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ECOLOGY-RELATED SPECTROMETRIC STUDIES OF AGRICULTURAL CROPS

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ЕКОЛОГИЧНО НАСОЧЕНИ СПЕКТРОМЕТРИЧНИ ИЗСЛЕДВАНИЯ НА ЗЕМЕДЕЛСКИ ПОСЕВИ

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Ключови думи: *спектрални отражателни характеристики, земеделски посеви, вегетационни индекси, стресови фактори, тежки метали, изкуствено наторяване, хранителен дефицит*

Резюме: *Екологичните рискове и деструктивните процеси, причинявани от човешката активност, са във фокуса на научните изследвания, които имат отношение към общосветовни екологични проблеми, свързани с антропогенното влияние върху околната среда и преди всичко върху биосферата. Съвременните технологии за мониторинг, получаване на навременна информация, моделиране и прогнозиране са предпоставка за успешно приложение на данните от наблюденията за целите на опазване на природната среда. Взаимосвързаният характер на повечето екологични проблеми налага осъществяването на многоцелеви програми и съвместното използване на информация от различни източници. Дистанционните изследвания широко се използват за управление на природните ресурси, за следене на изменения в екосистемите и не на последно чясто за оценка на състоянието на земеделски посеви, Настоящата работа се фокусира върху обработката на данни от многоспектрални измервания, анализирайки спектралните характеристики на земеделски култури като отговор на стресови фактори. Такива фактори в нашето изследване са хранителния дефицит, замърсяването на почвата с тежки метали, както и почвените свойства. Представени са резултати от емпирично регресионно моделиране, свързващи характеристики на спектралното отражение на растенията с биопоказатели за тяхното състояние и със стресовите фактори.*

Introduction

The spreading acceptance of the concept of precision agriculture running [1,5] generates much interest in the early detection of plant growth stress. The implementation of modern remote sensing technologies is one of the basic assumptions of this concept. Remote sensing has been recognized as a powerful tool in vegetation studies for natural resources management, land cover monitoring, ecosystem preservation and other significant problems. Special attention is being paid to vegetation monitoring in relation to change detection [6]. Agricultural observations supply information on crop growth processes and stress situations [2-4,7,8]. The assessment of crop growth conditions from spectral data has been and still is the focus of numerous investigations and experimental studies [2-4,6]. Their goal is to further develop and precise the up-to-now investigation results and bring them to an operational use. This requires advanced data processing technologies, development of models for assessment of impacts on agriculture and implementation of monitoring systems that consider variousl factors influencing crop growth. Efficientl methodologies to monitor crop vigor, diseases, and stresses are needed as well as improved analytical techniques to evaluate biological and physical processes.

Interest is rapidly spreading over the past years in the application of hyperspectral data for retrieving plant agronomic variables and yield predicting. Two issues are of essential importance for the application of airborne and satellite data: development of efficient algorithms for data analysis and explicit information about land covers spectral behavior under different conditions, both associated with a higher reliability of the derived information. In this context detailed ground-based spectrometric studies [3,7] complement the array of geo-spatial data products providing information on crop spectral behaviour under different environmental conditions and considering regional and local peculiarities. Being the most vital and anthropogenic-affected component of the biosphere, the vegetation has a leading position among the priorities of remote sensing observations applied for assessment of plant development and stress detection.

The goal of the paper is to examine the impact of soil properties and anthropogenic factors on crop development and spectral behaviour and to quantitatively describe the relationships between growing conditions, crop spectral reflectance and plant variables. Such relationships serve for crop state evaluation and stress assessment. Crops have been characterized by key bioparameters such as biomass, leaf area index, vegetation cover fraction and yield. Results are presented from the analysis of experimental data gathered over spring barley grown under different conditions, namely soil type, nutrient supply (fertilization type and amount), heavy metal pollution. The impact of these conditions on crop growth and productivity has been studied and related to plant spectral features in a statistical manner. The stress effects have been examined and quantified by empirical relationships with crop growth variables thus relating physiological and spectral response to the stress factors.

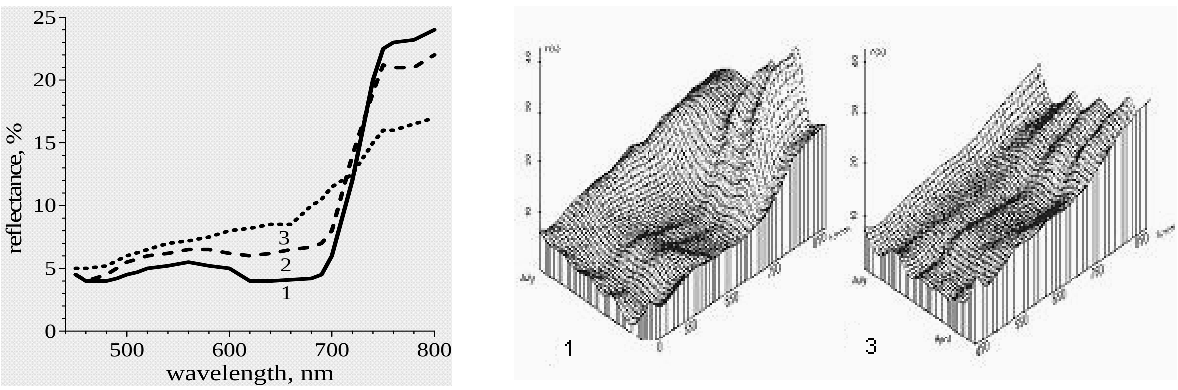
Materials and Methods

Reflectance, biometrical and phenological data were gathered from spring barley treatments throughout the entire growing season. The treatments comprised neutral (pH=7.0-7.5) chernozem soil and acid (pH=5.0-5.5) grey forest soil, Ni pollution of the soils in different concentrations and various fertilization conditions. The soils were chosen for their different reflectance spectra and response to heavy metal pollution. Four Ni concentrations 100, 200, 300 and 400 mg/kg were applied as well as NH_4NO_3, $(NH_4)_2SO_4$, $Ca(NO_3)_2$ and KNO_3 fertilization in different amounts. Ground-based VIS and NIR multispectral measurements were performed in the wavelength range (0.4-0.8) μm. Reflectance data were acquired at weekly intervals during plant development from emergence till full maturity. Biometrical sampling included fresh and dry above-ground phytomass, LAI, leaf biomass, plant cover fraction, stem number and height, and grain yield.

The data sets were statistically analysed to determine the significance of the variations, the presence and strength of correlation, and to examine and quantitatively describe plant physiological and spectral response to stress factors by deriving empirical relationships. In respect to stress detection from multispectral and multitemporal data the regression analysis was run on vegetation indices using spectral band ratios, contrasts and normalized differences as routinely implemented data transformations [7-9]. Special attention was paid to plant temporal response to the applied factors.

Results and Discussion

Because of the large amount of the study outputs only some main results of the data analysis are presented here. They concern plant spectral and growth response to stress factors. Growing conditions cause significant variations of plant spectral properties. This can be seen in Fig.1a where the spectral reflectance characteristics of Ni-treated spring barley on grey forest soil at stem elongation stage are shown. The contamination impact is observed through the entire growing season as seen in Fig. 1b which presents the spectral reflectance characteristics of non-polluted plants (1) and treatments with 400 mg/kg Ni concentration (3).

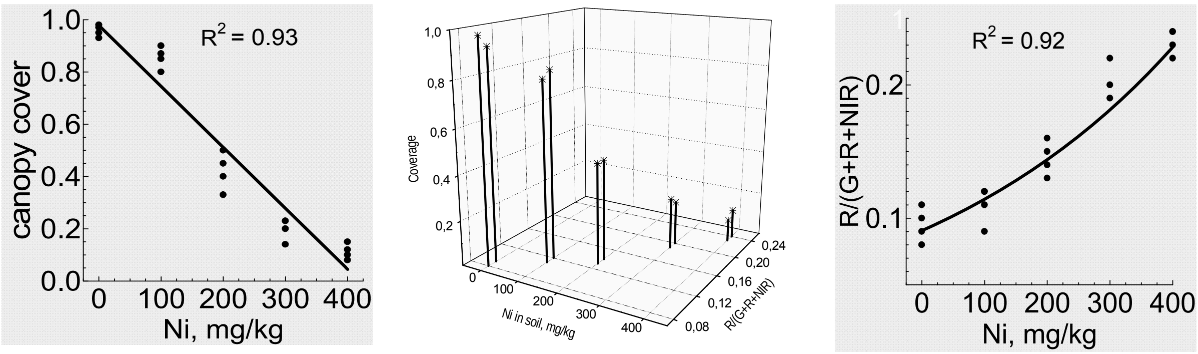


a) b)

Fig. 1 Spectral reflectance characteristics of spring barley on grey forest soil at stem elongation stage (a) and throughout the growing season (b): non-polluted (1), Ni=200 mg/kg (2), Ni=400 mg/kg (3)

The contamination affect on crop growth and reflectance features has been quantitatively examined by regression analysis. Various combinations of spectral ratios (vegetation indices) have been tested for their correlation with plant bioparameters and the stress factor. Many of them demonstrated high R^2 values from 0.86 to 0.95 being dependent also on the soil type and plant phenology. Meaningful statistical relationships between plant reflectance, growth variables and the stress factor have been established.

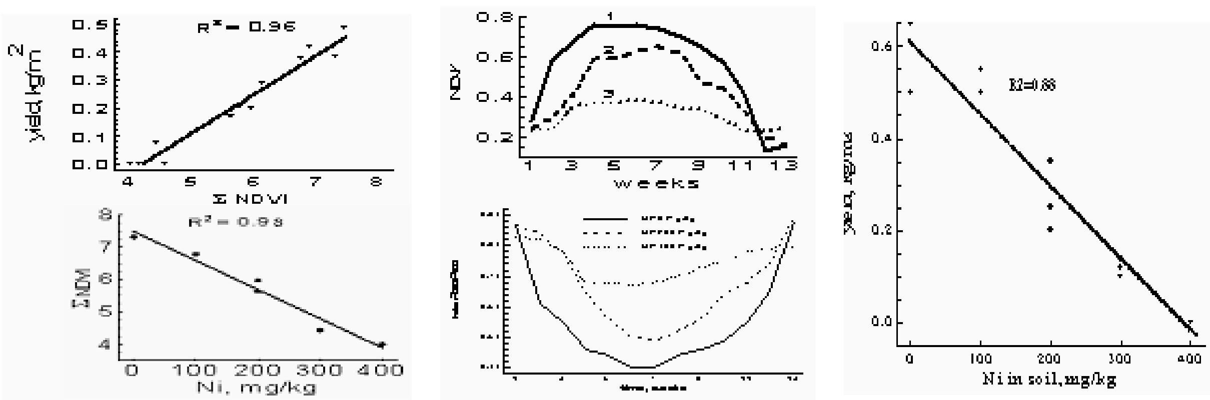
Variations in vegetation reflectance are attributed mostly to green canopy fraction. Besides, this variable is closely related to other plant bioparameters (biomass, LAI, etc.) and is a main indicator of crop growing conditions. The impact of the Ni pollution on the vegetation cover and, as a consequence, on plant reflectance is illustrated by Fig. 2. Crop depression due to the heavy metal contamination can be seen in Fig. 2a where the derived dependence of spring barley cover on Ni concentration in the grey forest soil is presented. The impact of the stress factor manifests itself in significant plant cover decresement. Dependences with high correlation were established between the stress factor and various crop vegetation indices. One is shown in Fig.3c. It is worth mentioning that the plots with 300 mg/kg Ni concentration were first excluded from the regressions and used later as a model validation data set. Good prediction accuracy was found and besides, the re-fit of the model after including the validation data proved its consistency. Fig.3b illustrates the stress-induced values of the crop canopy cover and the spectral index R/(G+R+NIR changing as functions of the Ni contamination.



a) b) c)

Fig. 2 Dependences of spring barley cover at ear-forming stage (a) and R/(G+R+NIR) vegetation index (b) on the Ni concentration in the grey forest soil; the impact of the heavy metal contamination on both spectral and growth variables

Special attention has been paid in the paper to data temporal aspects. The study of spectral features temporal behaviour during plant development is a precondition for crop growth monitoring and early stress detection. The spectral-temporal profiles of vegetation indices carry information about plant previous state and give a notation of development trends. Fig. 3b (up) shows spring barley (Ni-treatments on grey forest soil) NDVI - (NIR-R)/(NIR+R) vegetation index measured throughout the growing season from emergence till harvest. As seen, temporal spectral data is very indicative of differences in plant state caused by the heavy metal pollution. The dependence of NDVI as well of other indices - Fig. 3b (down) is clearly observed during the whole period of plant development. This fact permits crop stress detection at initial stages of plant development and early diagnostics.

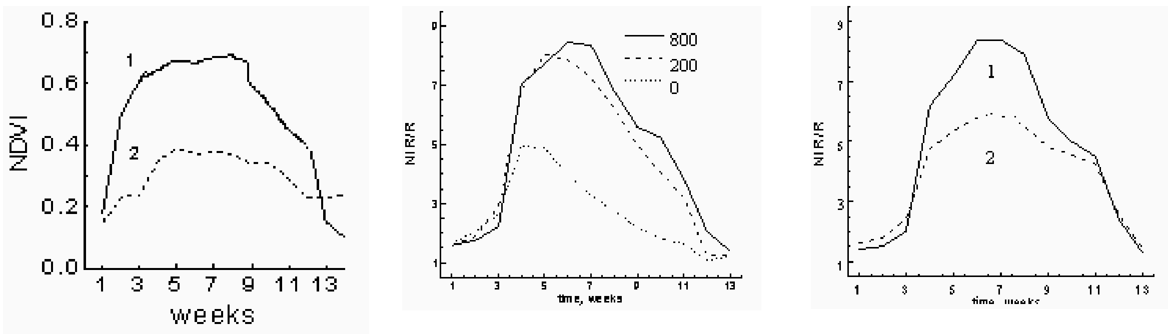


a) b) c)

Fig. 3 Fitted models of spring barley yield on Ni concentration in the grey forest soil (a, c); temporal behavior of vegetation indices throughout the growing season (b) of non-polluted plants (1) and plants with Ni concentration in the soil 200 mg/kg (2) and 400 mg/kg (3)

Another advantage of temporal data is the close relationship with crop yield. Accounting for the entire growth process, the temporal sum of various spectral indices appeared to be highly correlated to crop yield. The derived empirical relationship between spring barley yield and temporal sum of NDVI values is shown in Fig. 3a (up). The dependence of this sum on the Ni concentration in the soil is given in Fig. 3a (down). Crop yield prediction is of primary interest and a subject of many works dealing with remote sensing investigations. Since growing conditions predetermine yield, it is important to study their impact and the ability of spectral data to serve as an yield predictor. Fig. 3c shows the fitted linear model of barley grain yield as depending on the Ni contamination of the grey forest soil.

As crop production is a question of primary interest, barley grain yield was examined to its relationship with plant bioparameters, soil properties and the applied anthropogenic factors. There were not big yield differences between the non-polluted treatments over the two soil types, the grain yield of the chernozem plots being about 8-10% higher. However, the Ni-polluted treatments grown on this soil were much less affected by the heavy metal than those on the grey forest soil. Various soil properties impact plant development especially when acting in combination with other growing conditions. The acidity of the grey soil in our case appears to increase the accessibility of the heavy metal to plants thus inhibiting their growth in a greater degree than the neutral czernozem soil. This is clearly tracked by the NDVI temporal response shown in Fig. 4a for spring barley treatments on chernozem (1) and grey forerst soil (2) both polluted with Ni concentration of 400 mg/kg.



a) b) c)

Fig 4: (a) - NDVI seasonal profile of equally Ni-polluted (400 mg/kg) spring barley treatments grown on czernozem (1) and grey forest soil (2); (b) - NIR/R temporal behaviour as effected by the fertilization amount (NH_4NO_3) and (c) – by the fertilizer type: 1 - KNO_3, 2 - $Ca(NO_3)_2$

Nutrient supply is another factor detected from plant reflectance features and their temporal behaviour. Fig. 4b illustrates crop spectral response (NIR/R temporal profile) to fertilization amount, and Fig. 4c – to the fertilizer type (equal nitrogen concentration of 800 mg/kg being applied). As seen, already at layering and shooting stages crops manifest the nitrogen deficiency which leads to pronounced differences in reflectance compared to nutrient non-suffering vegetation.

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