Spectral determination of nitrogen content of wheat canopies

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ABSTRACT

A nitrogen status map reflecting the spatial variability of the nitrogen supply within a field is a useful tool for farmers to adjust their fertiliser input based on the actual needs of the plants. In particular, there is potential to accurately predict nitrogen need at each point in the field to reduce surplus nitrogen in the crop production system without reducing crop yield. Remote sensing collects spatially dense information that may contribute to nitrogen variable rate application within the precision farming concept. Plant spectral properties reflect crop nitrogen status and can be used for spectral determination of nitrogen content.

The aim of this study is the analysis of the relationship between spectral reflectance measurements and nitrogen content of wheat canopies. For this purpose reflectance measurements of wheat canopies from four different fields have been acquired over a full phenological cycle using an ASD FieldSpec II spectroradiometer. The nitrogen content of the biomass has been determined by wet digestion in the laboratory.

Reflectance spectra, their first derivative spectra and vector normalized spectra were used as statistical inputs and different spectral wavelength ranges were compared regarding their suitability for determination of nitrogen content of wheat canopies. The nitrogen content of the wheat canopies was predicted using partial least square regression (PLS). Obtained results with cross-validated r^2 higher than 0.8 suggest a practical application of the method for precision farming purposes.

Keywords: Nitrogen, spectrometry, wheat, PLS.

1 INTRODUCTION

The availability of hyperspectral imaging spectrometers (e.g. AVIRIS, HyMap) opens up new challenges for a quantitative remote sensing approach. The detection of small absorption features, caused by the chemical composition of the target object, will be enabled by a large number of discrete spectral bands.

The knowledge of the nitrogen status of cereal crops plays an important part in agricultural management. Nitrogen (N) is constituent of amino acids and organic bases (DNA, RNA), enzymes, vitamins and chlorophyll. Knowing the current N-content of the crop stand allows to draw conclusions on the nutritional supply and the expected quality of the products. Growth and development of resulting yield components can be positively controlled by time and amount of fertilizer application. Capturing information about the variation of the nitrogen status of crops within in the field by remote sensing techniques could therefore be an effective tool for decision making strategies for N fertilization.

Precision Agriculture will be an integral part of agricultural farm management practices in future and the exploitation of this tool for fertilizer use is essential for the harmonization of agricultural and ecological demands. The utilization of remote sensed images for the prognosis of the nitrogen demand could be an efficient method to assist the determination of variable rates-rates.

2 STUDY AREA AND DATA BASE

Reflectance measurements and nitrogen contents of wheat canopies of four fields have been acquired over a full phenological cycle (Fig. 1). The four wheat fields (B1a, B1b, B2a, B2b) are located in the Bitburger Gutland, approximately 20 km north of Trier (Rhineland-Palatinate, SW-Germany). Within every field three plots (40 cm x 40 cm) have been measured at three observation days under clear sky conditions during the vegetation period (Day of Year 129, 160, 172).

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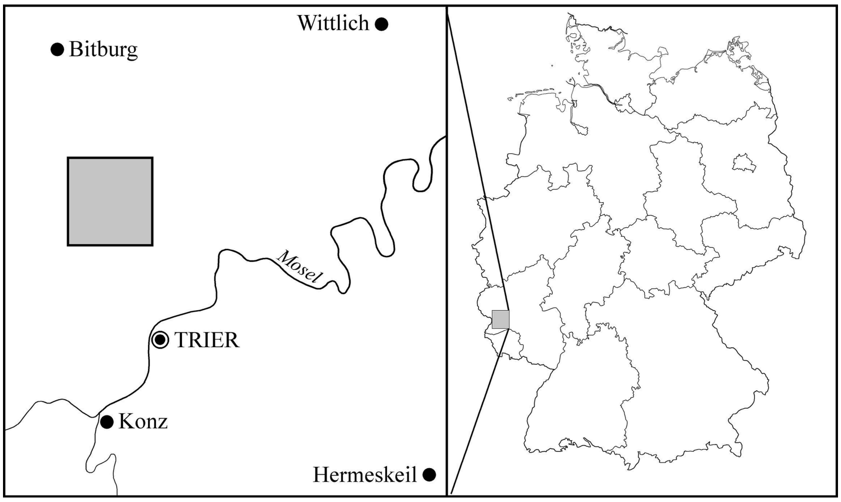

The bidirectional diffuse reflectance measurements were accomplished with an ASD FieldSpec II spectroradiometer. Spectral measurements were taken 1.5 m directly above of every single plot and converted into absolute reflectance values using a reflectance standard of known reflectivity. The instrument measures the radiance of the vegetation canopy in the spectral range 350 – 2,500 nm with a spectral resolution of 3 – 10 nm. Due to severe noise measurements below 420 nm and above 2,400 nm have been eliminated. The reflectance values within the water absorption bands of the atmosphere (1.34 – 1.45 µm, 1.75 – 1.97 µm) have also been eliminated.

Plant samples were oven dried at 60° C for 48 hours, prior to analysis. The total N content in the leaf material was determined using the standard Kjeldahl method [1] (Tab. 1 & Fig. 1).

Tab. 1: Descriptive statistics of the nitrogen content of the wheat canopies

	n	minimum	maximum	mean	std.-dev.
nitrogen	36	5.73	33.50	16.42	7.31

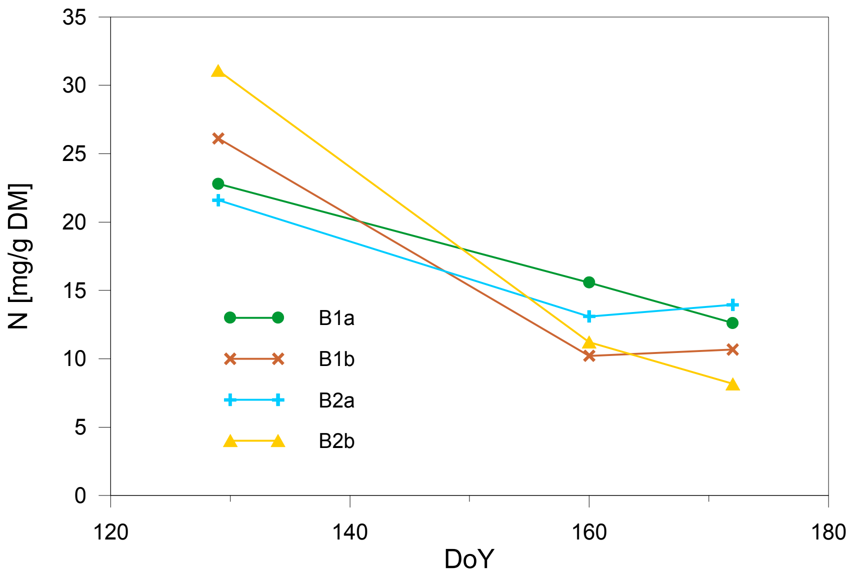

Figure 2: Temporal change of nitrogen content of wheat canopies (DoY = Day of Year)

3 METHODS

Partial-least-square regression (PLS) was used to examine the relationship between the reflectance measurements and nitrogen content of the wheat canopies. The optimum number of latent variables used for regression was determined iteratively by comparing the root mean square errors of cross-validation ($RMSE_{cv}$) of the predictions obtained from models with different numbers of latent variables.

Spectra pre-treatment techniques were applied including first derivatives [4], and vector normalization (VN) [3] after centering each spectra around its average.

4 RESULTS

The significant correlation between measured and estimated (cross-validation) nitrogen content of wheat and the shape of the correlation spectra indicate that data from the complete reflective domain (400-2400 nm) exhibit information about the nitrogen content which can be used by PLSR. Although, different wavelength regions in the correlation spectra were found where absorption alter according to changes in nitrogen content a certain absorption feature could not be unambiguously assigned to a specific chemical group. In contrast, the form of the correlation spectra derived from the reflectance data point on distinct albedo effects that were used for prediction. Highest correlation coefficients could be found in the visible domain of the spectra (Fig. 3). This supports the findings of many researchers tried to utilize visible and near infrared spectral response from plant canopies to detect nutrient stress [5, 6, 7, 8, 9]. The most common fact found by those studies is that reflectance near 550 nm seems to allow a good separation of leaf nitrogen concentration and can thus be used to detect nitrogen deficiency of crop plants.

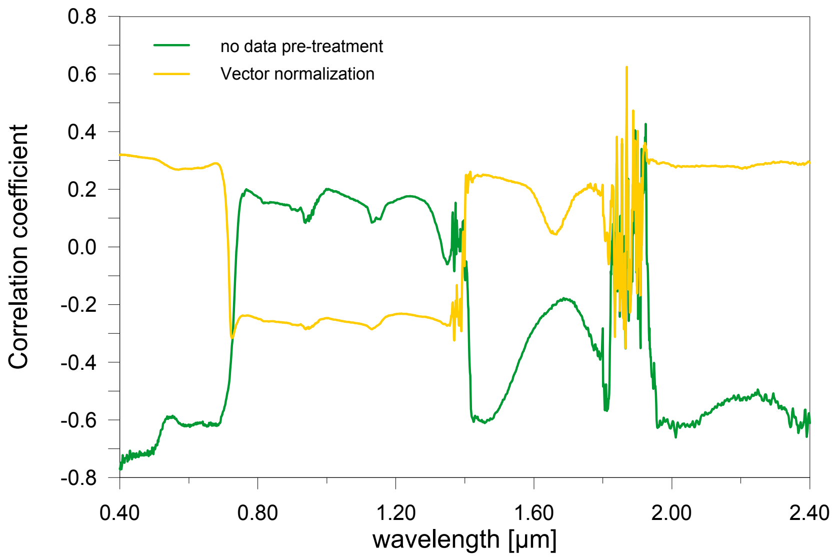

Figure 3: Correlation spectra for nitrogen content

But also the NIR spectral range, besides the water absorption bands, is useful for the estimation of nitrogen concentration. This is supported by many studies were the nitrogen content of plants is soley estimated from the NIR-spectral region (1000-2500 nm) [10, 11, 12]. In a further study it will be evaluated if a re-calibration with a limited number of significant wavelengths showing distinctive features in the correlation spectra can improve the nitrogen estimation of wheat further.

The best modeling results for nitrogen content of wheat were obtained using the original reflectance spectra. In this case cross validated r^2_{cv} of 0.838 with a Root Mean Square Error ($RMSE_{cv}$) of 2.94 was reached (Fig. 4). Prediction of the nitrogen content of the wheat canopies based on vector normalized data lead to simular results, while modeling results using derivative spectra were not satisfying.

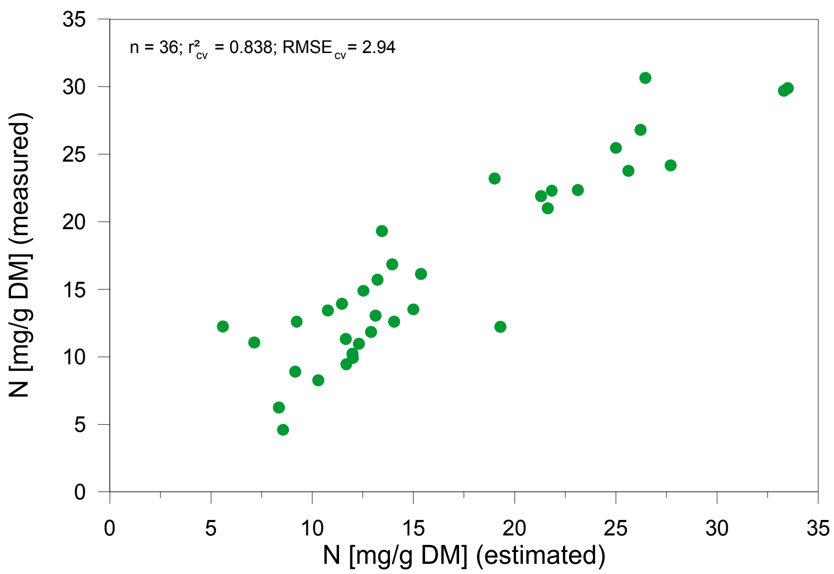

Figure 4: Scatterplot for cross validation of the model for nitrogen content of wheat canopies

5 CONCLUSIONS

In this study the level of precision with which nitrogen content could be estimated using field spectra is expected to be accurate enough to allow the estimation of the spatial nitrogen distribution in a parcel with relatively low costs, which is an importing issue for precision farming applications.

With the aim of spatial detection of nitrogen content of wheat canopies using remote sensing systems for precision farming applications new techniques have to be developed to scale the results to larger regions. Based on these promising results the developed model will be transferred to hyperspectral data. Beside this, a validation and adaptation of the approach for other geographical regions is intended.

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