50 years University of Mining and Geology "St. Ivan Rilski"
Annual, vol. 46, part I, Geology and Geophysics, Sofia, 2003, pp.355-359

INFORMATIONAL POTENTIAL OF VEGETATION SPECTRAL REFLECTANCE IN ANTHROPOGENIC IMPACT STUDIES

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ABSTRACT
The serious ecological problems relevant to the anthropogenic impact on the environment, and first of all on the biosphere, impose the necessity of methods for assessing these effects especially on vegetation land covers. In agriculture the possibility for timely identification of abnormal crop state is of particular importance. This paper is devoted to the implementation of reflectance spectra as informational featute about plant status as well as for the assessment of anthropogenic factors impact on plant development. Some results from ground-based reflectance measurements of plants grown up under different conditions (nutrient regime, heavy metal pollution) are presented.

The special attention paid to ecological problems associated with the anthropogenic impact on the environment, and first of all on vegetation, determines the importance of studies directed towards the development of efficient means for early phytodiagnostics. The identification of abnormal plant state (Kancheva, *et al*., 1992; Shibayama *et al*., 1993 Кънчева *и др*., 1996) caused by various stress factors such as soil toxic contamination is of particular interest. Remote sensing has proved abilities in this respect.

The goal of the this paper is to illustrate the use of spectral reflectance data for crop monitoring when anthropogenic factors are applied, represented here by nitrogen fertilization and soil heavy metal pollution.

The specific reflectance, absorption and emission of solar radiation by land covers is the basis of multispectral remote sensing. Widely used in soil and vegetation monitoring is the visible and near infrared (0.4-1.3 μm) spectral range due to some its advantages, such as: concentrates the largest portion of solar energy, covers the biologically active spectra, requires relatively simple technical devices, shows significant sensitivity to plant parameters variations.

At the root of spectrometric studies lies the fact that the reflected by the object radiation contains information about its biophysical properties. This information is carried by the specific spectral and energy distribution of the reflected solar radiation, i.e. by the reflectance coefficients $r(\lambda_i)$ which form the spectral reflectance characteristic $R\{r(\lambda_i)\}$ and are spectral informational features of the studied object, its 'spectral image'. Vegetation covers are characterized by a composition of biomorphological parameters Φk which are their 'substantial features'.

The so called 'inverse task' is to be solved that means to estimate the parameters Φk using measured spectral reflectance $R\{r(\lambda_i)\}$. A basis for the purpose provides the dependence of the reflectance features on the kind, properties and current state of the object. This dependence actually determines the informational content of spectral features. Vegetation reflectance for instance is a function of a number of bioparameters such as density, height, biomass, leaf area, chlorophyll, etc. This means that plant parameters variation cause reflectance spectra changes, i.e. between the radiometric and biophysical properties there exist adequate relationships $R\{r(\lambda_i)\}=f(\Phi k)$ which not only determine the informational content of spectral data but attaches to it quantitative expression.

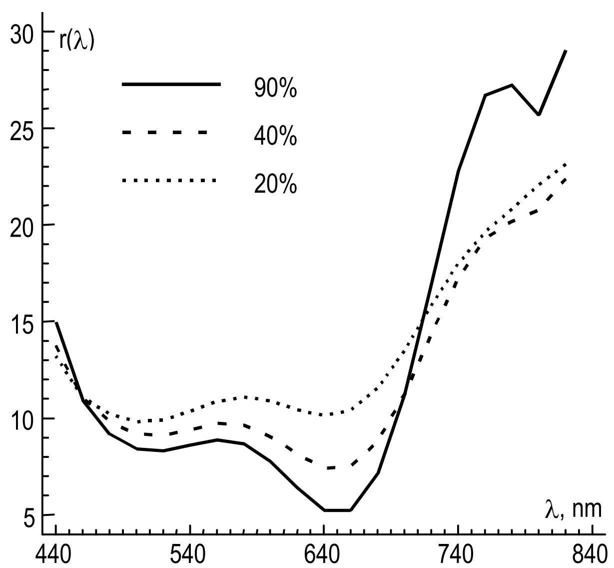


Figure 1. Spectral reflectance of spring barley plots with different plant canopy coverage.

Fig.1 shows the obvious difference of spring barley reflectance ability due to canopy coverage variance (the proportion of vegetation within the pixel area).

Crop bioparameters being an expression of morphological changes are indicators of plant state as a result of the growth process and of the impact of various factors including anthropogenic influences Fr. Along with the natural physiological development stress factors cause statistically significant variations of plant reflectance (Bammel and Birnie, 1994; Kancheva, *et al*., 1992; McMurtey, *et al*., 1994; Кънчева, 1995) because of their affect on chlorophyll content, biomass amount, etc. This is illustrated very well by Fig.2 where the spectral characteristics $R\{r(\lambda_i)\}$ of spring barley during the whole vegetation period are presented for the case of unpolluted (a) and 400 mg/kg Ni-polluted soil (b).

Statistical methods are used for data processing, including preliminarily correlation and regression analyses, the models being later applied for biophysical interpretation of spectrometric data. A peculiarity and wide spread practice in vegetation studies is the use of spectral transformations called vegetation indices (VI). They are various combinations of the measured reflectance coefficients $r(\lambda_i)$ at two or more wavelengths λ_i and have the form of ratios, weighted sums, normalized differences, etc. Some of the considerations for doing so are: the large data amounts are being reduced, the signal to noise ratio is being improved by minimizing the effects of 'noise' factors (such as varying illumination conditions, topography, etc.), spectral differences become more pronounced and the sensitivity to estimated variables is being increased, thus achieving better accuracy and reliability of the results. All this is aimed at improving the spectral data informativity.

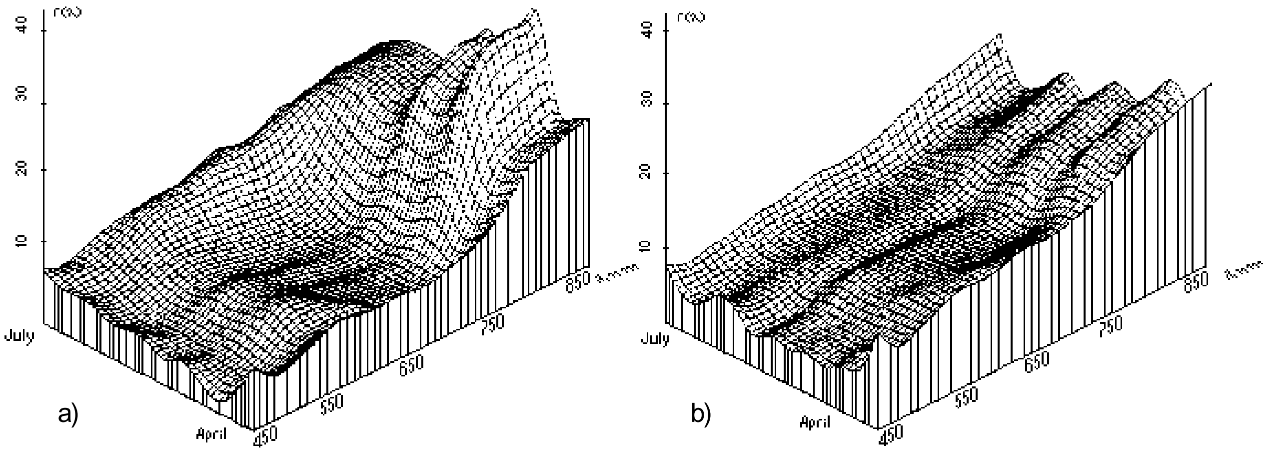
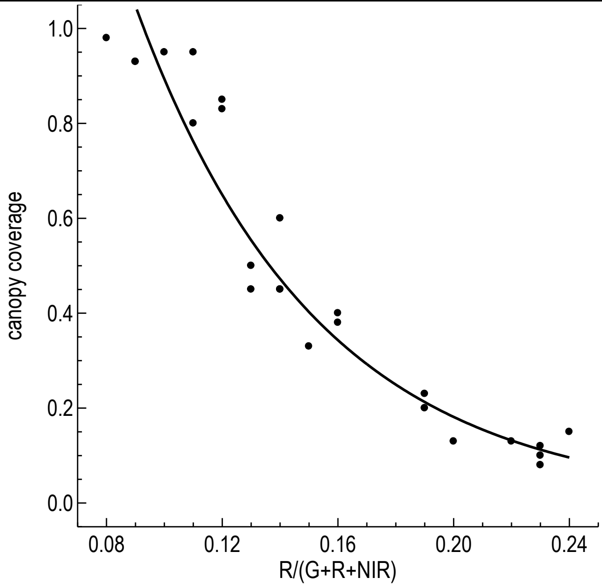


Figure 2. Barley spectral reflectance throughout the growing season for unpolluted (a) and Ni-polluted plots (b).

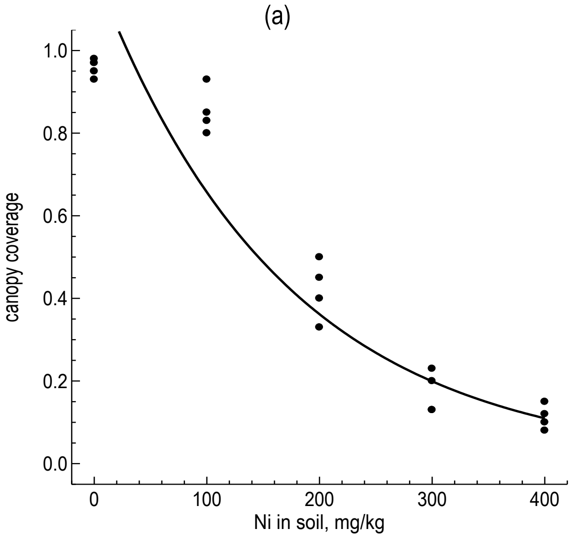
Thus spectral reflectance variations are a function of plant state which in return depends on growth conditions. The relation 'growth conditions → plant state → reflectance ability' determines the informational potential of vegetation spectral data and provides ground for vegetation abnormal status identification caused by stress factors. The aim is to extract the informational content which means plant bioparameters Φk to be estimated and anthropogenic influences Fr to be assessed using crop multispectral data $R\{r(\lambda_i)\}$. This is possible on the basis of empirical relationships derived from experimental data. The task is to establish quantitative dependences between reflectance features, bioparameters and anthropogenic factors: $R\{r(\lambda_i)\}=f(\Phi k)$, $\Phi k=f(Fr)$, $R\{r(\lambda_i)\}=f(Fr)$.

Vegetation indices are used as input variables in regression models for crop state and anthropogenic impact evaluation. More often these are indices formed in specific for vegetation spectral bands (see also Fig.1) of intensive reflectance and absorption of the incident light: green (G– 550 nm), red (R – 670 nm), near infrared (NIR – 800 nm) and the R-NIR region (700-780 nm) of sharp reflectance increase.

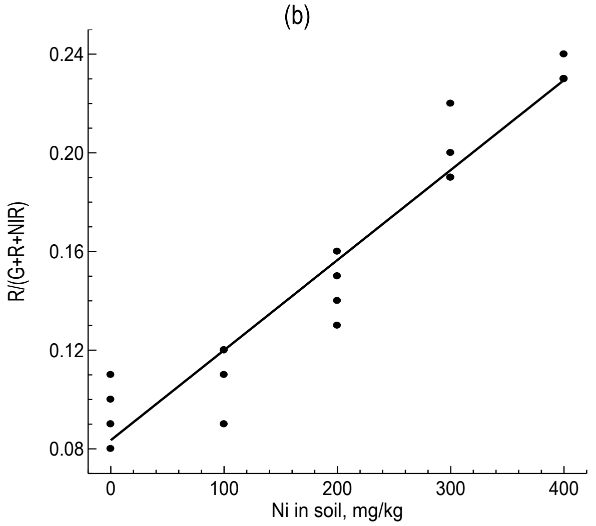
Examples are presented below illustrating some spectral-biophysical models. In Fig.3 the relationships between spring barley vegetation index R/(G+R+NIR), plant canopy coverage and Ni concentration in soil are shown (a, b, c) as well as the simultaneous change of the spectral and biometrical variables as functions of the pollution (d).



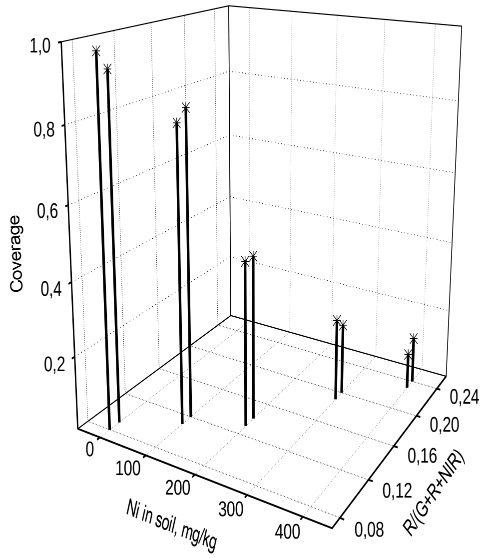
(a)



(b)



(c)



(d)

Figure 3. Relationships between barley vegetation index R/(G+R+NIR), plant canopy coverage and Ni concentration in soil.

Such empirical models when high correlations are observed allow plant parameters to be estimated using multispectral data as well as the impact of stress factors on crop development to be evaluated.

Should be mentioned also that special attention is being paid to data temporal aspect (Samson, 1993; Shibayama and Akiyama, 1989; Кънчева и Георгиев, 2000). The study of spectral features temporal behaviour during plant development is a condition for crop state periodical assessment, growth process forecasting and early identification of stress situations. The dependence VIj=f(t) called spectral-temporal profile carries information about the current and previous plant status and shows development trends. Temporal spectral data is indicative as well of plant state differences caused by anthropogenic factors. An example is Fig.4 where the temporal behaviour of r(λ=670nm)/r(λ=700nm) vegetation indices for Ni-polluted spring barley plots are shown.

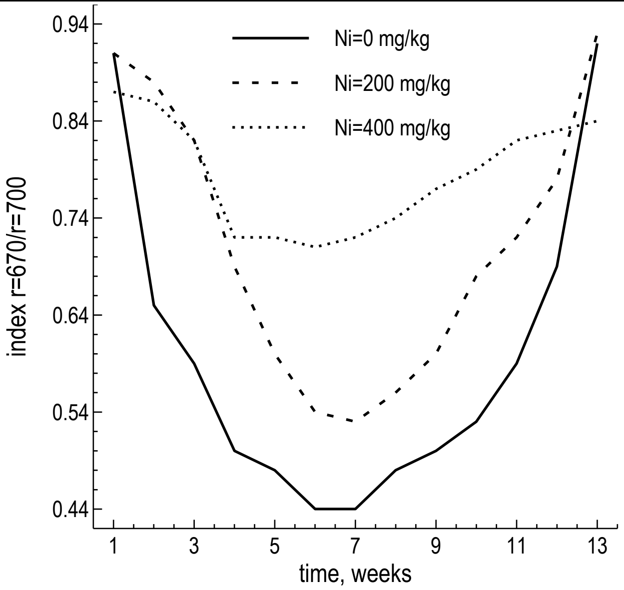
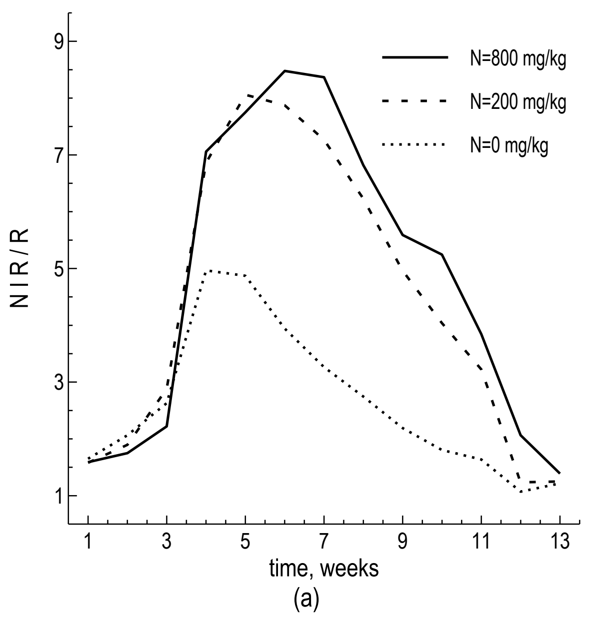


Figure 4. Temporal behaviour of r(λ=670 nm)/r(λ=700 nm) vegetation indices for spring barley plots with different Ni pollution.

It should be pointed out that the dependence of plant spectral reflectance on the heavy metal concentration in soil is observed almost throughout the whole vegetation period. This fact permits crop early diagnostics.

A stress factor can be also the nutrient deficit. Already at layering and tube-forming stages cereals manifest the insufficient nitrogen supply. Nitrogen fertilization effects plant growth bioparameters (height, biomass amount, canopy coverage, chlorophyll content) that leads to pronounced differences of reflectance features comparing to nutrient suffering vegetation. Fig.5a is an example of NIR/R index for spring barley plots with different nitrogen concentration in soil (the fertilizer is NH_4NO_3). It is interesting to point out that spectral differences are observed also in relation to fertilizer compound. This is seen in Fig.5b where the nitrogen content in soil is equal for all treatments (800 mg/kg) but the spectral-temporal profiles differ due to the fertilizer compound.



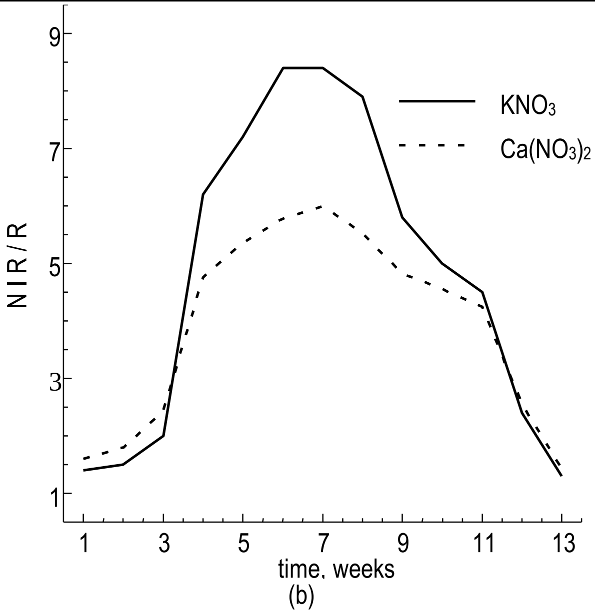


Figure 5. Temporal behaviour of barley NIR/R vegetation index depending on nitrogen amount (a) and fertilizer compound (b).

Summarizing the results of experimental studies, part of which are presented here, we draw the conclusion that reflectance spectra temporal behaviour and regression models relating plant reflectance features to bioparameters and growth conditions can be used for quantitative assessment of plant state and stress factors impact.

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Recommended for publication by Department Applied Geophysics, Faculty of Geology and Prospecting