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Hyperspectral remote sensing and fluorescence methods for wheat phenological change monitoring

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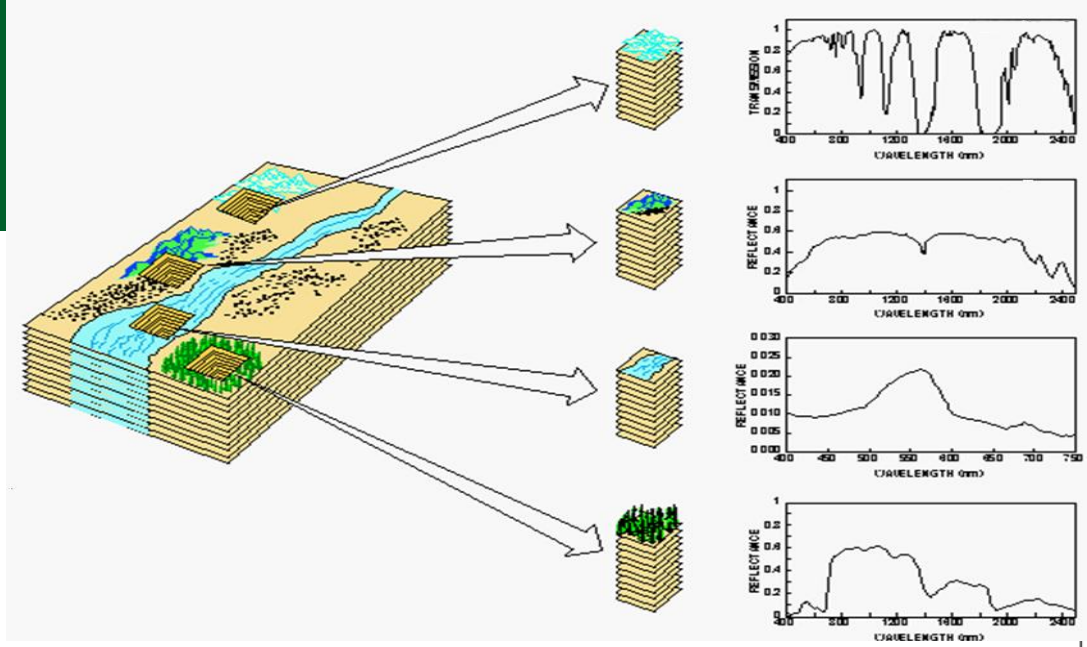
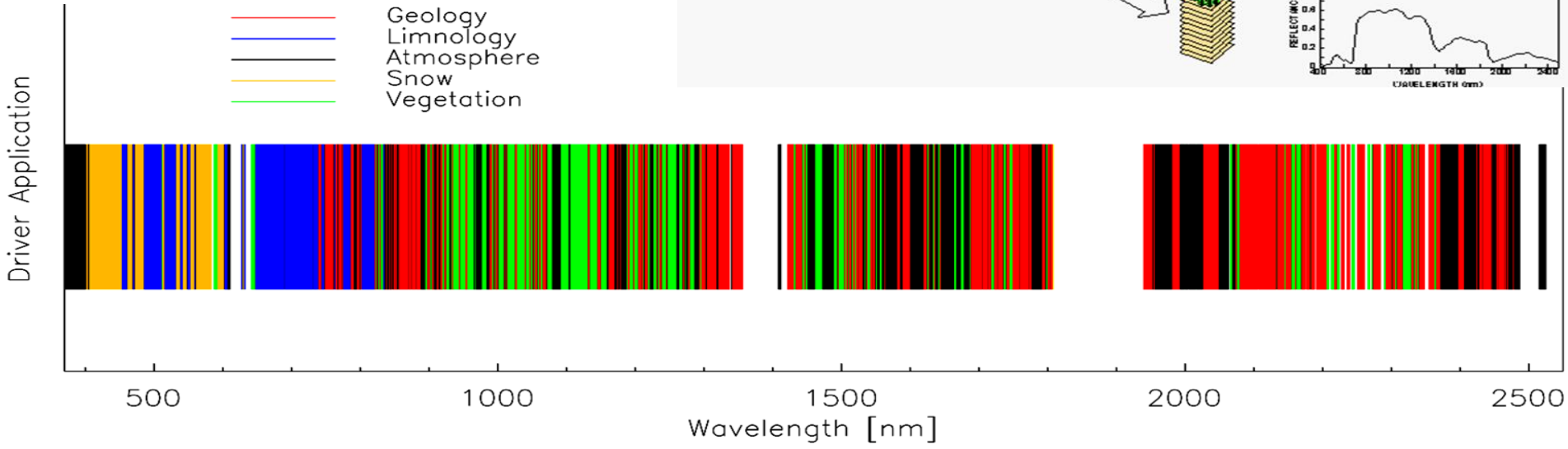
Idea of remote sensing

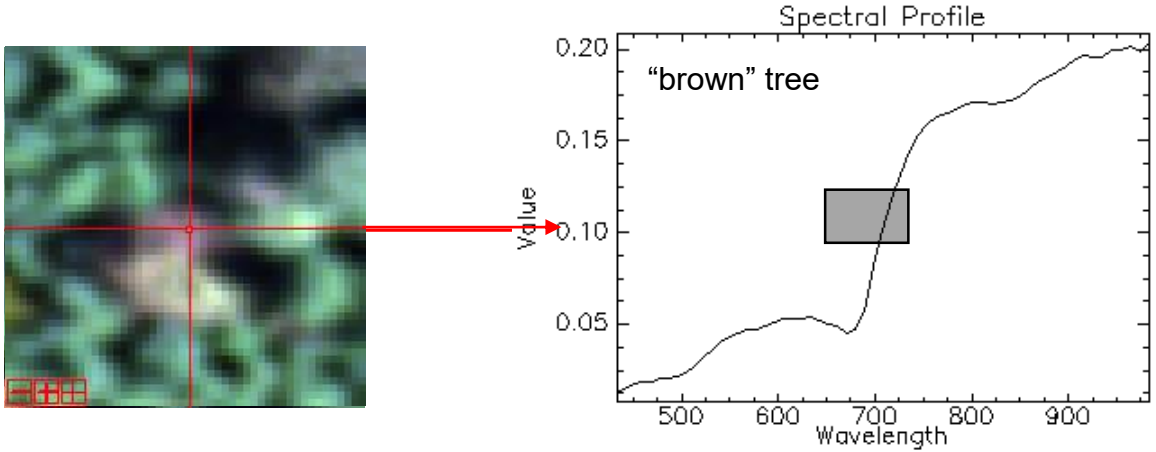




Selected absorption features of plants

Wavelength (nm)	Application	Source of information
463	analysis of b-carotene absorption	Ruban et al. 1993
470	analysis of the absorption of total carotenoids	Ruban et al. 1993
530-630	analysis of chlorophyll content	Gitelson, Merzlyak 1997
650	chlorosis analysis	Adams et al. 1999
663.2	analysis of absorption of chlorophyll-a	Lichtenthaler, Wellburn 1983
646.8	analysis of absorption of chlorophyll-b	Lichtenthaler, Wellburn 1983
670	soil effect normalization and AVI analysis, bands for the analysis of small amounts of chlorophyll	Plummer et al. 1994; North 2002; Gitelson, Merzlyak 1997
680	analysis of chlorophyll absorption	Datt 2000
695	analysis of plant stress PSI (760/695 nm)	Carter 1994
1450	analysis of water absorption in leaves	Aldakheel, Danson 1997
1510	analysis of the absorption of proteins and nitrogen compounds in conifers	Dawson et al. 1998
1650-1850	analysis of water content in cereals (wheat)	Tian et al. 2001
1870	analysis of dry matter content	Fourty, Baret 1998
1910	plant turgor analysis (water content)	Fourty, Baret 1998
2160	analysis of dry matter content	Fourty, Baret 1998
2180	analysis of the absorption of proteins and nitrogen compounds	Dawson et al. 1998
2310	analysis of dry leaves, absorption of hydrocarbons	Fourty, Baret 1998

Changes of spectral reflectance



Goals

- development of an **efficient non-destructive remote sensing method** to determine state of wheat,
- **monitoring of early stage toxin concentrations** caused by *Fusarium* and *Claviceps* infestations in wheat fields,
- **reduction of fungicides**,
- reduction of usage toxin content in wheat for food production.




Object of research

The research was carried out on **3 solehio winter wheat fields**:

- Field I – after maize, relatively wet microclimate;
- Field II – after maize, relatively wet microclimate;
- Field III – after oil rape in drier microclimate.

Each field has 5 pairs of experimental plots (6x6 m each).

In each pair, **one plot**

- **was a reference (a)**
- **was treated** with fungicide (**b**),

Field campaigns terms:

- 13-14.05.2018
- 25-26.05.2018
- 14-15.06.2018
- 05.07.2018

Research methods

- **hyperspectral measurements of plant properties** (ASD FieldSpec 4 + ASD PlantProbe),
- **chlorophyll content in leaves** (OptiScience CCM300),
- **chlorophyll fluorescence** (OptiScience OS1p),
- multispectral images (UAV's Tatracam Micro-MCA6).

Selected remote sensing indices

Application	Index	Name	Formula
General condition of vegetation	NDVI	Normalized Difference Vegetation Index	NDVI=(R860-R650)/(R860+R650)
	NMDI	Normalized Multi-band Drought Index	NMDI={[R860-(R1640-R2130)]/[R860+(R1640-R2130)]}
Amount of photosynthetic active pigments	GI	Greenness Index	GI = R554 / R677
	RARSa	Ratio analysis of reflectance spectra algorithm chlorophyll a	RARSa=R675/R700
Canopy nitrogen	NDNI	Normalized Difference Nitrogen Index	NDNI=[LOG(1/R1510)-LOG(1/R1680)]/[LOG(1/R1510)+LOG(1/R1680)]
Light use efficiency	PRI	Photochemical Reflectance Index	PRI=(R531-R570)/(R531+R570)
	SIPI	Structure Insensitive Pigment Index	SIPI=(R800-R445)/(R800-R680)
Dry or senescent carbon	PSRI	Plant Senescence Reflectance Index	PSRI=(R680-R500)/R750
	CAI	Cellulose Absorption Index	CAI=[0.5*(R2000+R2200)]-R2100
Canopy water	WBI	Water Band Index	WBI=R970/R900
		Normalized Difference Water	

Statistical analyses

1. Analysis of variance (ANOVA) - **differences in spectra characteristics** (350-2500 nm range), which depends on the condition of the research polygons;

2. Statistical volatility of remote sensing indices and the biophysical variables:

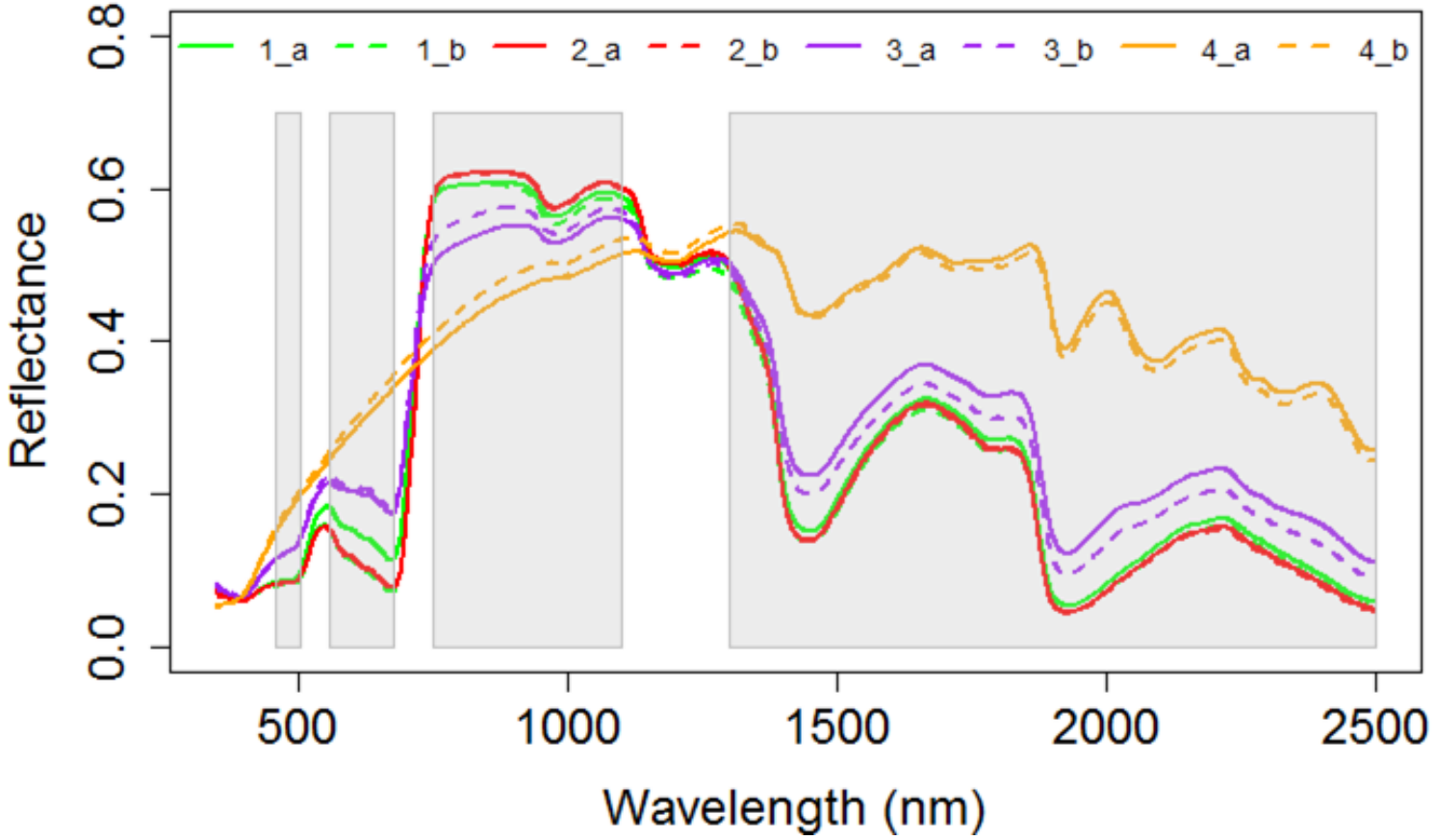
   - **Shapiro-Wilk test** to verify the assumption of **data normality distribution**,

   - **Levine's test** - **homogeneity variance**,

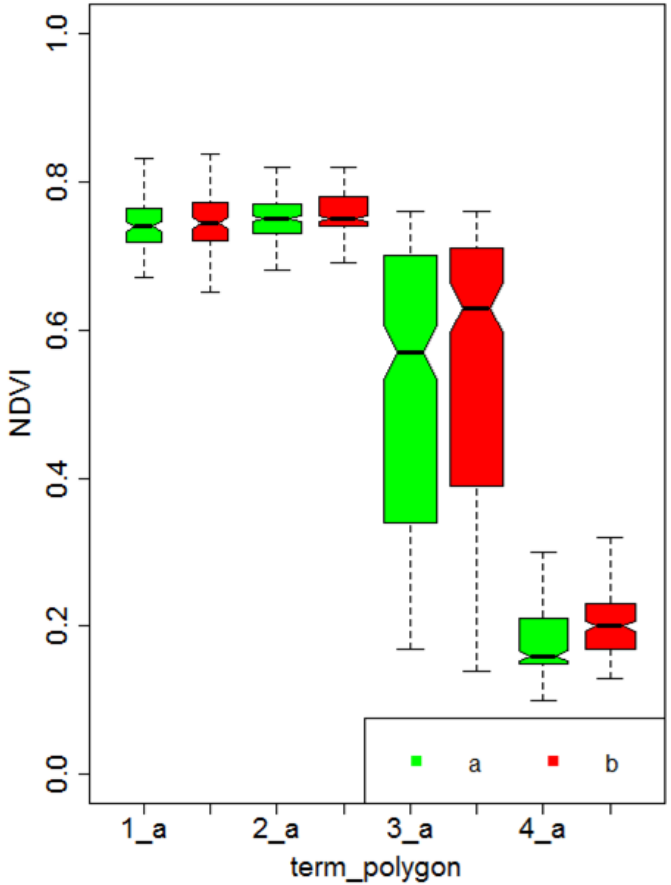
   - **ANOVA Kruskal-Wallis one-way analysis of variance** by ranks was applied to analyze the **wheat differences for different polygons and terms** at the α=0.05 significance level.

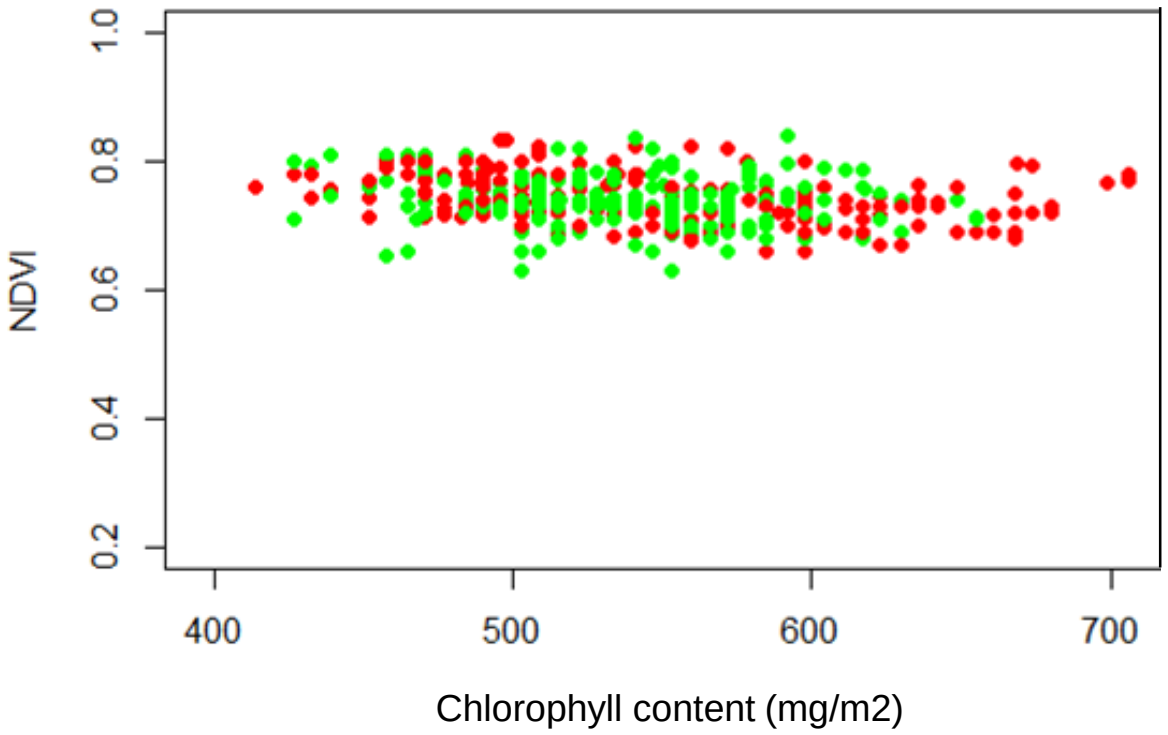
3. The correlation of calculated remote sensing indices and biophysical variables (Pearson or **Spearman's rank-order correlation coefficient** was applied).

Results: spectral curves

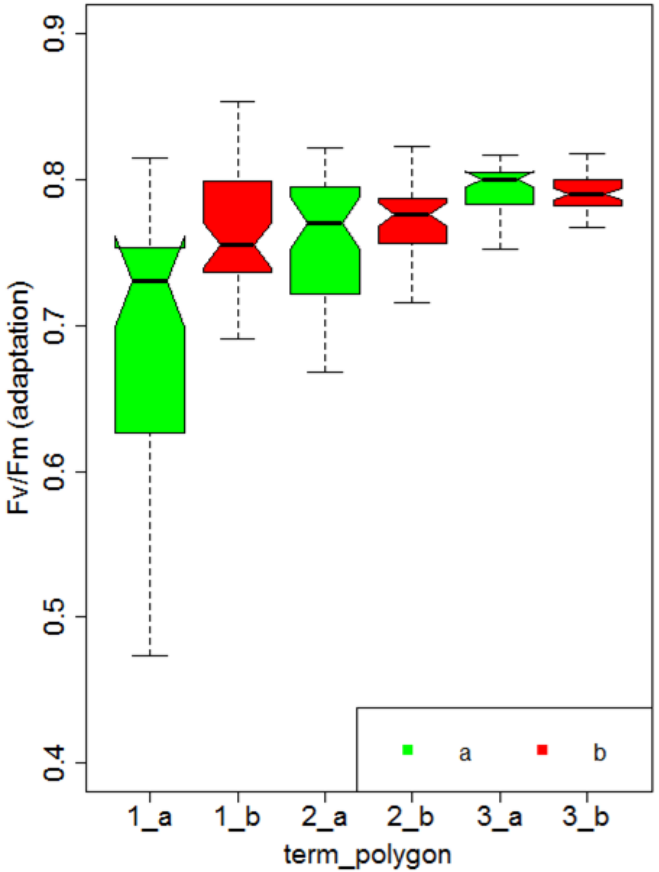


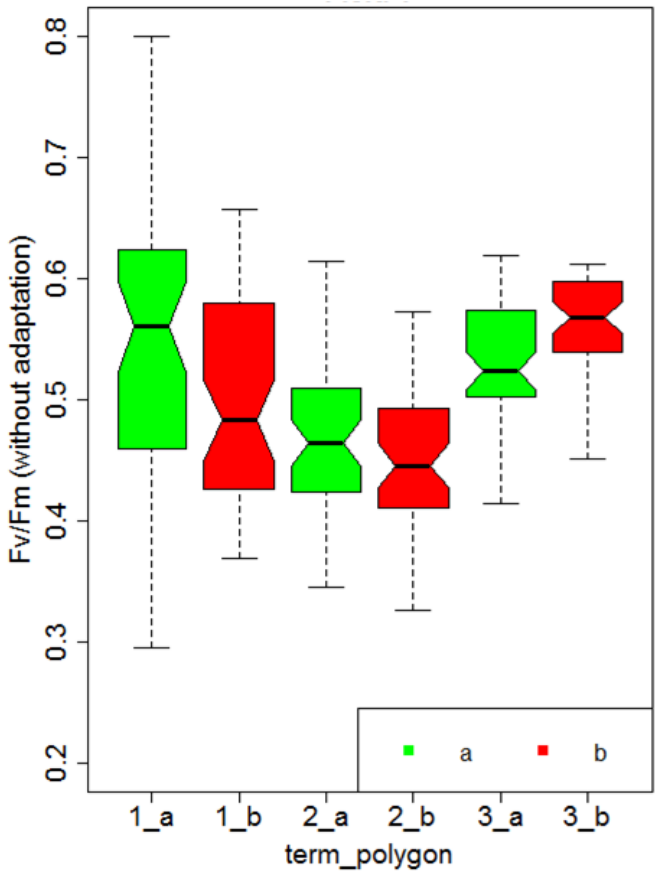
Results: vegetation indices



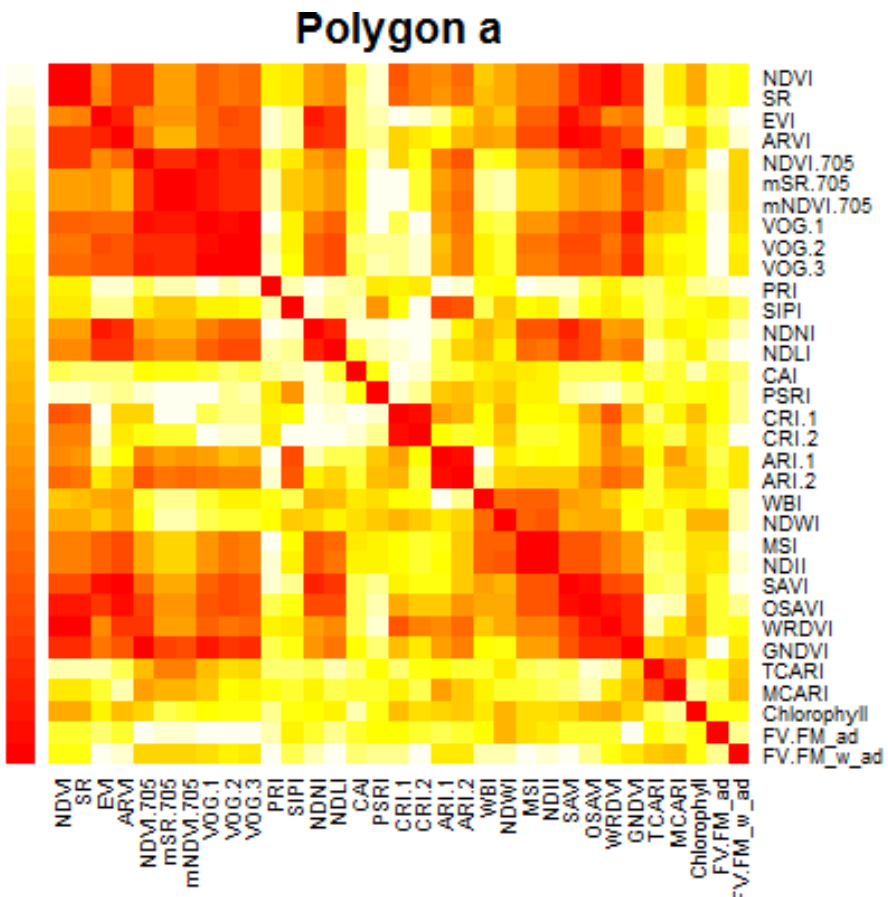


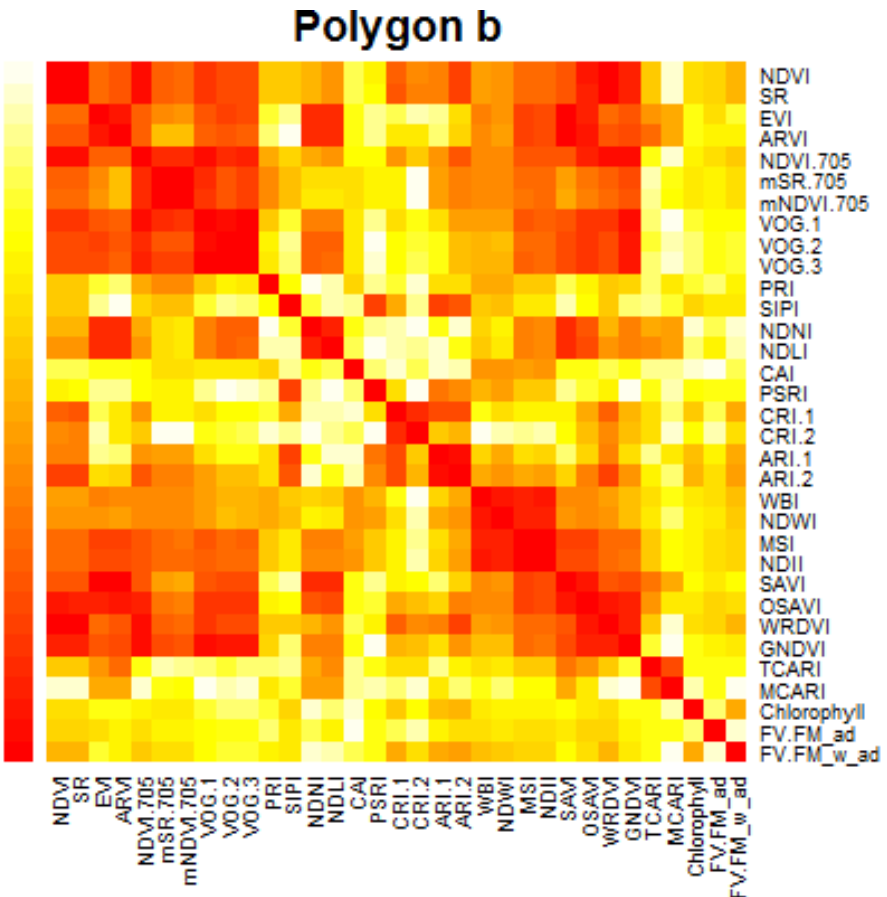
Results: Fluorescence indices



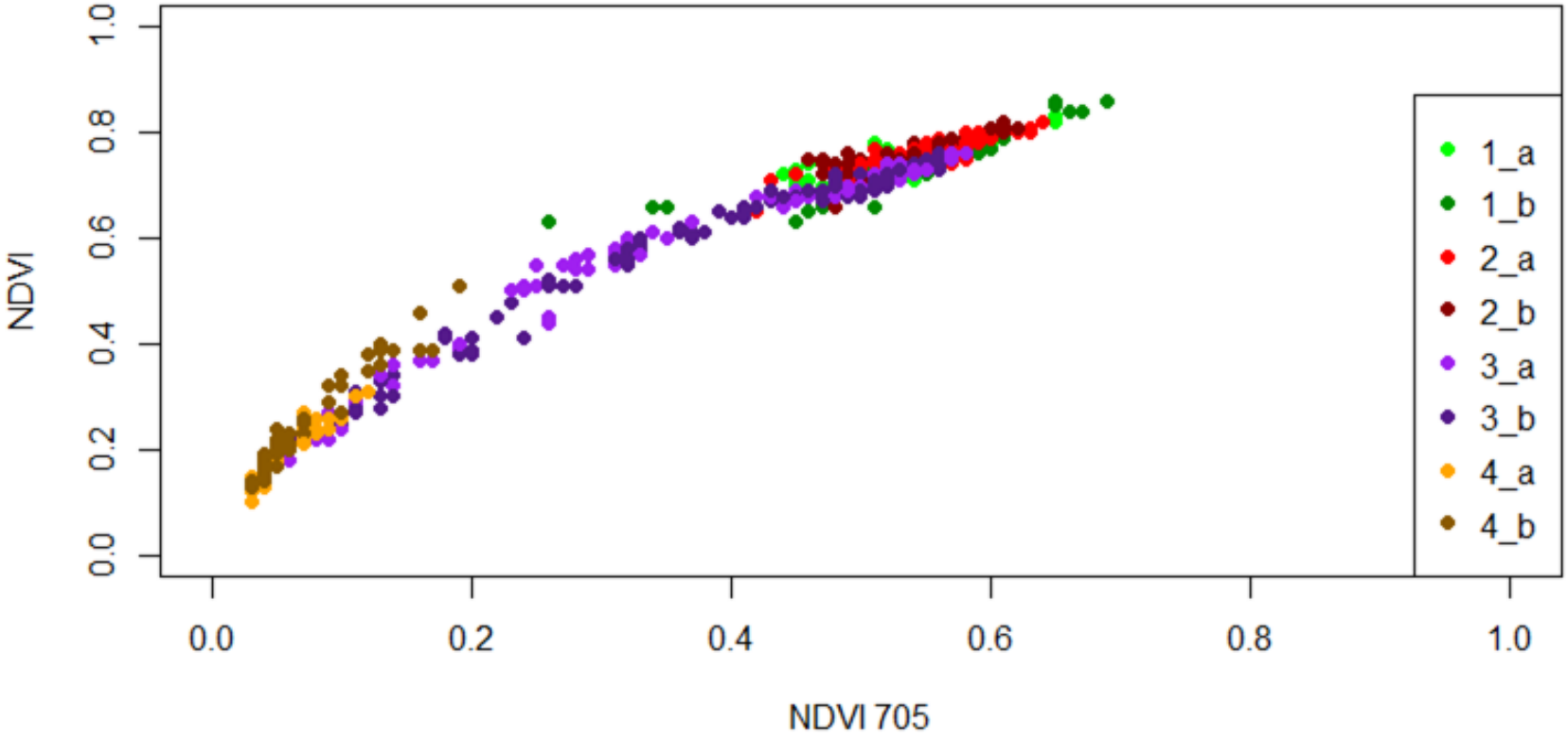


Correlations between tested indices





Correlation between narrow- and broadband indices



Statistical significance of index differences between a, b

	Term 1		Term 2		Term 3		Term 4		average
	a	b	a	b	a	b	a	b	difference %
NDVI	0.74	0.74	0.75	0.75	0.57	0.63	0.16	0.20	7%
ARVI	0.23	0.23	0.33	0.35	0.16	0.18	-0.33	-0.29	9%
NDVI 705	0.53	0.55	0.54	0.54	0.31	0.39	0.04	0.05	12%
mNDVI 705	0.68	0.74	0.67	0.67	0.40	0.48	0.07	0.08	9%
PRI	0.02	0.03	0.01	0.01	-0.04	-0.02	-0.07	-0.08	19%
SIPI	0.99	0.99	1.00	0.99	1.06	1.04	3.29	2.41	10%
CRI 2	4.12	3.77	4.06	3.95	3.06	3.38	2.01	2.40	9%
ARI 2	-0.38	-0.36	-0.23	-0.31	0.27	0.22	0.57	0.66	18%
WBI	1.03	1.03	1.03	1.04	1.03	1.02	1.00	1.01	1%
WRDVI	0.74	0.74	0.75	0.75	0.57	0.63	0.16	0.20	7%
GNDVI	0.60	0.62	0.63	0.62	0.46	0.51	0.28	0.31	7%
TCARI	0.15	0.13	0.15	0.16	0.15	0.14	0.02	0.09	28%
MCARI	0.08	0.07	0.08	0.08	0.08	0.07	0.02	0.04	18%
Chlorophyll	534	541	496	503	598	566	-	-	3%
FV/FM_ad	0.73	0.76	0.77	0.78	0.80	0.79	-	-	2%
FV/FM_w_ad	0.56	0.48	0.46	0.45	0.52	0.57	-	-	9%

* red value (statistical significant $p < 0.05$)

Conclusions

- Ranges showing statistically significant differences between a and b areas in the period considered are:
  - **450-525 nm, 550-710 nm** – amount of photosynthetic active pigments,
  - **750-990 nm** – cell structure,
  - **1400-2500 nm** – water and elements of building material.
- The values of chlorophyll florescence (e.g. without adaptation of leaves to the dark) show significant differences between the a and b range, and the **Fv / Fm index decreased by 2-9%** on average.
- The **18-28%** percentage of changes in the values of the indicators was characterized by the **Modified Chlorophyll Absorption Ratio Index Improved** (MCARI) and **Transformed Chlorophyll Absorption in Reflectance Index** (TCARI), also **PRI (19%)** defining the use of light in the process of photosynthesis and **ARI2 (18%)** defining the content of anthocyanins.

Conclusions

- **In first measurements** period **fungicides have statistically significant impact** on 8 of 30 indices **describing the chlorophyll content and its structure** (NDVI 705, mSR 705, mNDVI 705, VOG 1-3, GNDVI, TCARI, MCARI) and one **cellulose absorption index** (CAI), in all situations better parameters had plants treated by fungicides.
- Data of **2nd measurements** pointed: **1 index oriented on the chlorophyll** (PSRI), **3 indices of protective pigments** (SIPI, ARI 1-2), and **one on the water content in canopy layer** (WBI).
- **3rd measurement period confirmed observations from previous stages**: fungicides play more important role **protecting chlorophyll** and **non-green pigments** (10 indices)
- In case of the last **campaign water, nitrogen content were similar**, rest of indices confirmed influence of fungicides.

Acknowledgements

Research has been carried out under the projects

EIT Food 2018, ID: 18116:

Separating MycOtoxin-contaminated Wheat grains using Precision Farming technologies.

geoinformatics.uw.edu.pl/eit-food-2018

COST action project:

Optical synergies for spatiotemporal SENsing of Scalable ECOphysiological traits (SENESCO).

www.senseco.eu

Thank you very much for your attention