II. ECOMONITORING

SPECTRALLY-BASED APPROACH TO EVALUATING CROP PERFORMANCE UNDER STRESS GROWING CONDITIONS

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Abstract. Recent developments in environmental studies are greatly related to ecological problems arising from anthropogenic impacts on the biosphere and especially on vegetation. The interrelated nature of many environmental issues imposes the necessity to conduct interdisciplinary research and implement different approaches, to integrate the acquired data and share information between different databases. Remote sensing provides advanced monitoring and alerting techniques, timely information extraction, modeling and forecasting possibilities used for solutions of important environmental problems we are confronted with. Such worldwide pressing concerns are natural resources management, ecosystem preservation and biodiversity conservation. Remote sensing technologies make use of land cover spectral features for detecting and assessing changes associated with environmental conditions. In this paper, we investigate and analyze the relationship between growth variables and spectral response of agricultural species under stress growing conditions (heavy metal pollution, nutrient deficiency and soil acidity). Multispectral data obtained from ground-based spectroradiometric measurements are examined in terms of the ability to serve as an indicator of crop performance.

Keywords: remote sensing, spectral characteristics, growth variables, stress detection, nutrient deficiency, heavy metals

INTRODUCTION

The expansion of industrial development and rapid urbanization pose serious ecological problems associated with the increasing anthropogenic pressure on the environment. Destructive processes caused by human activities are in the focus of the scientific research and occupy the attention of social communities and government authorities. Air, water and soil pollution and its negative effects on the biosphere with unfavourable short-term and long-term consequences are a worldwide ecological problem. Industry, agriculture, forestry, and transportation all generate substances and by-products that are considered pollutants and contribute a significant impact on the environmental quality. Contaminated environments are a continuing concern because of the potential risks to natural resources and human health. Ecological monitoring and control are an objective of a great variety of projects, multipurpose programs and interdisciplinary research. In agriculture, abiotic stressors, including different types of pollution, are the most harmful factors concerning species growth and productivity. Heavy metals are among the most dangerous pollutants because of their high toxicity to organisms, persistent nature, high mobility, and long biological half-life. They constitute a group of environmentally hazardous substances whose deposition in soils and easy uptake by species affect soil fertility, plant development and production. In recent time, the desire for food safety and security has stimulated research on the danger associated with the consumption of food contaminated with heavy metals and other toxins. Soil is the primary recipient of these contaminants. Plants take up and absorb them and then they enter the food chain. Plant damage associated with heavy metals is of great concern throughout the world because of their toxic and mutagenic effects even at low concentration. Therefore, particularly great interest has focused on heavy metal-induced stress in plants, its mechanisms of action, consequences, and prevention [1-4].

The interrelated nature of environmental problems has imposed the need of data integration and information sharing between different databases. Advanced monitoring, risk detection and early warning techniques, timely information retrieval, modeling and forecasting possibilities are prepositions for successful data application and decision support in developing policies and strategies dealing with environmental issues. In this respect, remote sensing is an essential tool in ecology-related research. It plays an expanding role in vegetation studies and especially for diagnosis of plant stresses. In agriculture, a primary goal of remote sensing is the assessment of crop development throughout the growing season. Agricultural lands are subjected to enormous pressure and their monitoring and assessment have become an important economic and ecological issue. The spreading acceptance of the concept of precision agriculture running generates much interest in the early detection of crop stress. The implementation of modern remote sensing technologies is one of the basic assumptions of this concept [5, 6]. A lot of attention has been devoted to studying the influence of unfavourable environmental conditions on species performance and the relationship with their spectral behaviour. The impact of stress factors, such as drought, nutrient deficiency and toxic pollution, is described and evaluated from plant spectral response data. Various multispectral features have proven capabilities for crop health assessment and detection of stress situations [7-15].

The interactions between vegetation canopies and incident radiation lie at the root of vegetation remote sensing. Remote sensing of vegetation is based on the analysis of plant reflectance and emittance properties as a function of plant physiology and morphology. Vegetation spectral behaviour depends on plant biophysical and biochemical variables and reveals significant sensitivity to them. Growth variables are defined by plant development processes and health condition. This means that variations of plant performance cause spectral response changes. On the other hand, vegetation health and vigour are an expression of the growing conditions (meteorological, soil properties, agricultural practices) including stress factors (nutrient deficiency, high temperatures, drought, contamination, etc.). As such, knowledge of plant spectral response to different environments is necessary to interpret remote sensing data and extract the information content of spectral data. The information is carried by the specifics of vegetation spectral characteristics which depend on biomass amount, leaf area, canopy cover, chlorophyll content, and etc. The relation “growing conditions - plant state - spectral features” determines the informational potential of multispectral data and provides grounds for vegetation stress detection.

In view of all this, our paper studies various features of plant spectral response to crop performance and growing conditions. We use multispectral data in the visible and near infrared wavelength range to and describe plant canopies. Growth variables are associated with the phenological development and related to crop state and growing conditions. Spectral variables are used to characterize crop performance under different conditions. The paper is devoted particularly to studying the impact of heavy metal contamination and the role of the soil type and nitrogen fertilization on agricultural species. The main goal is to examine the ability of spectral signatures to serve as sustainable stress indicators. Stress factors and their effects on crop performance (growth and productivity) are related to plant spectral response in a statistical manner. The derived empirical relationships allow not only stress detection from plant spectral data but also stress monitoring during plant development period and quantitative assessment of stress-induced growth changes.

MATERIALS AND METHODS

The paper presents some results of an extended study on the impact of stresses on crop performance and spectral behaviour. The research comprised greenhouse and laboratory experiments. Spring barley, peas and alfalfa were cultivated under different conditions and controlled combinations of factors. The pot trials included spring barley grown on neutral (pH=7.0-7.5) chernozem soil and acid (pH=5.0-5.5) grey forest soil. These soils were chosen for their different properties and response to heavy metal pollution. The soils were contaminated with Ni in concentrations 0 (control), 100, 200, 300 and 400 mg/kg. In addition, different nitrogen fertilizers were applied to treatments with equal 200 mg/kg Ni concentrations. Calcium nitrate $Ca(NO_3)_2$, ammonium nitrate NH_4NO_3 and potassium nitrate KNO_3 were used in amounts to provide equal N supply. The effects and interactions of the three factors: Ni, soil pH and N-form, were examined as conditions influencing crop performance. The trials were grown from seeding to harvest. Peas and alfalfa were grown in greenhouse conditions on the same soil types. The stress factor applied was Cd-contamination of the soil in concentrations 0, 5, 10, 20 and 30 mg/kg. The experimental design included also spring barley fertilization treatments with varying nitrogen supply rates (0, 200, 400, 600, 800 and 1000 mg/kg) of ammonium sulphate $(NH_4)_2SO_4$. The greenhouse trials were conducted in 3-5 replications. A second set of experiments comprised peas hydroponically grown in different media (water and green algae supernatant) and subjected to Cd contamination in concentrations 0, 5, 10, 20 and 30 mg/l. The heavy metal was introduced through $CdCl_2 \cdot 2.5H_2O$. These treatments were replicated twice. The variety of growing conditions and their interactive effects ensured a wide range of plant performance and physiological status thus causing considerable variations of the spectral behaviour of the trials.

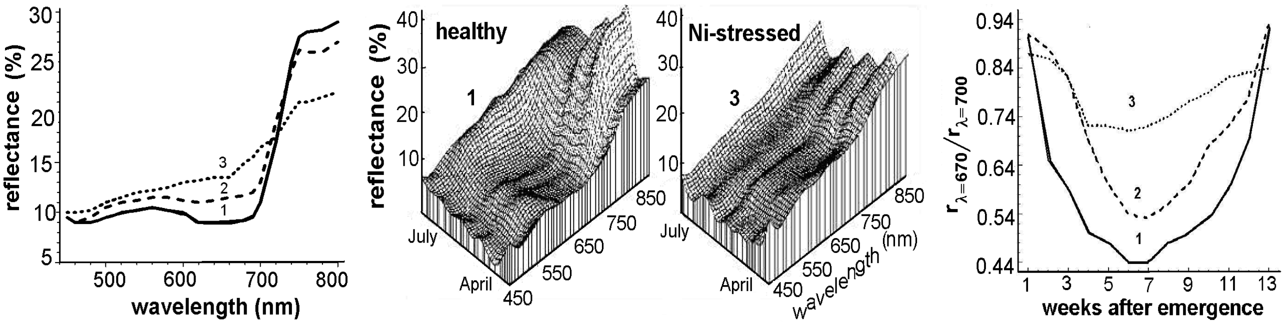
Reflectance, biometric and phenological data were collected on the greenhouse treatments throughout the entire growing season from emergence to full maturity for barley and to second harvest for alfalfa plots. Visible (VIS) and near infrared (NIR) multispectral measurements were carried out in the wavelength range 400-820 nm. Reflectance measurements were conducted at canopy level at weekly intervals. Crop performance under varying conditions was characterized by key growth variables (biomass, canopy cover fraction, height, pigment content) and yield (alfalfa biomass after harvest and barley grain production). The datasets were statistically analyzed to assess and describe the variations in plant development as a function of environmental conditions (heavy metal contamination, soil properties and nutrient deficiency). Multispectral reflectance data acquired during plant development were linked to plant variables and stress factors and examined for the ability to detect and quantify stress-induced changes in plants. Plant spectral response was examined for its sensitivity to crop performance (growth variables and productivity) and the stress level. Analysis of variance was conducted to determine the statistical significance of the differences between the samples (between replications and between different treatments). The analysis of variance allowed also to reveal the individual and interactive effects of the applied factors. Correlation analysis of the datasets was performed in order to determine the presence and strength of the relation between plant spectral and biophysical characteristics as well as to reveal the dependence of these variables on the growing conditions. Through regression analysis conducted on phenology-specific basis, i.e. at different phenological stages, empirical relationships were derived describing plant spectral and physiological response to the applied factors, Spectral models of plant performance were established quantifying the stress impact.

Remote sensing techniques make use of multispectral data to estimate plant biophysical and biochemical characteristics which are factors effecting plant canopy reflectance. Spectral variations carry information about plant growth and health condition, and the goal of data analysis is to extract this information. A common technique for multispectral data processing is the use of spectral transforms called vegetation indices (VIs). They are calculated as various combinations [7, 8, 10, 16-19] of the measured spectral reflectance factors r_λ and are defined usually as different ratios at two or more wavelengths λ, as for instance, $r_{\lambda i}/r_{\lambda j}$, $(r_{\lambda i}-r_{\lambda j})/r_{\lambda i}$, $r_{\lambda i}/r_{\lambda i}+r_{\lambda j}+r_{\lambda \kappa})$, weighted sums $ar_{\lambda i}+br_{\lambda j}+cr_{\lambda \kappa}$ or normalized differences $(r_{\lambda i}-r_{\lambda j})/(r_{\lambda i}+r_{\lambda j})$. The wavelengths correspond to specific absorption and high reflectance regions of vegetation spectrum in the green (G - 550 nm), red (R - 670 nm) and near infrared (NIR - 800 nm) range, or are located within the R-NIR interval (680-780 nm) where the reflection increases steeply. Various spectral indicators were used in our study to characterize crop performance under different conditions.

RESULTS AND DISCUSSION

In our study we examined a big number of vegetation indices for their correlation with plant variables and the applied stress factors. Various ratio combinations in different reflectance bands were calculated from the acquired multispectral data. Regression analysis was run on those indices which showed the best correlation with plant growth attributes and stress factors, the obtained empirical regressions being significant at 95% level of confidence. Special attention was paid to temporal aspects of plant spectral properties throughout the growing period. Statistical relationships were established also between the stress level and plant spectral and biophysical response, thus attaching a quantitative measure to the stress impact on crops. A comparison was made of the evaluated stress degree from growth and spectral data. The comparison demonstrated a very good agreement between the estimates from stress bioindicators (reduced canopy cover fraction and biomass, lower yield) and from spectral indicators (vegetation indices).

In this section we illustrate the performance of some vegetation indices for assessing plant condition and detecting nutrient and heavy metal-induced stress. Significant variations of crop biological and spectral performance were observed associated with the heavy metal impact. These variations were more pronounced and statistically meaningful for the trials on grey forest soil. The spectral reflectance characteristics of spring barley Ni-treatments at stem elongation stage plotted in Figure 1a provide evidence for considerable reflectance differences between control and stressed plants as well as for the reflectance variations due to the stress level. The contamination impact on plant spectral response was observed throughout the entire growing season. This can be seen in Figure 1b which presents the reflectance characteristics during the growing period of control barley plants and treatments polluted with 400 mg/kg Ni concentration in the soil. Crop monitoring over time is one of the important aspects of remote sensing for tracking the growth process and early detection of stress situations. Multitemporal data gathered throughout plant development or selected portions of it appeared to be very useful in crop condition assessment and yield prediction. The temporal behaviour of the spectral ratio $r_{\lambda=670}/r_{\lambda=700}$ shown in Figure 1c is highly indicative of stress in barley plants already at early growth stages. Differences of the index values (treatments 2 and 3 compared to the control 1) are associated as well with the degree of the stress impact (treatment 3 with higher Ni concentration is more depressed than treatment 2). This technique is able to detect stress responses and discriminate between the stress degree at early stages of plant phenological development.



a) b) c)

Fig. 1 Spectral reflectance characteristics of spring barley on grey forest soil at stem elongation stage (a) and throughout the growing season (b): 1- control, 2, 3 - treatments with Ni concentration in the soil 200 mg/kg and 400 mg/kg; temporal behaviour of the vegetation index $r_{\lambda=670}/r_{\lambda=700}$ of the trials

In the heavy metal treatments, significant worsening of plant performance was observed, especially of the trials on grey forest soil. Stress induced by heavy metals manifested itself in plant growth depression and resulted in reduced biophysical parameters. Ni and Cd inhibited also chlorophyll synthesis and accelerated carotenoid accumulation. Stress-induced changes of growth variables effected in turn plant reflectance features and a consequence of plant depression were variations of canopy spectral response. Strong correlations were found between spectral indicators and plant attributes. In Table 1 the correlation coefficients of different vegetation indices with peas growth variables and Cd concentration are given. One more evidence of the high correlation between spectral indices and stress factors is Table 2 which presents the established coefficients of correlation between various Vis and Cd concentration in the grey forest soil for alfalfa at different phenology stages. As it can be seen, the stress effect became stronger with time (and higher the correlation) which is explained with the longer action of the heavy metal.

Table 1 Correlation between vegetation indices and growth variables of Cd-polluted pea plants

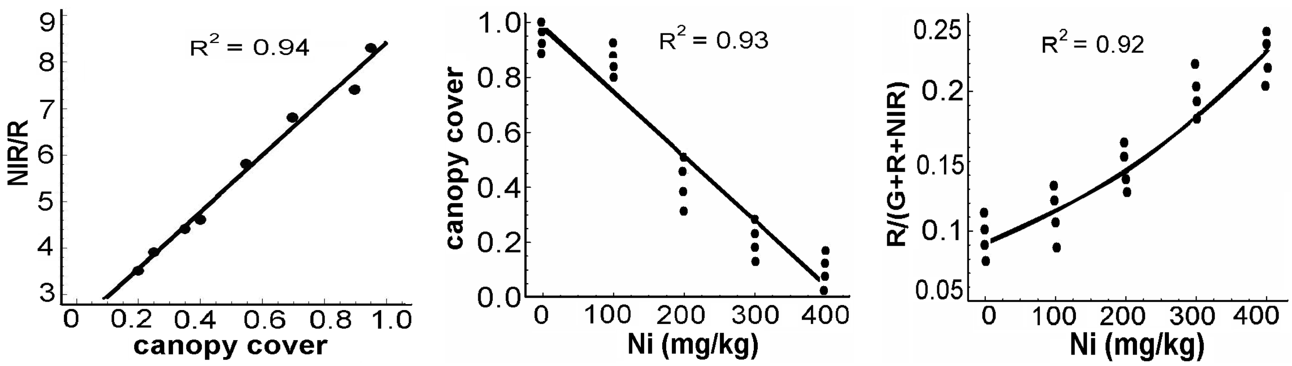
VI	Height	Biomass	Cover	Cd
$(r_{820}-r_{670})/(r_{820}+r_{670})$	0.88	0.86	0.97	−0.97
r_{820}/r_{670}	0.93	0.92	0.99	−0.97
$(r_{820}-r_{550})/(r_{820}+r_{550})$	0.75	0.75	0.93	−0.96
r_{820}/r_{550}	0.77	0.76	0.94	−0.97
$(r_{550}-r_{670})/(r_{550}+r_{670})$	0.96	0.96	0.97	−0.93
r_{550}/r_{670}	0.97	0.98	0.96	−0.91
$r_{820}.(r_{550}-r_{670})/(r_{550}+r_{670})$	0.89	0.90	0.98	−0.95
$r_{670}/(r_{550}-r_{670})$	−0.90	−0.90	−0.96	0.94
$r_{670}/(r_{550}+r_{820})$	−0.86	−0.86	−0.97	0.97
$r_{550}/(r_{670}+r_{820})$	−0.71	−0.71	−0.91	0.95
$(r_{670}.r_{670})/(r_{620}.r_{720})$	−0.90	−0.89	−0.98	0.97
$\sqrt{(r_{550}.r_{550})+(r_{820}.r_{820})}$	0.50	0.50	0.75	−0.77

The contamination impact on crop growth variables and reflectance features was quantitatively described by regression analysis. Notable differences in vegetation reflectance, especially in the infrared portion of the spectrum, were attributed to green canopy fraction. This growth variable is a factor of vegetation spectral reflectance and, on the other hand, is closely related to other plant characteristics such as (biomass, leaf area index, density, etc.) being indicative of crop development. Canopy reflectance signatures considerably varied with the amount of soil exposed, i.e. with canopy fraction.

Table 2 Correlation between Cd concentration in the grey forest soil and vegetation indices of alfalfa at different phenological stages: real leaf (1), rosette (2), button forming (3), and before flowering (4)

VI	1	2	3	4
$(r_{800}-r_{670})/(r_{800}+r_{670})$	-0.69	-0.74	-0.83	-0.91
$(r_{550}-r_{670})/(r_{550}+r_{670})$	-0.67	-0.79	-0.83	-0.9
r_{710}/r_{670}	-0.69	-0.74	-0.81	-0.88
$(r_{800}-r_{670})/r_{800}$	-0.68	-0.73	-0.83	-0.89
$(r_{550}-r_{670})/r_{550}$	-0.68	-0.79	-0.84	-0.89
$(r_{720}-r_{700})/r_{720}$	-0.81	-0.78	-0.85	-0.92
$(r_{720}-r_{670})/r_{720}$	-0.74	-0.79	-0.81	-0.87
$r_{670}/(r_{800}+r_{550})$	0.71	0.75	0.84	0.9
$r_{550}/(r_{650}+r_{670})$	-0.68	0.77	0.83	-0.91
$r_{670}/(r_{800}+r_{670}+r_{550})$	0.71	0.75	0.84	0.91
$r_{800}/(r_{670}+r_{680}+r_{690}+r_{700}+r_{710}+r_{720})$	-0.67	-0.79	-0.85	-0.9
$\sqrt{(r_{800}-r_{670})/(r_{800}+r_{670})+0.5}$	-0.68	-0.78	-0.83	-0.9

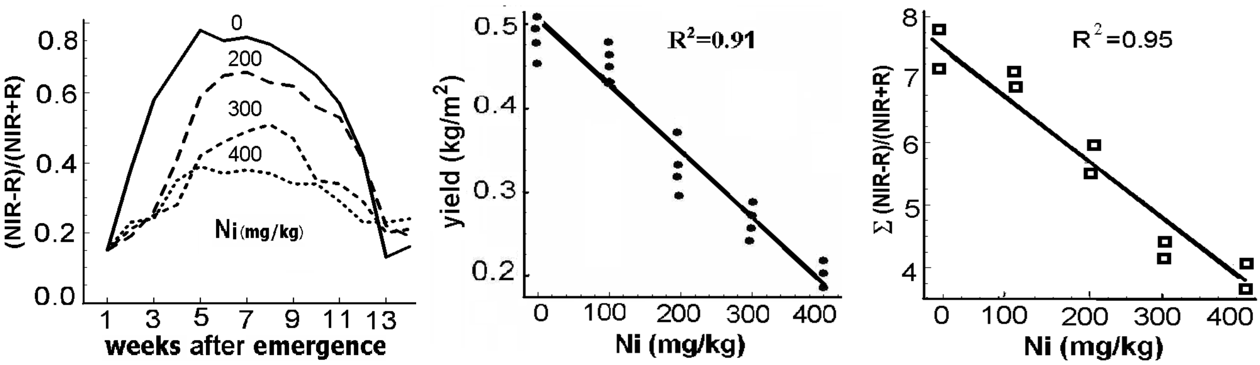
The derived dependence of the vegetation index NIR/R ($r_{\lambda=800}/r_{\lambda=670}$) on the canopy cover of spring barley Ni-treatments is shown in Figure 2a. In Figure 2b and 2c the obtained empirical relationships of barley fractional cover and R/(G+R+NIR) vegetation index on Ni concentration in the grey forest soil are plotted. Ni impact resulted in decreased vegetation fraction and considerable spectral reflectance changes. It is worth mentioning that the treatments with 300 mg/kg Ni concentration were first excluded from the regression fits and used later as a validation dataset proving the good consistency and prediction accuracy of the models.



a) b) c)

Fig. 2 Dependence of NIR/R vegetation index on barley cover fraction (a); dependence of spring barley fractional cover (b) and R/(G+R+NIR) vegetation index (c) on Ni concentration in the grey forest soil

Seasonal changes are a distinguishing feature of species biophysical and spectral properties. In agricultural monitoring, remote sensing time series data are a source of valuable information about the growth process. This determines the importance of studying the relationships between crop variables and spectral response at different stages of plant development. The temporal behaviour of spectral indices represents a typical canopy expansion and senescence curve and proves useful for crop growth assessment by tracking the onset and duration of phenological events. Crop stress detection from multitemporal data is based on the temporal trends and characteristics of vegetation index temporal curves (amplitude, minimum and maximum values, integrated area under the curve, slopes, and so on). The impact of Ni contamination on the seasonal behaviour of the (NIR-R)/(NIR+R) index of spring barley on grey soil is shown in Figure 3a. The temporal profiles considerably differed during the vegetative period. They denoted differences of crop performance and detected differences of plant condition related to the occurrence of stress. Temporal spectral patterns were indicative not only of plant depression but also of the stress level. The important point is that stresses were observed throughout the whole growing season and could be already detected at early stages of the phonological development.

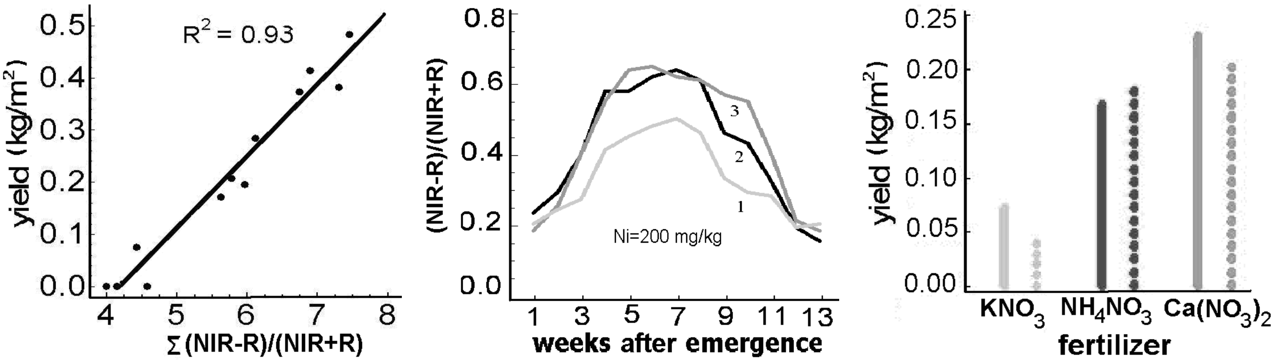


a) b) c)

Fig. 3 Dependence of the temporal behavior of barley (NIR-R)/(NIR+R) spectral index (a), grain yield (b) and accumulated sum of the index during the growing season (c) on Ni concentration in the grey forest soil

As far as crop production is a question of primary interest, species yield was examined for its relationship with the applied factors. Plant growth was adversely affected by the heavy metal contamination and this impact reflected in reduced yield. This is illustrated by Figure 3b where the negative dependence of barley grain yield on Ni concentration in the grey soil is plotted. In Figure 3c the link between Ni contamination level and spectral data acquired during the growing season is shown. Seasonally-integrated sums ΣVI_t of various vegetation indices were associated with crop stress response and related to yield. Figure 4a presents the close positive relationship and good regression fit of barley grain yield on the temporal sum of (NIR-R)/(NIR+R) spectral index. In Figure 4b an example of yield prediction applying this model is shown. Using the temporal sum of the spectral index and the obtained regression equation, the grain yield from three barley treatments was estimated. The nitrogen fertilizer type effected plant spectral behaviour, while the other factors (soil type, contamination, nitrogen amount) were constant. Good correspondence was found between actual (measured) and modeled (estimated) yield values, the maximum relative error being about 12%. Yield prediction models with high accuray were developed also for half-season VI sums and VI values at single growth stages. Temporal spectroradiometric data distinctly tracked plant ontogenetic changes and were able at the same time to discriminate between plant health condition. This explained the fact that accumulated VIs values during growth were found to be very closely related to crop yield. An advantage of using multitemporal predictions is that they account for any unfavorable effects on species development that exist or might occur during the growing season, and thus can serve as a type of “dynamic” predictors.

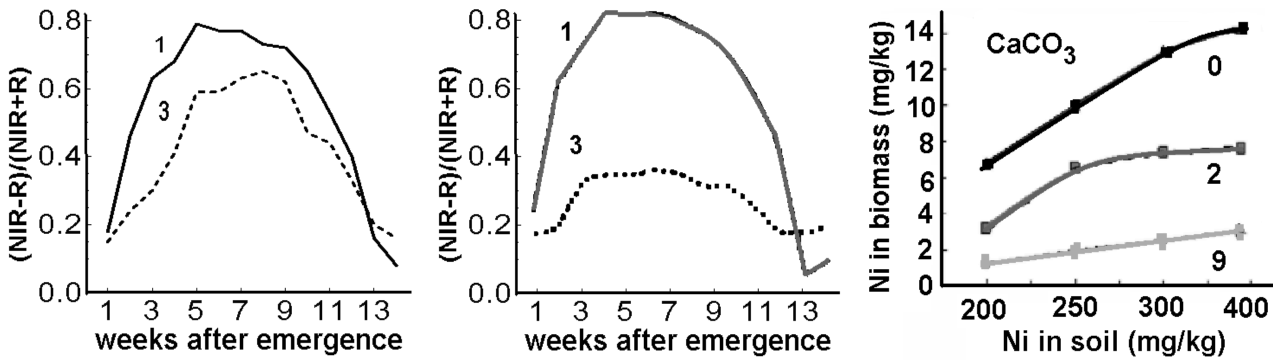
Soil properties were another factor effecting plant performance, especially in combination with other growing conditions. Neutral chernozem and acid grey forest soils exhibited different behaviour to heavy metals whose mobility and uptake by plants increased with higher soil acidity. The influence of the soil type was statistically significant and manifested in reduced heavy metal impact on crop growth in the case of chernozem soil trials and stronger stress impact on the acid soil treatments. There were not big yield differences between the control non-polluted treatments grown on both soils, the grain yield of the chernozem plots being about 10% higher. The polluted spring barley and alfalfa treatments grown on chernozem were less affected by the heavy metal than those on the grey forest soil.



a) b) c)

Fig. 4 Relationship between barley grain yield and (NIR-R)/(NIR+R) whole-season sum (a); actual (—) and predicted (---) from the regression model barley yield of equally Ni-contaminated (200 mg/kg) treatments with different fertilizers applied (b)

As a consequence, much smaller variations of plant spectral response to contamination of the chernozem soil were observed. This is clearly illustrated by Fig. 5a and 5b. They show (NIR-R)/(NIR+R) seasonal profiles of control and equally Ni-polluted spring barley treatments grown respectively on chernozem and grey soil. On the contrary, considerable spectral variations were observed for treatments on grey forest soil in relation to Ni concentrations (see also Figure 3a). The acidity of the soil in this case increased the mobility and accessibility of heavy metals to plants thus stronger inhibiting their growth. Application of $CaCO_3$ to acid soil treatments reduced the heavy metal uptake (Figure 5c) and improved plant performance.

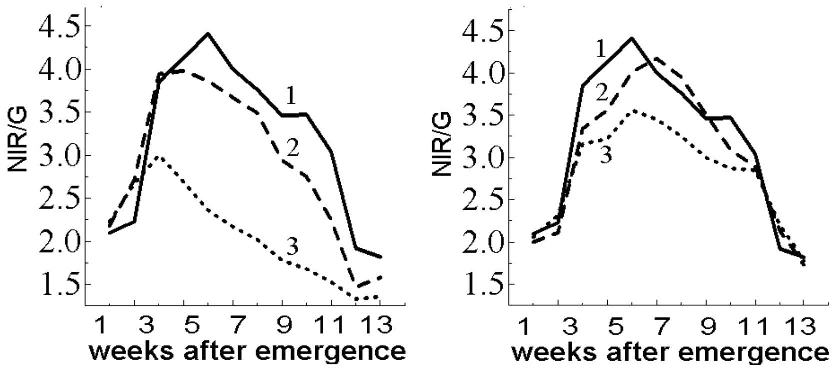


a) b) c)

Fig. 5 (NIR-R)/(NIR+R) seasonal profiles of control (1) and 400 mg/kg Ni-polluted (3) spring barley treatments on neutral chernozem (a) and acid grey forest (b) soil; Ni uptake by barley plants on acid grey forest soil as depending on the contamination level and the amount of $CaCO_3$ application (c)

Nutrient supply was another factor detected by measurements of plant reflectance response. Figure 6a shows the impact of nitrogen concentration in leached chernozem soil on NIR/G temporal profiles of barley fertilization treatments. As evident from the plot, nutrient deficiency was clearly manifested and observed from multispectral data. Differences in crop reflectance were observed also in relation to the fertilizer form regardless of the equal nitrogen amount as illustrated in Figure 6b which presents the variance of NIR/G temporal behavior of barley trials with equal nitrogen concentration introduced through different fertilizers. Spectral reflectance was a reliable sign and measure of plant growth performance.

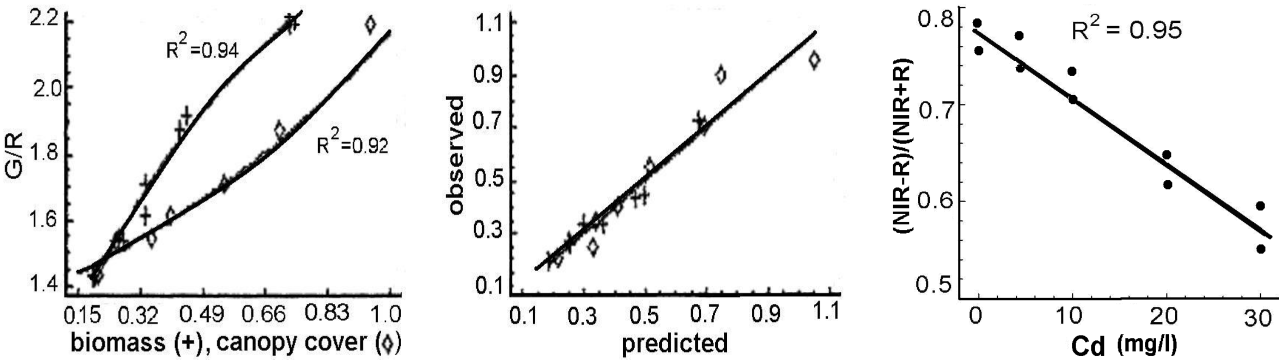
Close relationships were established between Cd contamination, biomass, canopy cover, height, pigments and various vegetation indices of hydroponically grown plants. Cd treatments demonstrated growth inhibition, the biomass and canopy cover fraction being reduces and the leaves being developed worse and suffering quick senescence.



a) b)

Fig. 6 Temporal behaviour of NIR/G spectral index of spring barley treatments with different nitrogen concentration: 1 - 800 mg/kg, 2 - 200 mg/kg, 3 - 0 mg/kg) introduced through the same fertilizer $(NH_4)_2SO_4$ (a); and with equal nitrogen concentration (800 mg/kg) introduced through different fertilizers (b): 1 - $(NH_4)_2SO_4$, 2 - NH_4NO_3, 3 - KNO_3

The toxic effect of the heavy metal was less severe in supernatant-grown plants. In all cases, however, pronounced dependence of growth variables on the contamination concentration was observed. Plant spectral response resembled plant condition as can be seen in Figure 7a where the values of G/R spectral index are plotted against canopy cover and biomass (both treatment groups included). The strong correlation makes the use of spectral models a reliable approach for plant performance assessment. Fig. 7b shows the respective good correspondence between the actual and spectrally estimated plant variables.



a) b) c)

Fig. 7 Dependence of G/R vegetation index on biomass and canopy cover of hydroponic Cd treated pea plants (a) and correspondence between the actual and spectrally estimated plant variables (b); dependence of (NIR-R)/(NIR+R) index on Cd concentration

CONCLUSIONS

The obtained results indicate that growing conditions cause statistically significant variations of plant spectral response associated with the sensitivity of the reflectance properties to crop growth characteristics. Various spectral features (vegetation indices) are highly correlated with stress impacts resulting in our study from heavy metal contamination and nutrient deficiency. Multispectral and multitemporal data proves applicable for reliable diagnosis of plants and detection of stress symptoms. Growth depression expressed in variations of plant performance is successfully evaluated from spectral measurements. The derived empirical dependences of biophysical and spectral variables on factors effecting growth attach a quantitative measure to plant condition assessment.

They permitted not only to discriminate between depressed and healthy canopies but also to quantitatively describe negative impacts and assess the degree of stress. These findings highlight a promising strategy for applying remote sensing techniques and spectrally-based approaches to characterize dynamic and environmentally sensitive aspects of species physiological development.

References

1. Rodrıguez-Serrano M., M. C. Romero-Puertas, D. M. Pazmino, P. S. Testillano, M. C. Risueno, L. A. del Rıo, L. M. Sandalio, Cellular Response of Pea Plants to Cadmium Toxicity: Cross Talk between Reactive Oxygen Species, Nitric Oxide, and Calcium. Plant Physiology, Vol. 150, 2009, 229–243.

2. Bavi K., B. Kholdebarin, A. Morad, Effect of cadmium on growth, protein content and peroxidase activity in pea plants, Pak. J. Bot., Vol. 43(3), 2011, 1467-1470.

3. Sobukola P., O. M. Adeniran, A. A. Odedairo, O. E. Kajihausa, Heavy metal levels of some fruits and leafy vegetables from selected markets in Lagos, Nigeria African Journal of Food Science, Vol. 4(2), 2010, 389-393.

4. Abii T.A., Levels of Heavy Metals Cr, Pb, Cd Available for plants within abandoned mechanic workshops in Umuahia Metropolis, Research Journal of Chemical Sciences, Vol. 2 (2), 2012, 79-82.

5. Seelan S. K., S. Laguette, G. M. Casady, G. A. Seielstad, Remote sensing applications for precision agriculture: A learning community approach, Remote Sensing of Environment, Vol. 88 (1-2), 2003, 157-169.

6. Liaghat S., S. Balasundram, A review: The role of remote sensing in precision agriculture, American Journal of Agricultural and Biological Sciences, Vol. 5 (1), 2010, 50-55.

7. Carter G. A., W. G. Cibula, R. L. Miller, Narrow-band reflectance imagery compared with thermal imagery for early detection of plant stress, Journal of Plant Physiology, Vol. 148, 1996, 515–522.

8. Penuelas J., J. Gamon, A. Fredeen, J. MerIno, C. Field, Reflectance indices associated with physiological changes in nitrogen- and water-limited sunflower leaves, Remote Sensing of Environment, Vol. 48, 1994, 135-146.

9. Filella I., J. Penuelas, L. Llorens, M. Estiarte, Reflectance assessment of seasonal and annual changes in biomass and CO_2 uptake of a Mediterranean shrubland submitted to experimental warming and drought, Remote Sensing of Environment, Vol. 90, 2004. 308–318.

10. Kancheva R., D. Borisova, Vegetation stress indicators derived from multispectral and multitemporal data, Space Technology, Vol. 26 (3), 2007, 1–8.

11. Kancheva, R., I. Iliev, D. Borisova, S. Chankova, V. Kapchina, Detection of plant physiological stress using spectral data, Ecological Engineering and Environment Protection, Vol. 1, 2005, 4-9.

12. Baret F., V. Houle, M. Guerrif, Quantification of plant stress using remote sensing observations and crop models: the case of nitrogen management. Journal of Experimental Botany, Vol. 58(4), 2007, 869–880.

13. Franke J., G. Menz, Multi-temporal wheat disease detection by multi-spectral remote sensing, Precision Agriculture, Vol. 8(3), 2007, 161-172.

14. Serrano L., I. Filella, J. Penuelas, Remote sensing of biomass and yield of winter wheat under different nitrogen supplies, Crop Sci., Vol. 40, 2000, 723–731.

15. Falkenberg N.R., G. Piccinni, J. T. Cothren, D. I. Leskovar, C. M. Rush, Remote sensing of biotic and abiotic stress for irrigation management of cotton, Agricultural water management, Vol. 87, 2007, 23–31.

16. Osório J., M. Osório, A. Romano, Reflectance indices as non-destructive indicators of the physiological status of Ceratonia siliqua seedlings under varying moisture and temperature regimes, Functional Plant Biology, Vol. 39, 2012, 588–597.

17. Hatfield J.L. J. H. Prueger, Value of using different vegetative indices to quantify agricultural crop characteristics at different growth stages under varying management practices, Remote Sensing, Vol. 2, 2010, 562-578.

18. Broge N. H., E. Leblanc, Comparing prediction power and stability of broadband and hyperspectral vegetation indices for estimation of green leaf area index and canopy chlorophyll density, Remote Sensing of Environment, Vol. 76, 2000, 156-172.

19. Glenn E., A. Huete, P. Nagler, S. Nelson, Relationship between remotely-sensed vegetation indices, canopy attributes and plant physiological processes: What vegetation indices can and cannot tell us about the landscape, Sensors, Vol. 8, 2008, 2136-2160.

СПЕКТРАЛЕН ПОДХОД ЗА ОЦЕНКА НА ЗЕМЕДЕЛСКА РАСТИТЕЛНОСТ ПРИ СТРЕСОВИ УСЛОВИЯ НА ОТГЛЕЖДАНЕ

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Резюме. Съвременните насоки в изучаването на околната среда са до голяма степен свързани с глобални екологични проблеми, произтичащи от антропогенното въздействие върху биосферата и преди всичко върху растителността. Взаимосвързаният характер на повечето екологични проблеми налага необходимостта от осъществяване на междудисциплинарни изследвания и приложение на различни подходи, обмен на информация и съвместяване на данни от различни източници. Съвременните дистанционни технологии за наблюдение и ранно предупреждение, навременно извличане на информация и използването й за моделиране и прогнозиране са предпоставка за вземане на решения по належащи екологични въпроси. Такива значими въпроси са управлението на природните ресурси, опазването на екосистемите и съхранение на биоразнообразието. Дистанционните изследвания използват спектрални характеристики на обектите за оценка на тяхното състояние и изменение под влиянието на фактори от околната среда. В настоящата работа се разглежда използването на различни спектрални признаци за оценка на състоянието на земеделски култури при стресови условия на отглеждане. Изведени са регресионни модели, свързващи растежните параметри със спектрални индикатори на състоянието. Анализирана е възможността на спектрометричните данни за количествена оценка на стресовото влияние на хранителния дефицит и замърсяването с тежки метали.

Ключови думи: дистанционни изследвания, спектрални характеристики, вегетационни индекси, растежни параметри, стрес, тежки метали, хранителен дефицит

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