the early afternoon, because there were only slight differences due to the variation of the solar position.

In the middle of June R(λ) of the healthy barley was slightly lower than R(λ) of the diseased barley in the visible, but slightly higher in the near infrared. Visually no difference in the color of both targets could be observed.

At the end of June, shortly before the harvest, the spectral response has strongly changed (see Fig. 12). The spectral reflectance factor of the diseased canopy was higher at 555 nm (about 7 %) and 860 nm (about 18 %), than R(λ) of the healthy field, but lower at 675 nm (11 %).

The assistance of Dr. C. MÜNTHER in the preparation of computer programs and the making available of barley test sites by the BASF Landwirtschaftliche Versuchsstation Limburgerhof are gratefully acknowledged. The investigations in Italy were carried out on behalf of the JRC Ispra in cooperation with the University of Milan and the Istituto sperimentale per le colture industriali of Bologna. Financial support was given by the Deutsche Forschungsgemeinschaft and the JRC.

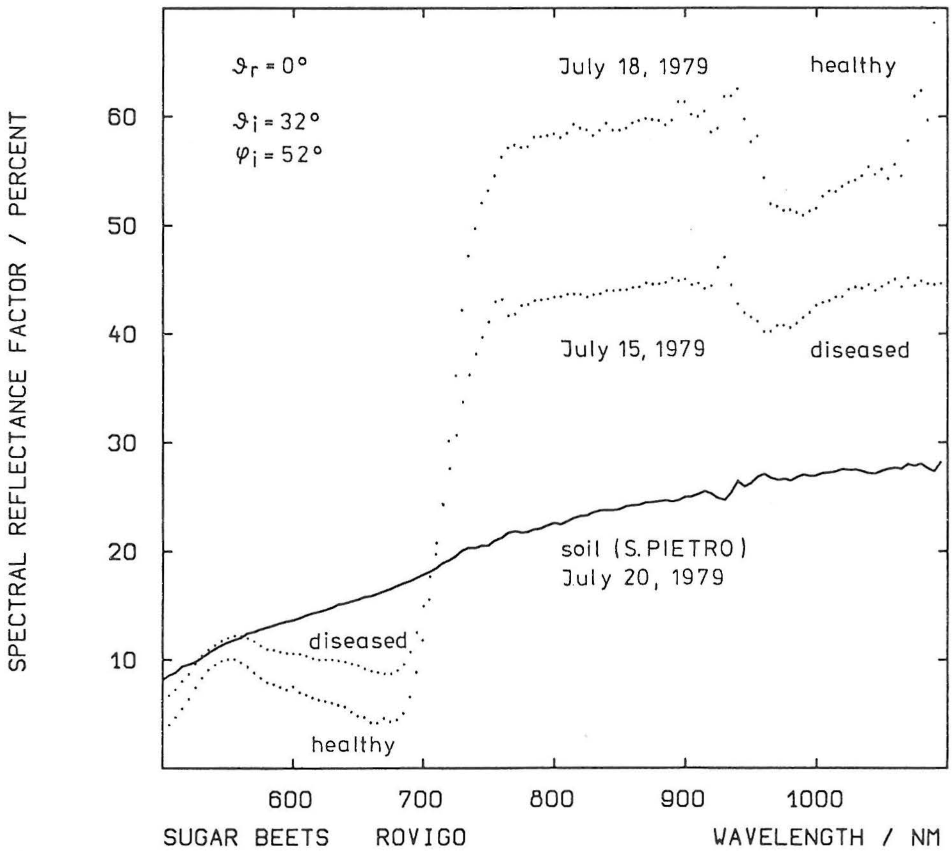


Fig. 1

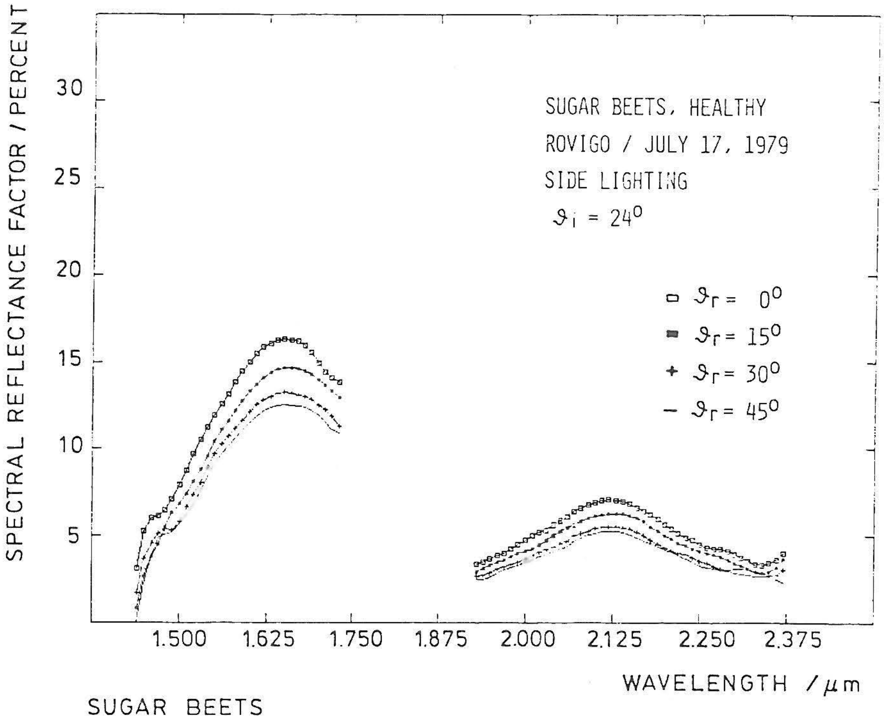

SUGAR BEETS, HEALTHY
ROVIGO / JULY 17, 1979
SIDE LIGHTING
$\vartheta_i = 24^0$
$\vartheta_r = 0^0$
$\vartheta_r = 15^0$
$\vartheta_r = 30^0$
$\vartheta_r = 45^0$
SPECTRAL REFLECTANCE FACTOR / PERCENT
30
25
20
15
10
5
1.500
1.625
1.750
1.875
2.000
2.125
2.250
2.375
WAVELENGTH / µm
SUGAR BEETS

FIG. 2

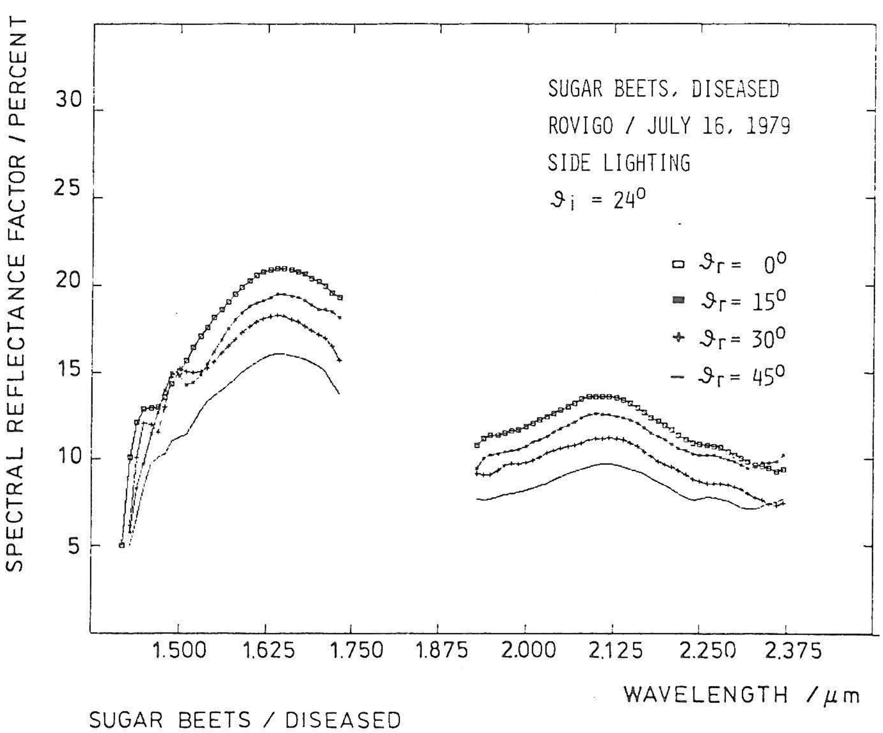
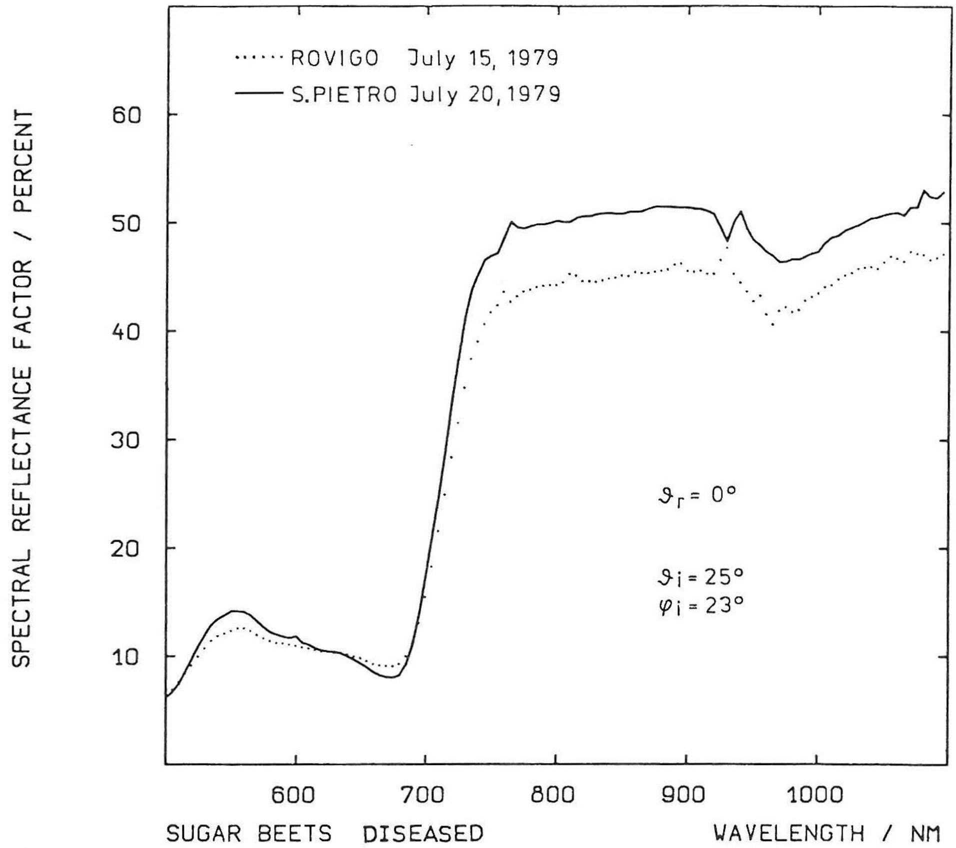
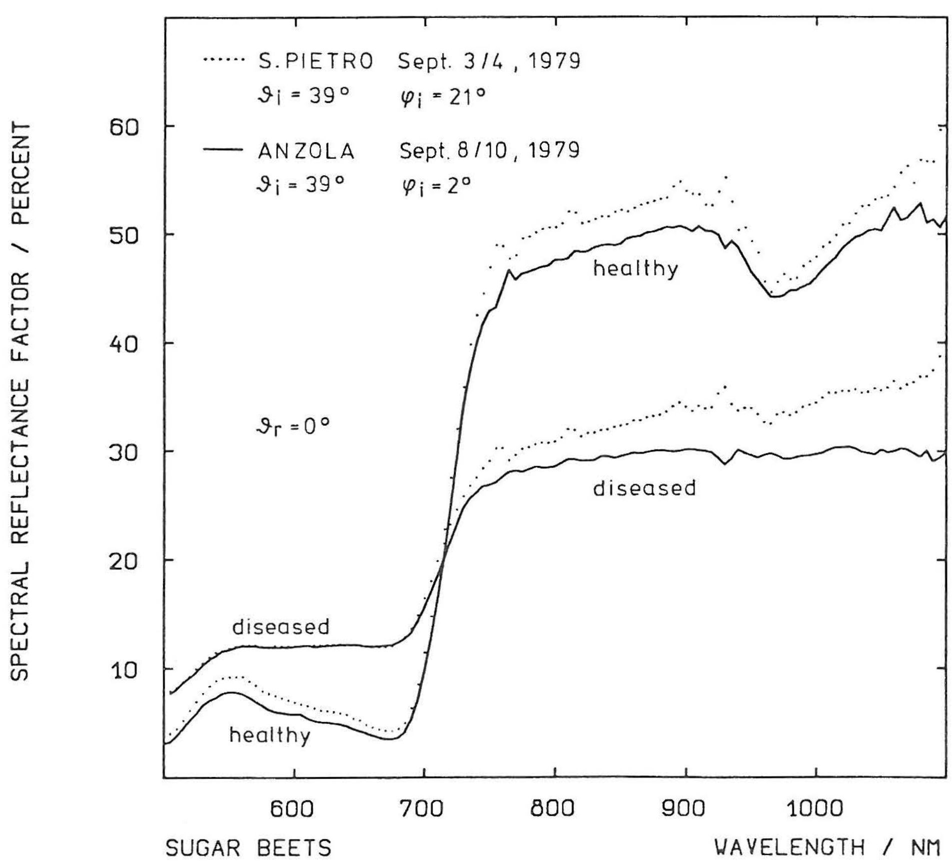

SUGAR BEETS, DISEASED
ROVIGO / JULY 16, 1979
SIDE LIGHTING
$\vartheta_i = 24^0$
$\vartheta_r = 0^0$
$\vartheta_r = 15^0$
$\vartheta_r = 30^0$
$\vartheta_r = 45^0$
SPECTRAL REFLECTANCE FACTOR / PERCENT
30
25
20
15
10
5
1.500
1.625
1.750
1.875
2.000
2.125
2.250
2.375
WAVELENGTH / µm
SUGAR BEETS / DISEASED

FIG. 3



ROVIGO July 15, 1979
S.PIETRO July 20, 1979
SPECTRAL REFLECTANCE FACTOR / PERCENT
60
50
40
30
20
10
$\vartheta_r = 0°$
$\vartheta_i = 25°$
$\varphi_i = 23°$
600
700
800
900
1000
SUGAR BEETS DISEASED
WAVELENGTH / NM

Fig. 4



S.PIETRO Sept. 3/4, 1979
$\vartheta_i = 39°$ $\varphi_i = 21°$
ANZOLA Sept. 8/10, 1979
$\vartheta_i = 39°$ $\varphi_i = 2°$
SPECTRAL REFLECTANCE FACTOR / PERCENT
60
50
40
30
20
10
$\vartheta_r = 0°$
healthy
diseased
diseased
healthy
600
700
800
900
1000
SUGAR BEETS
WAVELENGTH / NM

Fig. 5

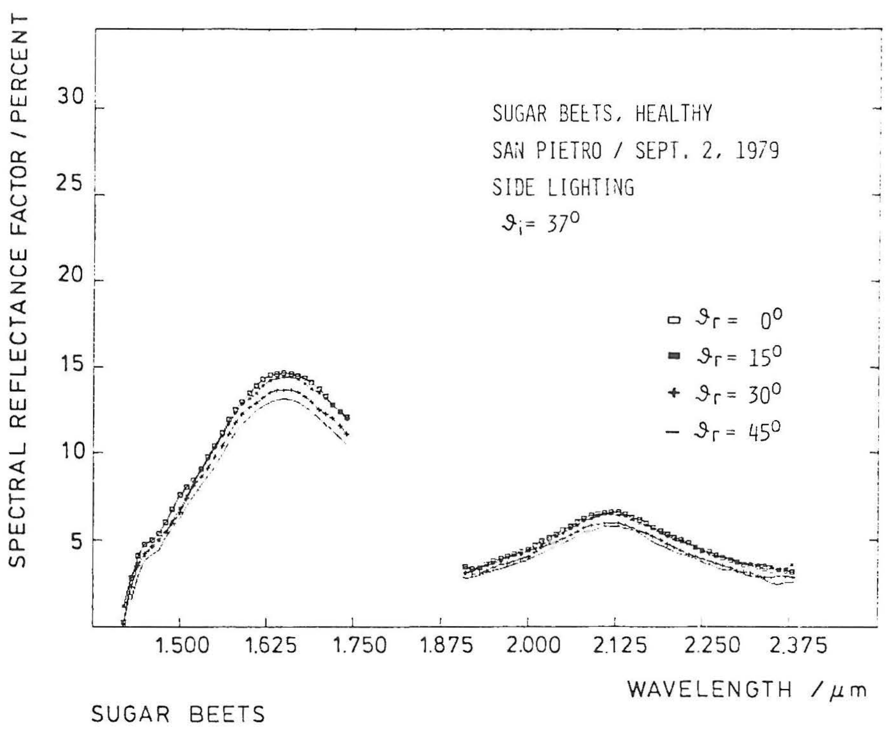

SPECTRAL REFLECTANCE FACTOR / PERCENT
SUGAR BEETS, HEALTHY
SAN PIETRO / SEPT. 2, 1979
SIDE LIGHTING
$\vartheta_i = 37^0$
$\vartheta_r = 0^0$
$\vartheta_r = 15^0$
$\vartheta_r = 30^0$
$\vartheta_r = 45^0$
WAVELENGTH / μm
SUGAR BEETS

Fig. 6

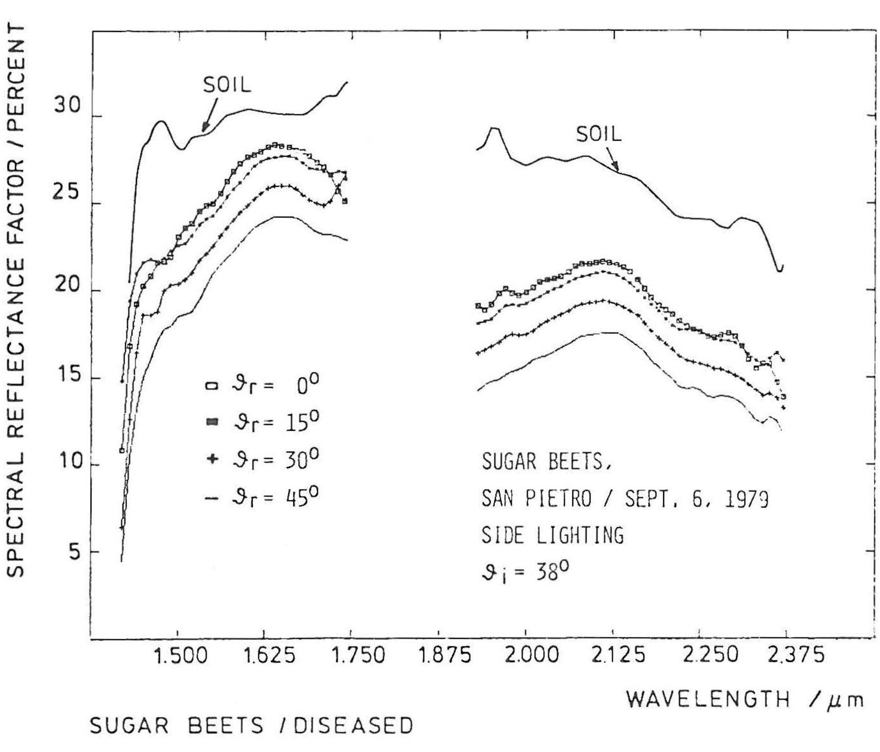

SPECTRAL REFLECTANCE FACTOR / PERCENT
SOIL
SOIL
$\vartheta_r = 0^0$
$\vartheta_r = 15^0$
$\vartheta_r = 30^0$
$\vartheta_r = 45^0$
SUGAR BEETS,
SAN PIETRO / SEPT. 6, 1979
SIDE LIGHTING
$\vartheta_i = 38^0$
WAVELENGTH / μm
SUGAR BEETS / DISEASED

Fig. 7

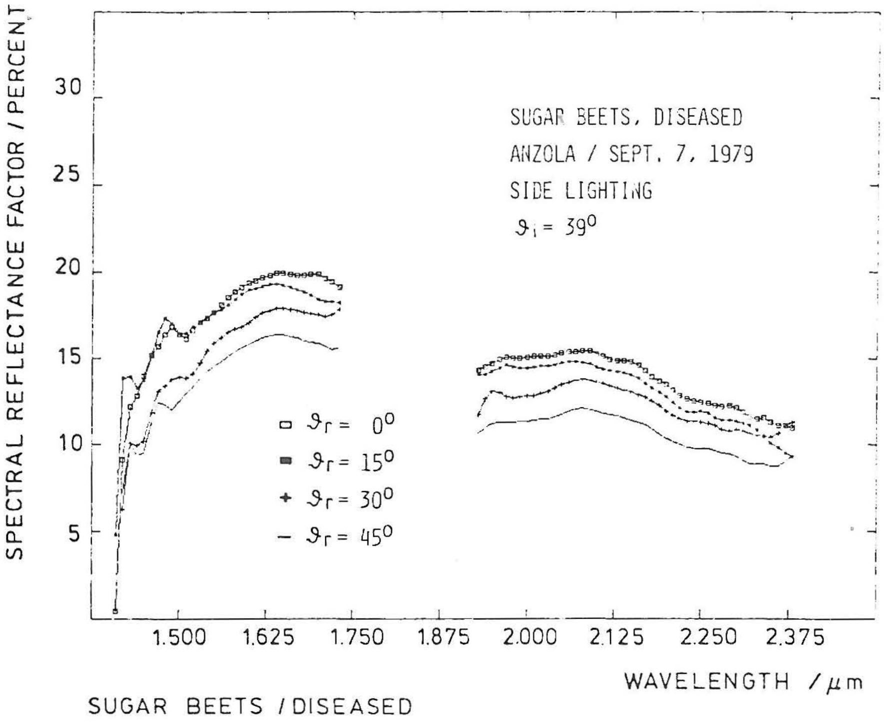

SPECTRAL REFLECTANCE FACTOR / PERCENT
SUGAR BEETS, DISEASED
ANZOLA / SEPT. 7, 1979
SIDE LIGHTING
$\vartheta_i = 39^0$
$\vartheta_r = 0^0$
$\vartheta_r = 15^0$
$\vartheta_r = 30^0$
$\vartheta_r = 45^0$
30
25
20
15
10
5
1.500
1.625
1.750
1.875
2.000
2.125
2.250
2.375
WAVELENGTH / μm
SUGAR BEETS / DISEASED

FIG. 8

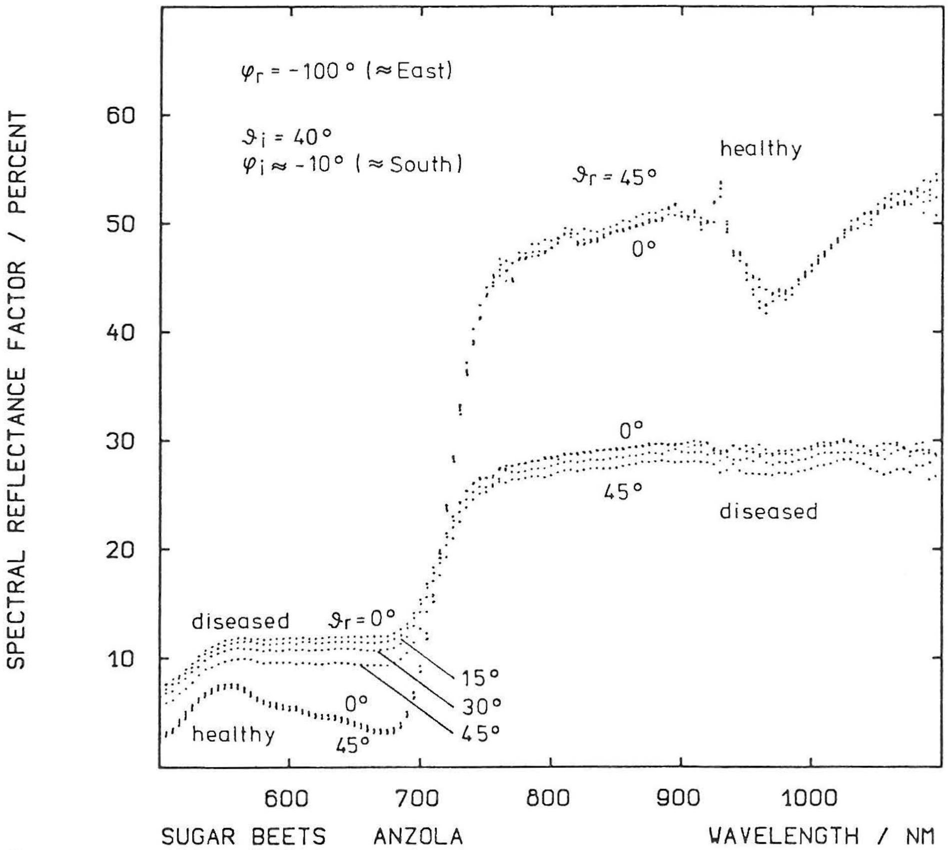

SPECTRAL REFLECTANCE FACTOR / PERCENT
$\varphi_r = -100°$ ($\approx$ East)
$\vartheta_i = 40°$
$\varphi_i \approx -10°$ ($\approx$ South)
healthy
$\vartheta_r = 45°$
0°
0°
45°
diseased
diseased $\vartheta_r = 0°$
15°
30°
45°
0°
healthy
45°
60
50
40
30
20
10
600
700
800
900
1000
SUGAR BEETS ANZOLA
WAVELENGTH / NM

Fig. 9

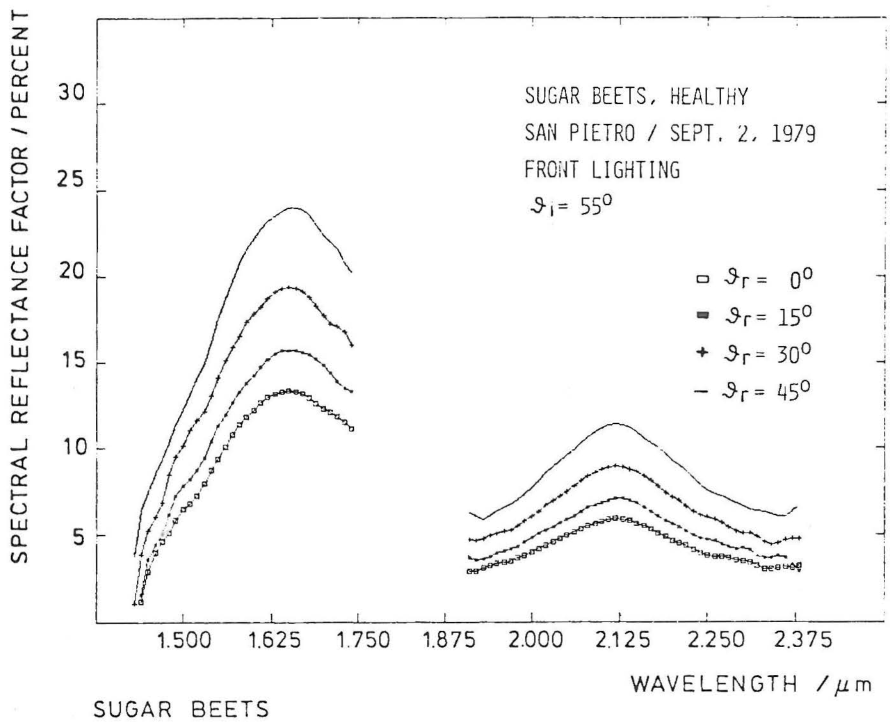

SPECTRAL REFLECTANCE FACTOR / PERCENT
SUGAR BEETS, HEALTHY
SAN PIETRO / SEPT. 2, 1979
FRONT LIGHTING
$\vartheta_i = 55^0$
$\vartheta_r = 0^0$
$\vartheta_r = 15^0$
$\vartheta_r = 30^0$
$\vartheta_r = 45^0$
30
25
20
15
10
5
1.500
1.625
1.750
1.875
2.000
2.125
2.250
2.375
WAVELENGTH / μm
SUGAR BEETS

Fig. 10

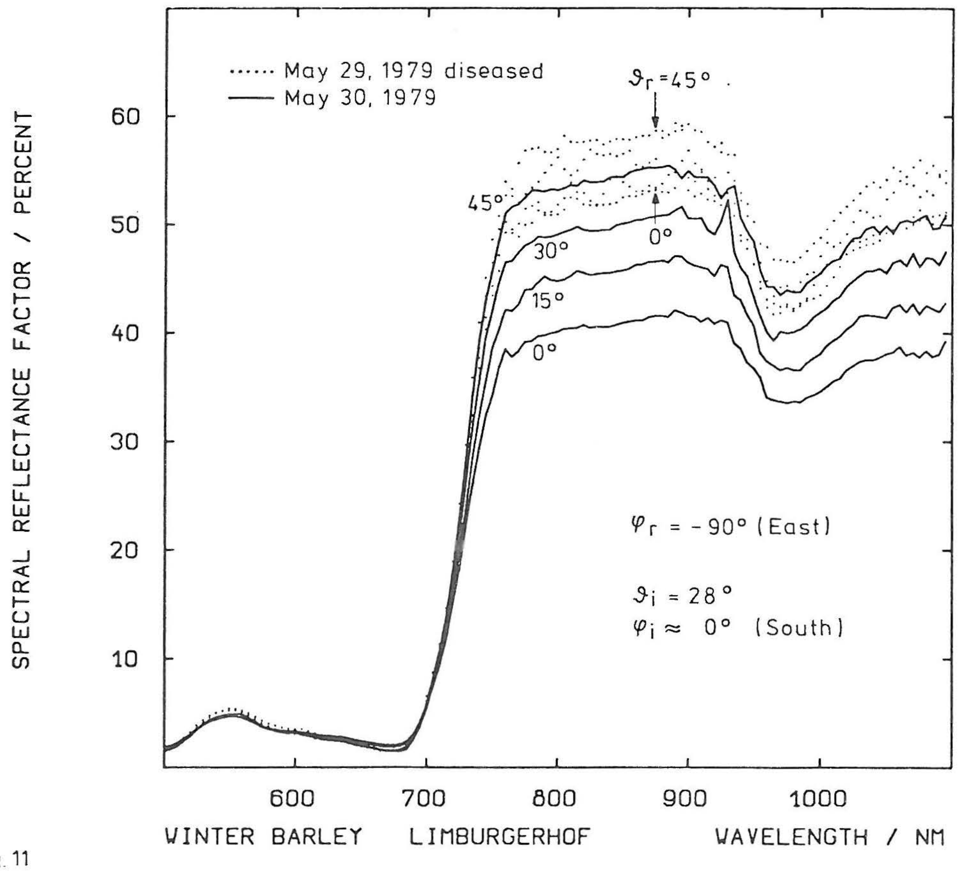

SPECTRAL REFLECTANCE FACTOR / PERCENT
May 29, 1979 diseased
May 30, 1979
$\vartheta_r = 45°$
45°
30°
15°
0°
0°
φ_r = - 90° (East)
ϑ_i = 28°
$\varphi_i \approx$ 0° (South)
60
50
40
30
20
10
600
700
800
900
1000
WINTER BARLEY LIMBURGERHOF WAVELENGTH / NM

Fig. 11

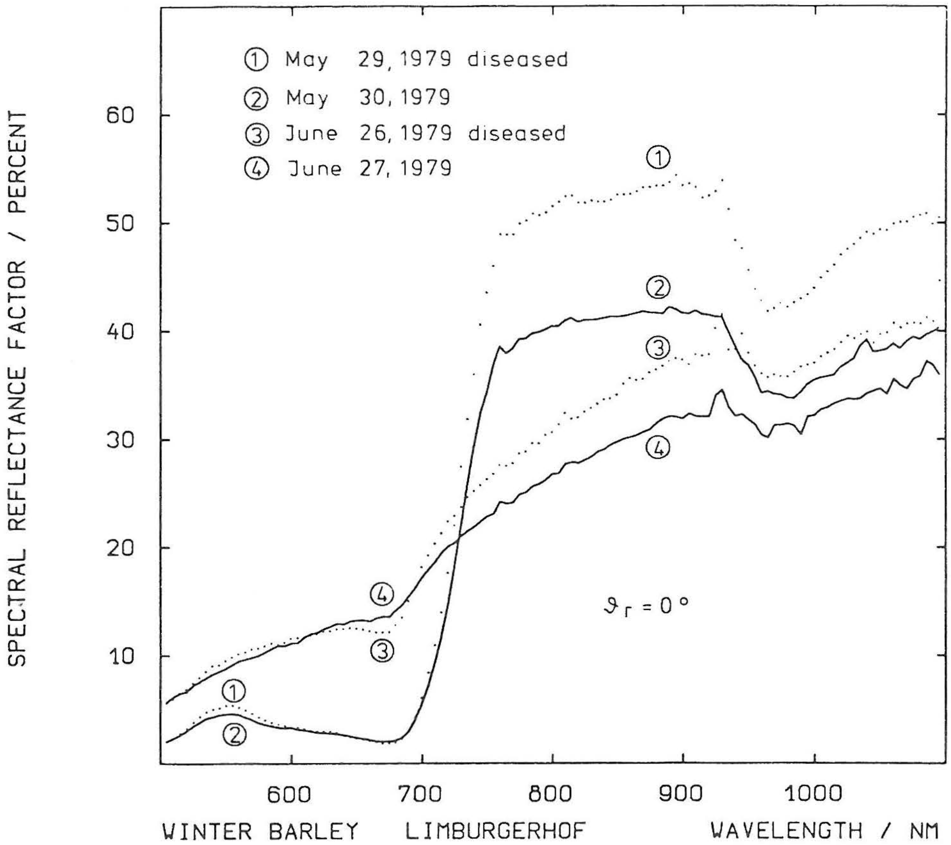


Fig. 12

References

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/2/ PLESSEY RADAR: Multispectral scanning systems and their potential application to Earth Resources. Reports to ESRO und Contract No. 1673/72 EL, Vol. 2, Dec. 1972.

/3/ SANWALD, E.: Private communication.