Field-scale validation of a tractor based multispectral crop scanner to determine biomass and nitrogen uptake of winter wheat

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Abstract

In spatially variable fields, nitrogen fertilisation should be site-specifically applied in the growing season. This can be achieved through on-the-go sensors detecting the nitrogen status of the plants combined with a fertilising algorithm to control the amount of nitrogen fertilizer being applied. The potential to detect the spatial variation of biomass, nitrogen content and nitrogen uptake in winter wheat was investigated in 2001 and 2002 with a tractor based multi-spectral scanner measuring crop reflectance. The results indicated that biomass and nitrogen uptake can be reliably detected with a tractor-based non-contacting sensor. Further, the spatial yield variation can be predicted based on spectral measurements at milk ripeness.

Keywords: biomass detection, nitrogen status, on-the-go sensor, spectral reflectance, yield monitoring

Introduction

Optimising nitrogen inputs is an essential requirement for high yields and decreasing nitrogen losses to the environment. Heterogeneous fields require a targeted, site-specific application of nitrogen. On-the-go sensors allow detection of the spatial variation in the nitrogen status of crops and, combined with a fertilising algorithm and spatial variable rate technology, nitrogen dressings can be site-specifically targeted to the needs of the plants. Thus nitrogen fertilisation can be optimised to achieve high yields and product quality, combined with strategies to minimize nitrogen losses to the environment (Ebertseder et al., 2003).

The principle to detect differences in the nitrogen status and biomass of crops by proximal and remote sensing has been described in the literature (Blackmer et al., 1994; Ma et al., 1996). In this work, the potential of a tractor based crop scanner, similar to the sensor described by Lammel et al. (2001) but used in a spectral detection mode, was tested to detect differences in biomass, nitrogen content and nitrogen uptake of winter wheat in two field experiments in 2001 and 2002. Calibration trials so far have been conducted on small field plots mainly with hand-held spectrometers (Reusch, 1997) or on areas which did not match tractor based spectrally sensed areas with the destructively sampled areas for biomass and crop nitrogen status determinations. Therefore, especially in the second year, the experiments were conducted with the goal to spatially match destructive ground-truth measurements of biomass and nitrogen content with the area sensed by the sensor. To our knowledge, no such measurements have been reported. The previously outlined potential to predict spatial differences in final yield based on spectral measurements at milk ripeness (Schmidhalter et al., 2001) with the proximal sensor was further evaluated.

Materials and methods

Spectral reflectance measurements with a crop scanner were performed in field experiments with wheat (*Triticum aestivum* L.). The measurements were conducted on two fields at Scheyern Farm, Pfaffenhofen in 2001, and the experimental research station Dürnast, Freising in 2002, in Bavaria, Germany, respectively, with the cultivars Biskay and Ludwig. Nitrogen applications were varied during the growing season to create differences in biomass, nitrogen content and nitrogen uptake. Randomised treatments were used with seeding rate (250, 450 and 650 grains/m^2) and nitrogen dose (100, 135, 170 and 205 kg N ha^{-1}) as variables in 2001 and nitrogen dose (90, 130, 170 and 210 kg N ha^{-1}) as variable in 2002. Cultivation strips for nitrogen dressings were 15 m in width and 50 m in length. All treatments were five times replicated.

Multispectral measurements were conducted at BBCH 37, 55 and 73-75 (BBCH monograph, 1997). Measurements during milk ripeness were conducted to predict the final yield. Spectral measurements were made simultaneously at 5 wavelengths (550, 670, 700, 740 and 780 nm ± 5 nm) and the following spectral reflectance indices were calculated:

Red edge inflection point: $REIP = [700+40((R_{670}+R_{780}/2-R_{700})/(R_{740}-R_{700}))]$,
Soil adjusted vegetation index: $SAVI = [1.5(R_{780}-R_{670})/(R_{780}+R_{670}+0.5)]$,
Normalised difference vegetation index: $NDVI = [(R_{780}-R_{670})/(R_{780}+R_{670})]$,
Green - red ratio: $G/R = [R_{550}/R_{670}]$,
Infrared - green ration: $IR/G = [R_{780}/R_{550}]$,
Infrared - red ratio: $IR/R = [R_{780}/R_{670}]$.

The sensor used has four optical inputs with 90° azimuth angle between them and an average view zenith angle of 64° each. Light is collected from four inputs and optically averaged through a four-split light fibre. This arrangement allows average measurements from four ellipsoids located around the tractor practically independent of solar azimuth direction (Figure 1). The sensor consists of a two-diode array spectrometer; the first one is used to measure the crop reflectance, the second one to measure the irradiance to normalize the reflectance signal.

In the first year, the scanner was mounted 3 m to the side on the rear of the tractor at a height of 1 m above the plant canopy which allowed reduction of the scanned area to 2 m^2 (Schmidhalter et al., 2001), and in the second year, the scanner was mounted midway in front of the tractor, 2.2 m above the crop stand and the area scanned was between 10 to 18 m^2.

Measurements were usually conducted at around noon which helped to avoid any influence of shadowing by the tractor in the first year. No such precautions had to be taken in the second year due to the alternative positioning of the sensor. In the first year, destructive measurements by manually cutting biomass were done on an area of 2 m^2 equivalent in size to the area of two ellipsoids, but positioned between two of the four sensed ellipsoids, whereas in the second year

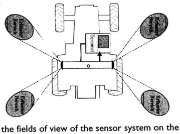

Figure 1. Diagram of the fields of view of the sensor system on the ground.

destructive determinations of biomass were made exactly on the sensed area on both sides of the tractor with a green forage chopper with 1.5 m cutting width equipped with a weighing unit to represent 10 to 18 m^2 in area. Spectral measurements were averaged across these areas. Fresh and dry weight of biomass were determined and the shoot nitrogen content measured in representative sub-samples. Nitrogen uptake per area was calculated as biomass x nitrogen content.

Results and discussion

Close relationships between different spectral indices and biomass, nitrogen content and uptake were determined in 2002 (Table 1) and a reasonable agreement with biomass and yield was observed in 2001. In 2001, goodness of linear fits (R^2-values) between IR/R measurements and biomass was 0.51, whereas final yield correlated to REIP measurements at BBCH 37 and 55 with 0.62 and 0.42, respectively. Crop stand in the different plots was much more homogeneous in 2002 and the comparative measurements were located on exactly the same areas. This was not the case for the 2001 measurements.

In general, the closest relationship was found between the investigated crop parameters and the spectral indices REIP, IR/R and IR/G, followed by NDVI and SAVI. All relationships reported were highly significant.

Measurements conducted at two different growth stages in 2002 indicated slightly better results at BBCH 37 than at BBCH 55. The relationship between biomass, nitrogen content and nitrogen uptake and spectral measurements at BBCH 37 and 55 obtained with the REIP index is shown in Figure 2.

A close relationship between spectral measurements conducted at growth stage BBCH 73-75 and final grain yield determined with a plot harvester was found particularly with the index REIP but also with other indices (Figure 3).

The results from these field studies agree with those from other studies obtained under well-controlled experimental plot conditions with hand-held spectrometers (Reusch, 1997; Liebler et al., 2001), but have been obtained under a considerably narrower range of nitrogen fertilization of 90-210 kg N ha^{-1}, than e.g. in the work done by Liebler et al. (2001), where nitrogen fertilization ranged from 0-220 kg N ha^{-1}. In general, at higher nitrogen fertilization levels or higher N uptake, the relationship between reflectance and the investigated parameters flattens. The best results were achieved with the indices REIP, IR/G and IR/R which proved to be better than NDVI and SAVI.

Table 1. Relationship of six spectral indices to destructively measured parameters biomass, nitrogen content and nitrogen uptake in field experiments with winter wheat at BBCH 37. The goodness of linear and quadratic fits (R^2-values) is indicated (n=25).

	linear			quadratic		
	Biomass	N-content	N-uptake	Biomass	N-content	N-uptake
	R^2			R^2		
IR/R	0.70	0.65	0.73	0.85	0.76	0.88
IR/G	0.75	0.82	0.86	0.85	0.91	0.92
REIP	0.77	0.78	0.84	0.84	0.90	0.94
G/R	0.12	0.01	0.05	0.59	0.09	0.44
NDVI	0.59	0.42	0.53	0.91	0.60	0.84
SAVI	0.49	0.46	0.48	0.78	0.63	0.78

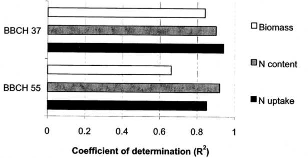

Figure 2. Relationship between the spectral index, REIP, and destructively measured parameters of biomass, nitrogen content and nitrogen uptake in field experiments with winter wheat (n=25).

In general, with the best indices, the closest relationships were found for N content and N uptake followed by biomass.

Other studies have shown that such relationships are cultivar dependent (Lammel et al., 2001; Liebler et al., 2001) and most likely also crop specific. By means of easily measurable or available reference values built into the calibration, such differences can be compensated for. In all of our studies so far, a close relationship between the destructively determined parameters biomass and N content was found.

Conclusions

The results indicated that biomass, nitrogen content and nitrogen uptake can be reliably detected with a tractor-based non-contacting sensor. The results suggest that carrying out destructive measurements for the determination of plant parameters on the same area as used for the spectral detection markedly improved the calibration results. A very good potential to detect the final yield

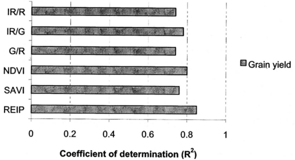

Figure 3. Relationship between spectral measurements conducted at the growth stage BBCH 73-75 and final grain yield.

by proximal sensing was corroborated in agreement with previous studies. Future research work should concentrate on other crops and the further development of fertilising algorithms.

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References

BBCH-Monograph 1997 Growth stages of mono- and dicotyledonous plants. eds. U. Meier et al.. Berlin; Wien: Blackwell Wiss.-Verlag.

Blackmer, T.M., Schepers, J.S., and Varvel, G.E. 1994 Light reflectance compared with other nitrogen stress measurements in corn leaves. Agronomy Journal 86 934-938.

Ebertseder, T., Gutser, R., Hege, U., Brandhuber, R., and Schmidhalter, U. 2003. Strategies for site-specific nitrogen fertilization with respect to long-term environmental demands. In: Proceedings of the 4th European Conference on Precision Agriculture, ed. J V Stafford, Wageningen Academic Publishers, The Netherlands.

Lammel, J., Wollring, J., and Reusch. S. 2001 Tractor based remote sensing for variable nitrogen fertilizer application. In: Horst, W.J. et al., Plant nutrition - Food security and sustainability of agro-ecosystems, eds. Horst et al., Hannover, 694-695.

Liebler, J., Sticksel, E., and Maidl, F.-X. 2001 Field spectroscopic measurements to characterize nitrogen status and dry matter production of winter wheat. In: Grenier, G., Blackmore, S. (eds.): Proceedings of the 3rd European Conference on Precision Agriculture. Agro Montpellier, France p. 935-939.

Ma, BL, Malcolm, J., Morisson, J. and Dwyer, L.M. 1996 Canopy light reflectance and field greenness to assess nitrogen fertilization and yield of maize. Agronomy Journal 88 915-920.

Reusch, S. 1997 Entwicklung eines reflexionsoptischen Sensors zur Erfassung der Stickstoffversorgung landwirtschaftlicher Kulturpflanzen. Dissertation Albrechts Universität zu Kiel.

Schmidhalter, U., Glas, J., Heigl, R., Manhart, R., Wiesent, S., Gutser, R., Neudecker, E. 2001 Application and testing of a crop scanning instrument - field experiments with reduced crop width, tall maize plants and monitoring of cereal yield. In: Grenier, G., Blackmore, S. (eds.): Proceedings of the 3rd European Conference on Precision Agriculture. Agro Montpellier, France, p. 953-958.