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MONITORING OF *PHYTOPHTHORA INFESTANS* DEVELOPMENT WITH A LUMINANCEMETER

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Abstract: Two potato cultivars, sprayed and nonsprayed with fungicides, were evaluated to determine the association of late blight (caused by *Phytophtora infestans*) and radiometric leaf reflectance to disease development. Spectral radiance measurements were taken with CIMEL CE3132 luminancemeter in the visible (450 nm, 550 nm and 650 nm) and near-infrared (850 nm) range of the electromagnetic spectrum. The measurements were taken at two view zenithal angles: $\phi_v = 0°$ (at nadir) and $\phi_v = 50°$. Six vegetative indices based on these measurements were used to detect differences between sprayed and nonsprayed plants. Vegetation indices based on the reflectance measurement enable to distinguish infected potato plants from noninfected plants. Among the vegetation indices used in this studies the best indicators of disease were NIR/RED and ELAI. Results of our study show that for Mila cultivar oblique viewing may be more effective then nadir viewing (perpendicular to the ground surface) for distinguishing between plants infested at different degree.

Key words: spectral radiance measurements, vegetation indices, potato

I. INTRODUCTION

Multispectral remote sensing offers the potential to obtain information about the condition and yield of crops. Several investigators have used aerial photography to study crop disease incidence. Brenchley and Dadd, cited by Odle and Toler (1976) detected late blight (*Phytophtora infestans* [Mont.] de Bary) of potato with black and white aerial infrared photography and subsequently revealed some interesting aspects of disease initiation and spread over the course of a growing season. Ground truth measurements, aerial photography, and satellite data have been used to measure disease incidence in many agricultural surveys on a number of crop species (Nutter 1989; Nutter and Cunfer 1988; Nutter et al. 1990; Sharp et al. 1985). Satellite images have been using in plant protection applications to a small extent so far since the spectral data from the current generation of earth-orbiting satellites have limitations in providing accurate estimates of biophysical characteristics of agricultural crops and in quantifying stress due to pests (Fassnacht et al. 1997; Thenkabail et al. 1995; Wiegand et al. 1991; Wiegand and Richardson 1990). In the near future it may change. The new generation of satellites is planned for launch by various governments and private industry with hyperspectral sensors onboard. Such technological advance enable to use new remote sensing methods of pest detecting and monitoring in arable crops which could be applied in precision farming systems (Lipa 1998).

Elaboration of remote sensing methods for detecting and monitoring of plant disease occurrence needs an improved understanding of the spectral properties of crops. Ground truth measurements are of major importance for remote sensing since they serve to characterise the physical properties of the objects of interests e.g. arable crops. One objective in remote sensing of vegetation is the monitoring of physiological activity, indicating the health and productivity of plants or stress and damage effects.

The goal of this study were to (1) determine if field spectral measurements could be used to detect and monitor of late blight in potato caused by *Phytophtora infestans*, (2) draw a comparision between six vegetation indices as indicators of disease severity, and (3) determine if oblique observation give greater advantage in disease detecting than nadir view.

1. Spectral properties of crop canopies

Five physical factors determine the interaction of solar radiation with an ensemble of plant elements: 1) leaf optical properties, 2) canopy geometry, particularly leaf area index (LAI) and leaf angle distribution, 3) soil (background) reflectance, 4) solar illumination and view angles and 5) atmospheric transmittance (Bauer 1985). Radiation incident on plant elements is reflected, absorbed and transmitted. The wavelength interval from 400 to 2500 nm can be divided into three regions, each associated with a different phenomena affecting leaf reflectance, transmittance and absorption. The reflectance of leaves is relatively low in the visible portion of the spectrum. This low reflectance (and transmittance) is due to absorption by leaf pigments. Chlorophyll absorbs most of the incident energy in the blue and red wavelength bands centered at approximately 450 and 670 nm. In the near-infrared region there is a marked increase in reflectance. Leaves typically reflect 40 to 50 percent and absorb less than 5 percent of the incident energy in these wavelengths. The high reflectance, as well as transmittance, in the near-infrared "plateau" between 700 and 1300 nm is explained by multiple reflections in the internal mesophyll structure, caused by the differences in the refractive indices of the cell walls and intercellular air cavities. Since the internal structure of leaves often varies considerably among species, reflectance differences are frequently greater in the near-infrared than in the visible wavelengths.

2. Influence of stress on plant spectral properties

Reflectance, transmittance and absorption by leaves depend on the concentration of pigments and water, along with the internal cell structure of each species. These physiological and morphological quantities depend on leaf type, growth stage of plant, senescence and stress. A plant stress which reduces chlorophyll production will cause leaves to absorb less in the chlorophyll absorption bands; such leaves will appear yellowish or chlorotic and will have a higher reflectance, particularly in the red region. Most of the biotic and abiotic agents responsible for plant damage do not immediately produce visible symptoms but they affect physiological and biochemical processes. Stresses such as disease may alter the optical properties of leaves; together with canopy geometry changes such as reduction of green LAI, wilting and leaf curl, stress can significantly influence canopy reflectance. The similarity of changes in spectral reflectance associated with nutrient deficiencies, moisture stress, and leaf blight, suggest that it may be difficult to identify specific causes of crop stress from spectral data. However, weather and other ancillary data, combined with spectral data, should increase the capability to identify specific types of stress.

3. Vegetation Indices

Various spectral vegetation indices have been developed that reduce multiband observation to a single numerical index. The index is typically a sum, difference, ratio, or other linear combination of reflectance factor or radiance observations from two or more wavelengths intervals. Among these, the normalized difference vegetation index $NDVI = (R_{NIR}-R_{RED})/(R_{NIR}+R_{RED})$, and the ratio vegetation index ($RVI = R_{NIR}/R_{RED}$) have become the most popular ones (Wiegand et al. 1990)

II. METHOD

The spectral measurements were taken in Winna Góra were Plant Protection Institute in Poznań Experimental Station is situated (52°13'N, 17°27'E). Two cultivars of potato: Bekas and Mila were planted. The experimental design was a completly randomised block design with four replication. Half of the plots was protected against the phytophtora infestans while the rest were control plots. Fungicide applications were made according to NegFry model on 25 June (Ridomil MZ 72 WP), 7 July (Acrobat MZ 69 WP), 24 July (Bravo 500 SC) and 10 August (Dithane 75 WG).

Spectral radiance measurements were taken with CIMEL CE3132 luminancemeter in the visible (450 nm, 550 nm and 650 nm) and near-infrared (850 nm) range of the electromagnetic spectrum. The luminancemeter's field of view (FOV) is 10° at nadir and was placed 170 cm above the potato canopy. The measurements were taken at two view zenithal angles: $\phi_v = 0°$ (at nadir) and $\phi_v = 50°$. At the latter view angle reflectance was measured in

Table 1

Disease severities at different dates of two potato cultivars infected with late blight pathogen (*Phytophtora infestans*)

Date	Mila cultivar		Bekas cultivar	
	Sprayed	Nonsprayed	Sprayed	Nonsprayed
29 June	0	0	0	0
3 July	4	6	6	5
16 July	9	11	10	11
31 July	13	14	31	40
11 August	24	48	71	91
20 August	38	82	92	94

the principal plane and the sun was behind the sensor (backwardscattering) The measurements were made on the six dates each time at the same three plants selected randomly at each plot. The measured data were then analysed for infestation effects using analysis of variance and Newman-Keuls' means comparison. On the same days when the spectral measurements were taken late blight disease evaluations were made according to scale proposed by Jorg (1998) (Tab. 1). This was accomplished by comparing infected leaves to standard area diagrams depicting percent necrotic tissue. Reflectance measurements were recorded during cloud-free periods about midday.

The vegetative indices used in this study were following: five non-linear:

$$\mathrm{NDVI} = \frac{R_{850}\text{-}R_{650}}{R_{850}+R_{650}}$$

$$\mathrm{NIR/RED} = \frac{R_{850}}{R_{650}}$$

$$\mathrm{NIR/VIS\ 2} = \frac{R_{850}}{(R_{550}+R_{650})/2}$$

$$\mathrm{GREEN/RED} = \frac{R_{550}}{R_{640}}$$

$$\mathrm{NIR/VIS\ 2} = \frac{R_{850}}{(R_{450}+R_{550}+R_{650})/3}$$

and one linear:

$\mathrm{ELAI} = 0.441+0.285\times(R_{850}/R_{650})$, (Nilsson 1985)

III. RESULTS

The first spectral measurements were made on 29 June, at the plant growth phase during which canopy is closed and most of the biomass is produced. In this time leaves covered soil entirely and plants did not show late blight symptoms. After 16 July spectral reflectance of all plots, both sprayed and unsprayed, begun decrease in near-infrared wavelengths since the plant leaves begin to senesce and the amount of cell-wall/air interface which is mainly responsible for the internal scattering of radiation in near-infrared wavelengths is reduced. At the same time an increase in red wavelengths reflectance was observed what resulted from a decrease in chlorophyll content in leaves. Beside these usual changes all measured plants were infected by late blight at a certain degree. As a result, values of all analysed indices after 16 July started to decrease (Fig. 1). This observation is consistent with other reports that deal with correlation between spectral data and plant development (Baush 1993; Giovacchini et al. 1984). By 20 August late blight epidemics on cultivar Mila were well under way while plants of Bekas cultivar died. The vegetation indices NIR/RED and ELAI, in that order, gave the best indication of these changes. On the last measurement date the ELAI indices for Mila nonsprayed plants were eight and nearly eleven times lower at view zenith angles $\phi_v = 0°$ and $\phi_v = 50°$ respectively than on the first date (Tab. 2). For Bekas cultivar greater differences between the first and the last date of measurement were observed at na-

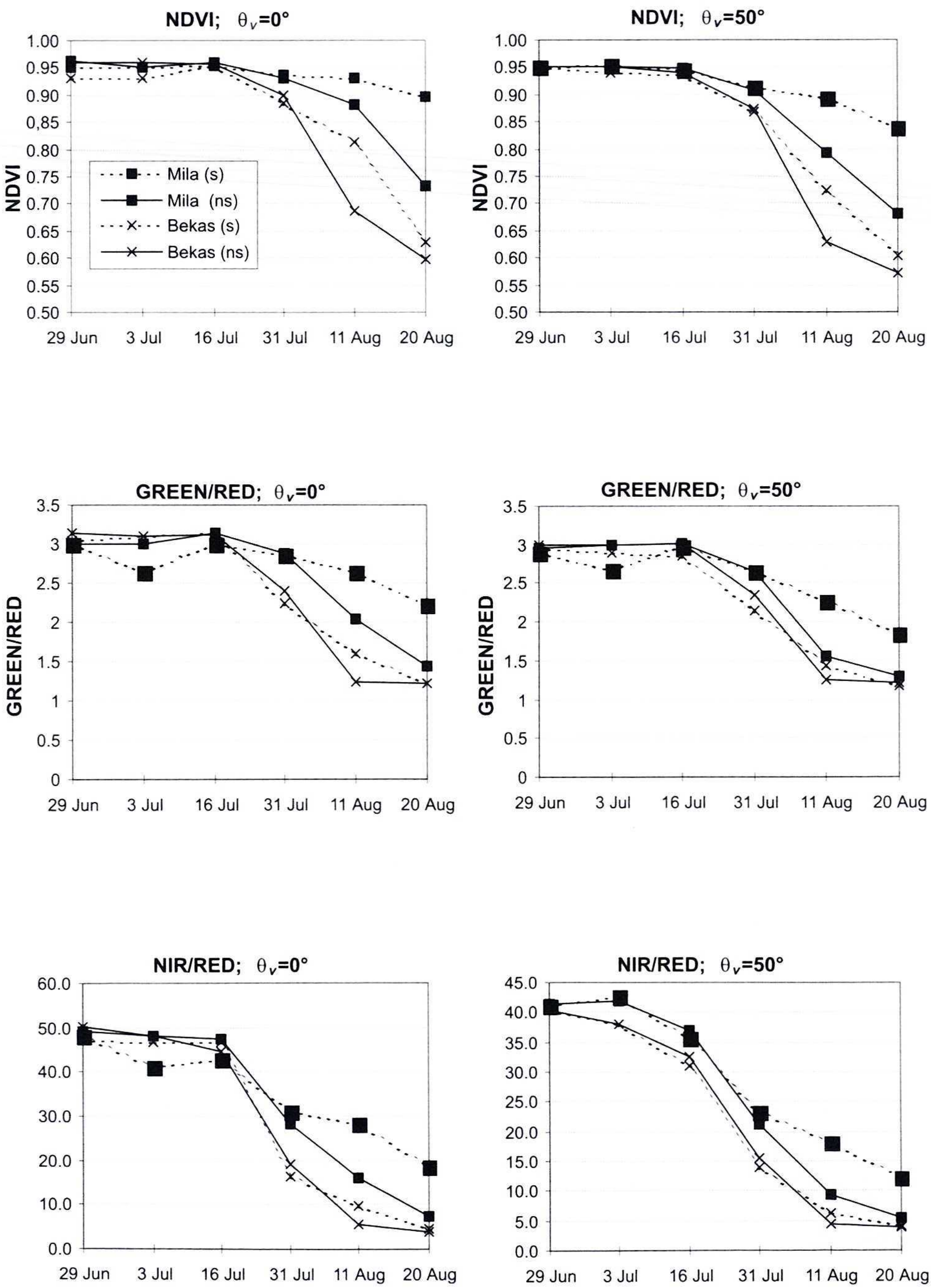

Fig. 1. Vegetation indices of two potato cultivars sprayed (s) and nonsprayed (ns) at two view zenith angles (ϕ_v)

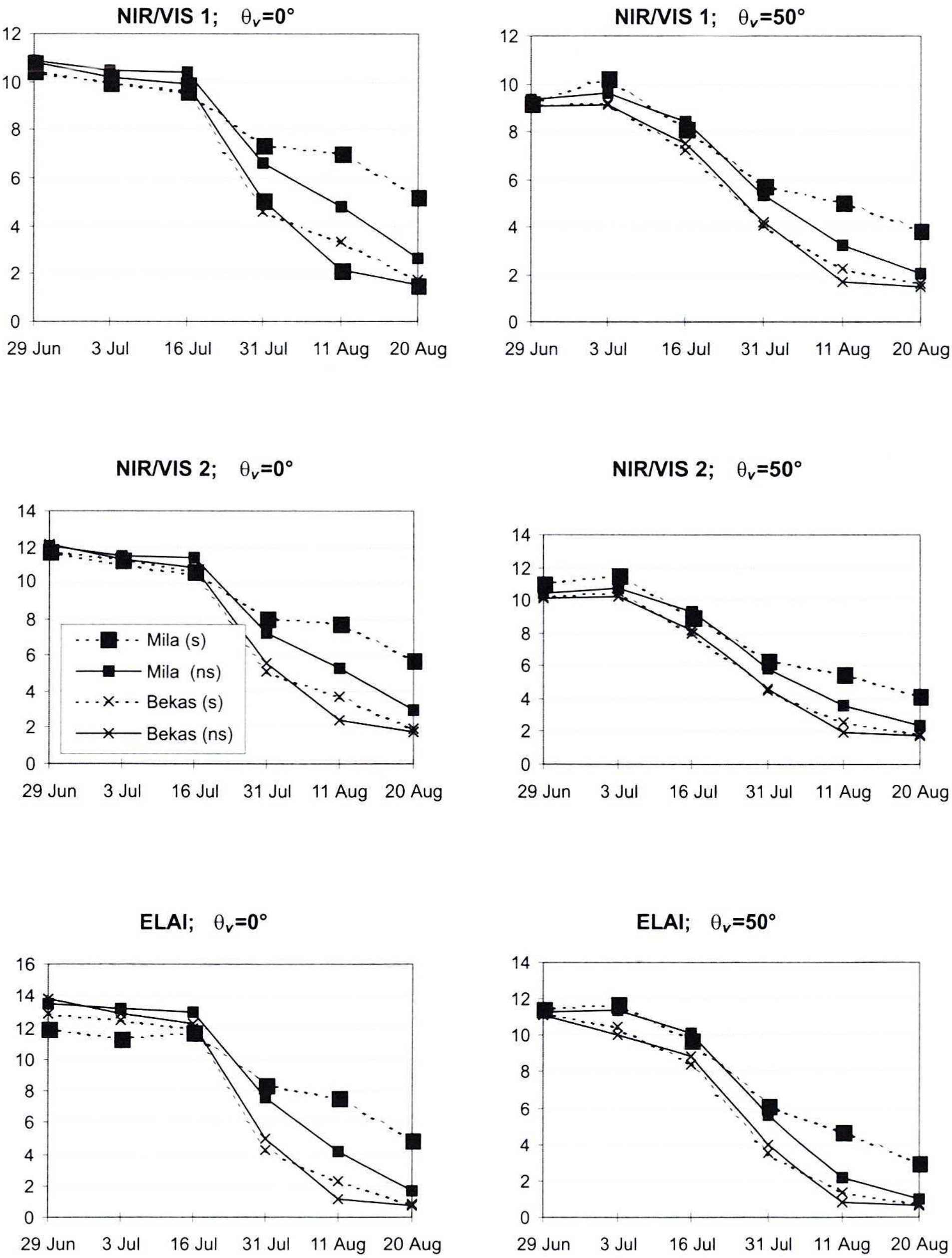
NIR/VIS 1; θv=0°
NIR/VIS 1; θv=50°
NIR/VIS 2; θv=0°
NIR/VIS 2; θv=50°
ELAI; θv=0°
ELAI; θv=50°
Mila (s)
Mila (ns)
Bekas (s)
Bekas (ns)
29 Jun
3 Jul
16 Jul
31 Jul
11 Aug
20 Aug
0
2
4
6
8
10
12
14
16

Fig. 1. cont.

Table 2

Mean values of vegetation indices for two potato cultivars canopies sprayed (s) and nonsprayed (ns) with fungicides calculated on spectral data gathered on six measurement dates

Vegetation Indices	Treatment	Cultivar Mila						Cultivar Bekas					
		Spectral measurement date						Spectral measurement date					
		29 Jun	03 Jul	16 Jul	31 Jul	11 Aug	20 Aug	29 Jun	03 Jul	16 Jul	31 Jul	11 Aug	20 Aug
NDVI	s	0.950	0.953	0.950	0.927	0.913*	0.869*	0.941	0.935	0.946	0.877	0.769*	0.617
	ns	0.957	0.950	0.953	0.920	0.839	0.707	0.956	0.955	0.949	0.886	0.659	0.586
GREEN/RED	s	3.02	2.87	3.07	2.55	2.12*	1.72*	2.93	2.79	2.92	2.39	1.84*	1.51
	ns	3.07	3.05	3.13	2.64	1.65	1.33	2.97	3.00	3.01	2.50	1.41	1.26
NIR/RED	s	47.48	44.02	44.77	23.82	18.96*	11.47	40.68	40.32	33.37	18.60	12.14	8.10
	ns	49.60	48.00	46.00	23.66	10.82	5.72	40.88	40.00	34.85	18.41	6.82	4.57
NIR/VIS 1	s	10.70	9.98	9.62	7.37	7.05*	5.23*	10.37	9.98	9.57	4.63	3.32*	1.71
	ns	10.86	10.60	10.37	6.65	4.80	2.66	10.80	10.20	9.92	5.10	2.16	1.55
NIR/VIS 2	s	12.20	11.33	10.71	8.08	7.75*	5.76*	11.65	10.90	10.52	5.08	3.72*	1.99
	ns	12.09	11.90	11.43	7.27	5.28	2.99	12.12	11.00	10.85	5.58	2.45	1.81
ELAI	s	11.75	11.51	10.76	7.30	6.16*	3.93*	12.05	11.50	10.18	3.91	1.83	0.77
	ns	12.43	12.30	11.58	6.61	3.17	1.36	12.47	11.45	10.58	4.48	0.97	0.68

Means denoted by * were significantly different from the corresponding nonsprayed plots mean ($p<0.05$).

dir ($\phi_v = 0°$) than at oblique view angle $\phi_v = 50°$). The statistically significant decrease of these two indices was first observed on 16 July.

All six indices gave clear indications of late blight disease regardless of the potato cultivar or the view angle. These indices were significantly lower in control plots than in sprayed with fungicide plots by 11 August. The differences for Bekas cultivar narrowed after 11 August when the high infection levels in both sprayed and nonsprayed plots eventually caused premature senescence of plants. The greatest differences showed ELAI and NIR/RED indices. For Mila cultivar greater differences between sprayed and nonsprayed plots were found in all vegetation indices when measurements were taken at view zenith angle $\phi_v = 50°$. At this view angle ELAI index in sprayed plots was 2.1 times that in nonsprayed plots compared to a factor of 1.8 at $\phi_v = 0°$. Dissimilar results were obtained in case of Bekas cultivar. More significant differences between sprayed and nonsprayed plots were observed at $\phi_v = 0°$ than at $\phi_v = 50°$. This may result from dissimilar susceptibility of Mila and Bekas cultivars to the disease and Haverkort and Harris (1986) showed that there was genetic variation in the radiation use efficiency of the crop among potatoes and that this efficiency was lower in spring and autumn.

IV. CONCLUSIONS

Our results indicate that it is possible to use remotely collected radiometric reflectance data to detect and estimate late blight on potato plants incidence. Vegetation indices based on the reflectance measurement enable to distinguish infected potato plants from noninfected plants. Early detection of infection can be very useful for chemical control and can lead to more reliable estimates of disease loss over large areas that may not be accessible except by remote sensing.

Among the vegetation indices used in this studies the best indicators of disease were NIR/RED and ELAI. The capability of a vegetation index to detect plant stress varied substantially with wavelength (Carter and Miller 1994). In our study best results in monitoring late blight infestation gave indices calculated on reflectance factor only of wavelengths 850 and 650 nm. NDVI indice, commonly used in remote sensing applications, turned out to be worse disease indicator.

Further investigations are necessary to determine the best viewing conditions in disease detecting on potato plants. Results of our study show that for Mila cultivar oblique viewing may be more effective then nadir viewing (perpendicular to the ground surface) for distinguishing between plants infested at different degree.

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CHARAKTERYSTYKA SPEKTRALNA ROŚLIN ZIEMNIAKA PORAŻONYCH PRZEZ GRZYB *PHYTOPHTHORA INFESTANS*

STRESZCZENIE

Opracowanie technik teledetekcyjnych służących do wykrywania i obserwacji rozwoju chorób roślin wymaga poznania ich właściwości spektralnych. Służą temu polowe pomiary spektralne roślin, których celem jest stwierdzenie różnic w ilości pochłanianego i odbijanego promieniowania słonecznego przez rośliny chore i zdrowe. Zastosowanie wskaźników wegetacyjnych, czyli porównanie od-

bicia fal elektromagnetycznych o różnych długościach od tego samego obiektu w tym samym czasie, może stanowić lepszą podstawę do opisu jego charakterystyki spektralnej niż pomiary odbicia każdej z fal analizowane oddzielnie.

Celem badań było stwierdzenie, który ze wskaźników wegetacyjnych obliczonych na podstawie zmierzonych danych spektralnych najbardziej nadaje się do wykrycia zróżnicowania między zdrowymi i chorymi roślinami ziemniaka. Ponadto podjęto próbę uzyskania odpowiedzi na pytanie, czy pomiary wykonywane pod kątem innym niż 0° umożliwiają łatwiejsze zidentyfikowanie chorych roślin.