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CANOPY REFLECTANCE MEASUREMENTS USED TO ESTIMATE LATE BLIGHT (*PHYTOPHTHORA INFESTANS*) INFLUENCE ON POTATO YIELD

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Abstract: The present study was conducted to investigate potato late blight (*Phytophtora infestans*) influence on leaf chlorophyll level using datasets extracted from multispectral data captured at the canopy level. Field experiments were carried out to the National Institute of Research and Development for Potato and Sugar Beet Brasov, Romania in 2014-2016 period. It was used a complete randomized block design with four replicates, two planting distances between plants on row (25 and 30cm) and different fungicides, control technologies. Normalized Difference Vegetation Index (NDVI) was introduced to achieve a spectral vegetation index that can separate the vegetation from the uncovered ground. It is defined as the ratio between the infrared bands-red differences and sum them. Due to the different growth conditions, the effects of resulting variants from combinations of factors -varieties-planting density-late blight control technology-on the tubers yield have manifested with different intensity. In two of three years, the average NDVI value of plants grown at a density of 53.3 thousands hill/ha was significantly lower than the values determined at a density of 44.4 thousands hill/ha (NDVI 0.817 compared to 0.859 in 2014 and 0.905 compared to 0.895 in 2015). The correlation between the average values of NDVI yields and tubers were positive.

Key words: *potato, late blight, Normalized Difference Vegetation Index (NDVI)*

INTRODUCTION

Late blight of potato exploded into the public consciousness in the mid 1840s when the oomycete pathogen *Phytophthora infestans* was introduced into northern Europe. The new disease caused by this pathogen affected both foliage and tubers, devastating potato production with highly variable consequences in different regions (Forbes & Simon, 2007). Temperature between 7 and 27°C is favourable for blight development. Humidity plays a major role in development of an epidemic. Prolonged survival of sporangia requires high RH (Martin, 1923). The magnitude of disease progress depends on an interaction between biotic factors such as cultivar, age, nutrition, the amount of inoculum present on the host and the abiotic factors such as distribution and duration of saturated or near-saturated air within a favourable temperature in the crop canopy (Arora et al., 2014). Demand for late blight resistant varieties is always at top priority of the farmers to manage the disease (Rana et al., 2013).

One of the most important characteristics of late blight is that lesions and disease symptom appear quickly. Typically, green brown or yellow spots which become necrotic regions may appear in two or three days after infection with *P. infestans* depending on environmental conditions and potato genotype susceptibility (Fry, 2008).

Now there are a number of non-invasive methods to determine the level of chlorophyll concentration in leaf or plant. It is well established that the measured values gives a good

estimate of the level of chlorophyll present in potato leaf, confirming the accuracy of the measurements (Vos & Born, 1993). Screening of genotypes against potato late blight under field conditions is essential to identify resistant genotypes of interest for plant breeding and to provide early warning tools for potato infected crops, supplying images that enable precise and reliable statistics (Duarte-Carvajalino et al., 2018).

Normalized Difference Vegetation Index (NDVI) is very commonly used because it can minimize the topographically effect by making a linear measuring scale. NDVI was introduced to achieve a spectral vegetation index that can separate the vegetation from the uncovered ground on the basis of satellite imagery analysis. It is defined as the ratio between the infrared bands-red differences and sum them. In the visible field (460-700 nm), green plant pigments (chlorophyll) causes a strong bright energy absorption. The absorption maximum is in red and blue stripes, which leads to the appearance of green plant leaf feature. In the field of infrared the interaction is different. So the energy in this field is not used for photosynthesis, but is strongly reflected by the internal structure of the leaves, this leading to a very strong luminous reflectance in the near infrared domain (NIR). This strong contrast between the amount of energy reflected in the red and infrared areas of the electromagnetic spectrum is the basis for identifying quantitative indices of vegetation using satellite images (Jensen, 2000). Calculating the report of visible light and near infrared reflected by a sensor is obtained a number from -1 to + 1. If the value of NDVI is zero, it means that there are no green vegetation and a value of 0.8-0.9 indicates the highest density possible of green leaves.

NDVI provides an estimation of the health of vegetation and represent a tool to monitor the changes during the growing season and remains the most well known and used index to detect green plants canopy using multispectral data.

The aim of this research was to investigate *Phytophtora infestans* influence on leaf chlorophyll level using datasets extracted from multispectral data captured at the canopy level. Also of great importance was the observation of the influences resulting from the use of different potato varieties and different planting densities.

MATERIALS AND METHODS

The study was conducted between 2014 and 2016 at the National Institute of Research and Development for Potato and Sugar Beet Brasov, Romania.

Research design: Planting was on about the 1st of April in 2014, 27th April 2015 and 31st March 2016. Plot size was 18 m^2 with three replications in a randomized complete block using qualified seed potatoes of each cultivar, Riviera (Dutch potato variety) very susceptible to late blight, Christian and Roclas (Romanian potato varieties), moderately susceptible to late blight at spacing of 75 × 30 cm and 75 × 25 cm and with two control technologies (TECH1 – only contact fungicides and TECH2 – contact and systemic fungicides)
In all cases, cultivation and maintenance was in line with current good agricultural practice.

Measurements: First symptom of late blight observation: daily check for all plots after emergence till first symptom observed in one of the plots (2014, June 17th, 2015, July 1st, 2016, May 31st). All plots were assessed weekly for the extent of blight spots on the leaves. Each plot was assessed as a whole for percentage disease severity using a standard accepted severity key. (Anonymous, 1947; Cruickshank et al., 1982).

Yield assessment: two central rows in each plot were harvested mentioned the number and the weight of tubers with blight. NDVI determinations: 3 plants on each plot with 3 measurements.

Data analysis: For the statistical part of the measurements has been used Duncan's test, Pearson correlations and regressions introduced into the data of the SPSS program (Huzsvai, 2011).

RESULTS AND DISCUSSIONS

NDVI measurements were carried out to study the possibilities for non-invasive assessment of plants in field compared with slaughtered plants measurements in early July. In the years 2014 and 2016 when planting was made earlier and climatic conditions were favourable to yield, but with stronger late blight attack resulting in foliage senescence, NDVI values were lower compared to the values measured in 2015, a year in which planting was carried out later and the attack of blight was lower.

In the year 2014, NDVI measurements to Riviera variety could not be carried out after the proposed methodology because of the advanced age of foliage. Statistical interpretation this year was limited to the values measured on plants of Roclas and Christian varieties. Measurements of NDVI performed in July 2014 indicates significant differences in the values of the two varieties. The value of Roclas variety was 85.9 significantly higher compared to value 0.817 of Christian variety.

Plants of Roclas and Christian varieties at 31st June 2015 had a foliage with maximum activity indicated by NDVI average (0.918 and 0.912), while to Riviera variety, due to earliness, the value was 0.817. Variants resulting from combinations of densities and late blight control technologies were differentiated significantly (p = 5%) based on NDVI values only to Riviera variety to both ways of combinations. The plants had significantly higher NDVI to the density of 44.4 thousands hill/ha (average NDVI 0.884), towards 0.858 obtained at a density of 53.3 thousands hill/ha. Using TECH2 late blight control technology, NVDI values were higher than in TECH1 (0.897 compared to 0.871 at 44.4 thousands hill/ha and 0.868 compared to 0.848 at 53.3 thousands hill/ha).

In 2016 significant positive effects on the value of NDVI were registered at Riviera and Roclas varieties. The Riviera variety on the TECH1 to the density of 53.3 thousands hill/ha obtained the highest NDVI value (0.700), compared with the rest of combinations of this variety with NDVI between 0.654 and 0.664. To Roclas variety the difference in NDVI between treatments was significant on density of 53.3 thousands hill/ha. In this case, the plants from which has been applied TECH1 technology had NDVI of 0.739, compared with TECH2 (0.699). To Christian variety studied plants had NDVI values between 0.716 and 0.732 without significant differences (Table 1).

Table 1. Interaction effects of varieties-densities and *P. infestans* control technology on plants NDVI values

No.	Variety	Density thousands plant/ha	*P. infestans* control technology	NDVI value		
				2014, 2nd July	2015, 31st June	2016, 8th July
1	Riviera	44.4	TECH1	-	0.871 d	0.663 c
2			TECH2	-	0.897 c	0.654 c
3		53.3	TECH1	-	0.848 e	0.700 b
4			TECH2	-	0.868 d	0.664 c
Mean				-	**0.871 b**	**0.670 b**
5	Roclas	44.4	TECH1	0.857 a	0.921 ab	0.746 a
6			TECH2	0.866 a	0.926 a	0.740 a
7		53.3	TECH1	0.857 a	0.910 abc	0.739 a
8			TECH2	0.854 a	0.914 abc	0.699 b

Mean				**0.859**	**0.918 a**	**0.732 a**
9	Christian	44.4	TECH1	0.829 b	0.907 bc	0.730 ab
10			TECH2	0.845 ab	0.906 bc	0.732 ab
11		53.3	TECH1	0.794 c	0.912 abc	0.716 ab
12			TECH2	0.799 c	0.921 ab	0.727 ab
Mean				**0.817 O**	**0.912 a**	**0.727 a**
Experimental mean (CV)				**0.838** (1.7%)	**0.900** (3.7%)	**0.709** (3.2%)
LDS 5% (Variety)				1.3 %	1.0%	2.4%
LDS 5% (Variety*Dens*TECH)				2.2 %	1.6%	3.4%

In two of three years, the average NDVI value of plants grown at a density of 53.3 thousands hill/ha was significantly lower than the values determined at a density of 44.4 thousands hill/ha (0.817 compared to 0.859 in 2014 and 0.905 compared to 0.895 in 2015) (Table 2).

Table 2. Interaction effects of varieties and densities on plants NDVI values at the beginning of July

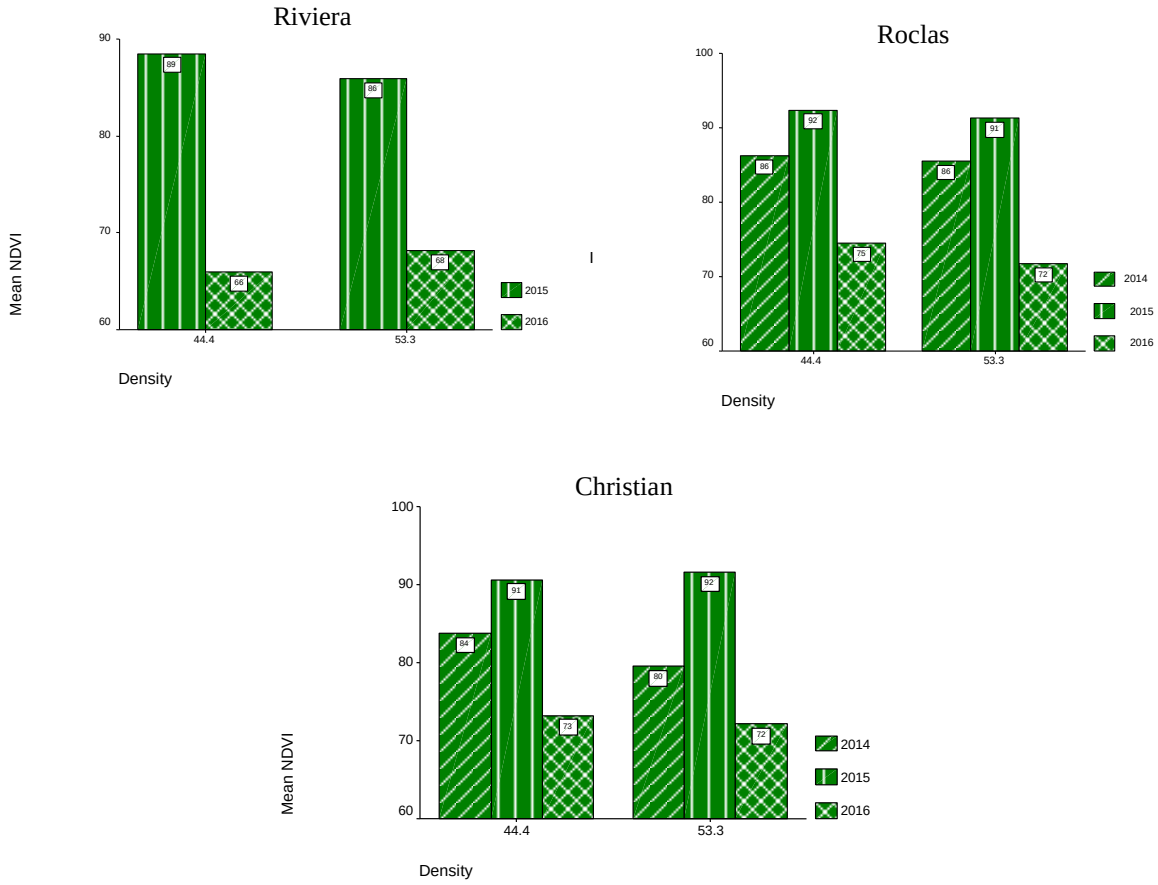
Variety	Density thousands plant/ha	NDVI value		
		2014, 2nd July	2015, 31st June	2016, 8th July
Riviera	44.4	-	0.884 c	0.659 b
	53.3	-	0.858 d	0.682 b
Roclas	44.4	0.861 a	0.924 a	0.743 a
	53.3	0.856 a	0.912 ab	0.719 a
Christian	44.4	0.837 ab	0.907 b	0.731 a
	53.3	0.797 b	0.916 ab	0.722 a
Mean	**44.4**	**0.859**	**0.90,5**	**0.711**
	53.3	**0.817 O**	**0.895 O**	**0.708 ns**
Dl 5% (Dens)		1,4 %	0,5%	1.5%
LDS5%(Variety*Dens)		4.1 %	1.1%	2.4%

Effects of different late blight value have been reduced, thus the mean to TECH1 was between 0.716 in 2016 and 0.895 in 2015. To TECH2 the mean was between 0.703 in 2016 and 0.905 in 2015 and without statistical significance in most cases, with exception of TECH2 in 2015 when the value of NDVI was 0.905 (statistically significant) (Table 3).

Table 3. Interaction effects of varieties and late blight control technology on plants NDVI values at the beginning of July

Variety	Late blight control technology	NDVI value		
		2014, 2 July	2015, 31 June	2016, 8 July
Riviera	TECH1	-	0.860 c	0.682 b
	TECH2	-	0.883 b	0.659 b
Roclas	TECH1	0.857 a	0.916 a	0.743 a
	TECH2	0.860 a	0.920 a	0.720 a
Christian	TECH1	0.812 b	0.909 a	0.724 a
	TECH2	0.822 b	0.914 a	0.729 a
Mean	**TECH1**	**0.834**	**0.895**	**0.716**
	TECH2	**0.841 ns**	**0.905 ***	**0.703 ns**
Dl 5% (TECH)		1.4 %	0.5%	1.5%
LDS5%(Variety*TECH)		1.5%	1.1%	2.4%

Figures 1 - 3 presents the dynamic of evolution of NDVI values to Riviera, Roclas and Christian varieties influenced by the two planting densities.



Figures 1 - 3. NDVI values dynamics to Riviera, Roclas and Christian varieties

Due to the different growth conditions, the effects of resulting variants from combinations of factors varieties -planting density-late blight control technology on the tubers production have manifested with different intensity. In the year 2014, with unfavorable conditions of growth and with strong attack of blight, only partially controlled, were found significant differences between variants resulting from the combination of the studied factors.

In 2014, the highest total of 28.8 t/ha was reached to Roclas variety with density of 44.4 thousands hill/ha, to which the late blight control was done by TECH2, while to Christian variety, to the same combination, total production was significantly lower (26.2 t/ha). To Riviera variety total productions to all variants were between 16.8 t/ha and 20.6 t/ha, without significantly differences due to the high late blight attack

In the year 2015, with low late blight attack have capitalisation of part of the production potential of varieties, in which the differences between variants remained on the threshold of statistical significance (Roclas and Christian) or insignificant (Riviera).

In 2016, the experimental media was virtually the same as that from 2014. Also there were bastions with yields the previous year average yields at Riviera varieties (29.0 t/ha) and Christian (34.5 t/hectare). The Roclas production averaged 41.5 t/ha significantly exceeded the yields achieved in previous years.

The highest yields (45.2-38.4 t/ha) were to Roclas variety and the lowest yields (30.2 and 25.7 t/ha) to Riviera variety. To Christian variety, higher productions, between 38.1 and

31.1 t/ha, were in the variants where plant density was lower, but without differences between the two applied technologies (Table 4).

Table 4. Interaction effects of late blight control technology and densities on total yield to Riviera, Roclas and Christian varieties

No.	Variety	Density thousands plant/ha	Late blight control technology	Total yield (t/ha)		
				2014	2015	2016
1	Riviera	44.4	TECH1	18,4 ef	31,4 abc	33,2 bcd
2			TECH2	18,8 ef	33,2 abc	30,3 cd
3		53.3	TECH1	16.8 f	27.0 c	25.7 d
4			TECH2	20.6 de	30.0 bc	26.7 d
Mean				**18.6 a**	**30.4 b**	**29.0 b**
5	Roclas	44.4	TECH1	24.8 bc	38.1 a	45.2 a
6			TECH2	28.8 a	36.3 ab	40.1 ab
7		53.3	TECH1	23.1 cd	34.5 ab	38.4 abc
8			2	24.6 bc	33.9 ab	40.9 ab
Mean				**25.3 a**	**35.7 a**	**41.2 a**
9	Christian	44.4	TECH1	23.9 bc	36.9 a	36.1 bc
10			TECH2	26.2 b	35.1 ab	38.1 abc
11		53.3	TECH1	22.5 c	31.7 abc	31.1 cd
12			TECH2	24.4 b	32.0 abc	32.7 bcd
Mean				**24.2 a**	**34.0 ab**	**34.5 ab**
Experimental mean (CV)				**22.7** (7.2 %)	**33.4** (12.1%)	**34.9** (15.1%)
LDS 5% (Variety)				8.0 t/ha	2.2 t/ha	9.7 t/ha
LDS 5% (Variety * Distance * Treatment)				2.4 t/ha	6.0 t/ha	7.8 t/ha

In the three years of experimentation, the correlation between the average values of NDVI yields and tubers were positive. Correlations in the year 2014 refers only to Roclas and Christian varieties due to lack of measurements of Riviera variety. In the years 2015 and 2016 with measurements to all varieties are found close correlations between NDVI measurements and final production, total production and commercial one. Correlation coefficients were significantly higher for both variables in 2015 (0.820* and 0.735*) compared to 2016, a year with powerful late blight attack (0.649* and 0.589*). In correlation of the average NDVI values with the average weights of foliage and underground parts of plants resulted positive relations (Table 5).

Table 5. Correlations of NDVI values with plants biomass components and final yield/ha

NDVI correlations with:	**Pearson** correlation coefficients		
	2014	**2015**	**2016**
Total yield (t/ha)	+0.657	+0.820**	+0.649*
Comercial yield (t/ha)	+0.639	+0.735**	+0.589*
Aerial part of plant (g/plant)	+0.835**	+0.273	+0.416
Roots+stolons (g/plant)	+0.248	+0.514	+0.498
Tubers number (buc/plant)	-0.380	-0.367	+0.005
Tubers weight (g/plant)	-0.601	-0.236	-0.236
	N=8	N=12	N=12

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

The benefits of using multispectral imagery for precision disease management were clear, as also noted by Toler et al. (1981), Blakeman (1990) and Zhang et al., (2005). The

current results show the possibility to realize visual estimation of late blight severity on potato crops using multispectral imagery.

CONCLUSIONS

As a result of the measurements during the experiment have been found significant differences between NDVI values measured in different years at the beginning of July.

In the years 2014 and 2016 when planting was made earlier and climatic conditions were favourable to yield, but with stronger late blight attack resulting in foliage senescence, NDVI values were lower compared to 2015, a year in which planting was carried out later and the attack of blight was lower.

In the three years of experimentation, the correlation between the average values of NDVI yields and tubers were positive. In our case the healthy plants have the highest digital number in the near infrared band while the plants affected by late blight have the lowest.

Developing a remote sensing method to detect late blight at field level would be of great value for potato crop.

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