NORMALIZED RED-EDGE INDEX – NEW REFLECTANCE INDEX FOR DIAGNOSTICS OF NITROGEN STATUS IN BARLEY

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ABSTRACT

Existing vegetation indices used for the diagnostics of nitrogen nutrition, such as NDVI, often provide inaccurate results. The main reason is the saturation of these indices at higher doses of nitrogen and a large dependence on canopy structure. These indices are then unable to detect differences at higher levels of nitrogen nutrition and provide highly variable results, depending on the variability of canopy density. For this reason, the new index based on reflectance in the red-edge band, normalized to the reflectance in the red and infrared was developed (NRERI). This index provides a nearly linear relationship to the level of nitrogen nutrition up to higher doses, while it is relatively little affected by the crop density. This index was tested in experiments with graduated nitrogen nutrition and crop density and also verified on the contrasting barley genotypes. Based on these results, the prototype of a sensor for measurement of NRERI in field conditions was also developed.

Key words: barley, spectral reflectance, vegetation indices, nitrogen nutrition, sowing density

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INTRODUCTION

Nitrogen is often considered to be the most important limiting factor, after water deficit, for plant growth and crop productivity. Indeed, nitrogen is involved in the functioning of meristematic tissues, in photosynthesis, and in the determination of the protein content of harvested organs. In cropping and grassland systems, N fertilization practices can provide a sufficient N supply for plants to achieve the potential productivity allowed by the actual climatic conditions. But because of climate variability, the applied quantities of N fertilizers are often larger than the quantity strictly required for achieving optimum yield. High climate variability combined with spatial variation in soil N supply according to soil type lead to increased risk of N leaching in most of the intensive cropping systems. Nowadays, protection of soil water and air quality becomes a necessary constraint for agriculture, and the current fertilization strategy cannot be longer used. Thus there is high demand to improve nitrogen fertilization strategy on the basis of nitrogen physiology knowledge and development of related remote sensing approach. By providing both spatial and temporal information remote sensing based on spectral reflectance may function as an important source of data for site-specific crop management. Leaf or canopy reflectance may be an effective early indicator of crop plant physiological a particularly nutritional status. The application of reflectance spectroscopy for the estimation of leaf pigment content has recently received considerable attention. Vegetation indices that combine reflectance from few spectral bands have been developed for pigment retrieval (Gitelson et al. 1996). Specific absorption coefficients of leaf pigments are high for blue and red wavelengths and the depth of light penetration into the leaf is very low (Merzlyak and Gitelson 1995). As a result, even low amounts of foliar pigments are sufficient to saturate absorption. The widely applied Normalized Difference Vegetation Index (NDVI), due to its early saturation (Buschmann and Nagel 1993), was found to be insufficiently sensitive to changes of medium and high chlorophyll content. For the green and red edge regions, the absorption coefficient is very low and rarely exceeds 6% of that for blue and red (Lichtenthaler 1987), however, green leaves absorb more than 80% of incident light in these spectral ranges (Gitelson and Merzlyak 1994). Therefore sensitivity of absorption to chlorophyll content is much higher in these spectral regions than for the blue and red spectral regions. Despite of poor estimation of chlorophyll concentration using NDVI, there is often reported good correlation to biomass and leaf area index. E.g. Alvaro et al. (2007) found strong associations between NDVI and plant dry weight and green area per plant.

The main objective of this study was to test the newly developed vegetation index NRERI based on reflectance in red-edge and normalized to red and near infrared bands in field experiments with three nitrogen doses and six sowing densities and in experiment with three spring barley varieties. One of the main objectives was particularly to test the ability of this index to differentiate the level of nutrition in higher doses of nitrogen, in which the other indices show saturation and to test the robustness of this index in changing environmental conditions, sowing density and barley variety. It was also carried out the comparison of indices measured using spectroradiometer with high resolution and a new prototype of sensor based on measurement of this index in combination with the vegetation index NDVI.

MATERIAL AND METHODS

The field experiment on spring barley variety Bojos was conducted in 2012 in Kroměříž. The preceding crop was maize. Spring barley was sown in six graded sowing densities ranging from 1 to 6 million of germinating seeds (MGS) per hectare. The experimental plots were fertilized before sowing with nitrogen in three doses (0, 40 and 80 kg ha^{-1}). At the growth stage BBCH 30, 32 and 39 the measurement of the spectral reflectance was carried out on the canopy level from the distance approximately 1m using spectroradiometer FieldSpec 4 HiRes (ASD, USA) and the prototype of new sensor for simultaneous measurement of NDVI and NRERI (Fig. 1).

The measurement with spectroradiometer FieldSpec was done directly by fiber optics without lens and pistol grip for remote measurements. At the same time the aboveground biomass was harvested and dried to constant weight in oven to determine dry weight per area unit. Part of the dry mass was used for the subsequent analysis of the nitrogen content in dry mass using elemental analyzer Leco (USA). In the full ripening of barley the harvest of grain was done using small plot harvester. After determining the weight and moisture content of grain the yield was converted to a standard humidity 14%. The samples of grain were then used for analyses of the protein content using elemental analyzer Leco. The basic statistical analyses (ANOVA, Tukey post-hoc test, regression and correlation analyses) were done using Statistica 8 software (USA).

Fig. 1 Prototype of the handheld sensor for simultaneous measurement of NDVI and NRERI indices. The instrument consists of measuring optical head with filters and detectors, small portable computer and a support rod with a joint mechanism to ensure the vertical position of the sensor

RESULT AND DISCUSSION

Comparison of vegetation indices NDVI and NRERI measured with scientific spectroradiometer FieldSpec 4 HiRes and the sensor prototype at the end of tillering demonstrated the advantages of the newly developed index NRERI compared to the standard index NDVI, i.e. the ability to detect differences in higher doses of nitrogen, when NDVI is saturated (Fig. 2).

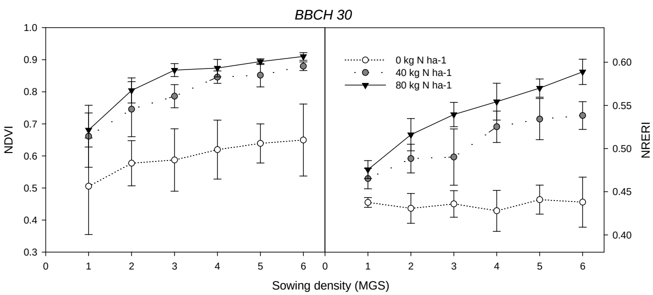

Fig. 2 Effect of nitrogen nutrition and sowing density on reflectance indices NDVI and NRERI. Means (points) and 95% confidence intervals (error bars) are presented (n=6)

This is evident from a comparison of the differences in these two indices between nitrogen doses 40 and 80 kg ha^{-1}. While the differences in the index NDVI are non-proportionally reduced as compared to the differences between the nitrogen doses of 0 and 40 kg ha-1, the index NRERI showed proportional differences between both low and high nitrogen doses, which indicate a higher linearity of the relationship between index and nitrogen nutrition. Similar improvement of nitrogen detection compare to NDVI found Kanke et al. (2012) using the red-edge position (REP), which however, need hyperspectral data to be calculated.

The measurement with prototype of handheld sensor showed very similar course of response to nitrogen nutrition and sowing density compare to data measured with spectroradiometer FieldSpec. This demonstrates the correlation analysis carried out on data from the measurement in the growth stage of end of tillering (Fig. 3).

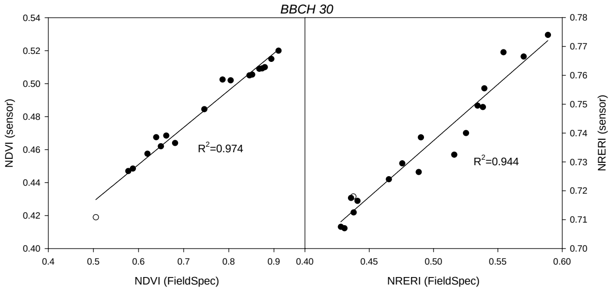

Fig. 3 The correlation between indices measured with scientific spectroradiometer FieldSpec 4 HiRes and prototype of sensor at the growth stage end of tillering

Despite the same pattern of response and high values of coefficients of determination for both indices, there are clear differences in the absolute values of indices between measurements using a spectroradiometer and a sensor prototype. This shows the need to improve the calibration process. Nevertheless, it is evident that the prototype provides data fully comparable with precise scientific instruments.

It was found, that the slope of the relationship to the dry weight of aboveground biomass is significantly changing during vegetation period for the vegetation index NDVI (Fig. 4), which is probably due to the high sensitivity of this index to the biomass and also rapid saturation at high levels of biomass.

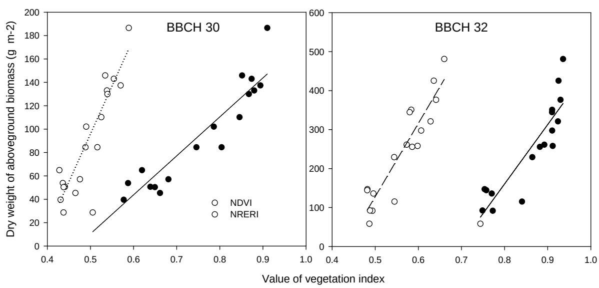

Fig. 4 Changes in the relationships between vegetation indices NDVI and NRERI and dry weight of aboveground biomass in two growth stages of spring barley

Conversely, index NRERI exhibits stable slope according to the dry weight as well as the yield in all three measurement periods. However, estimates of dry matter in the later growth stages (end of stem elongation) are problematic for both vegetation indices.

CONCLUSIONS

The index NRERI is compare to index NDVI not saturated at higher levels of nitrogen nutrition, which means that it provides a linear response in almost the entire range from low levels of nitrogen nutrition to high doses of nitrogen.

A better prediction of aboveground biomass and grain yield is provided by vegetation indices in earlier growth stages. Moreover, relationship between NDVI and weight of biomass amends the slope during the vegetation, which reduces the reliability of diagnostics.

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