An Image Processing Based Approach for Detection of Nitrogen Status in Winter Wheat Under Mild Drought Stress

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Abstract. Nitrogen is one of the most important agricultural inputs affecting crop growth, yield and quality in rain-fed cereal production. In this study an image processing based approach was used for detection of nitrogen status in winter wheat. Four N fertilization rates (0, 60, 120 and 240 kg N ha^{-1}, in total) and two water regimes (irrigated and non-irrigated) were applied to winter wheat. Digital images of the plant canopy were acquired using a Canon camera during the growing season 2012. Different indices were extracted by processing of the images. According to the statistical analyses, all the indices were affected by both N and water supplies. However, Rm, RMB, NRMB, Hue and INT were less sensitive to water supply. Among the indices, crop coverage (CC) showed better results for detection of nitrogen status of the plant. We conclude that digital cameras can be used to assess nitrogen status of winter wheat.

Keywords: Precision agriculture, nitrogen, drought stress, wheat, digital camera.

1 Introduction

Nitrogen (N) is one of the most important agricultural inputs affecting crop growth, yield and quality in rain-fed cereal production. A mismatch between N supply and crop requirement can potentially hamper crop growth or harm the environment, resulting in poor N use efficiency (NUE) and economic losses (Tremblay et al., 2009). Thus, considerable efforts have been done to develop crop sensors that provide instant information as a basis for decision making on nitrogen fertilization. Examples are: Spectral-optical spot-sensors: like Yara N-Sensor (Tremblay et al., 2009), Acoustic sensors (Sui and Thomasson, 2006), Chlorophyll fluorescence sensors (Limbrunner and Maidl, 2007), Laser distance sensors (Ehlert et al., 2008), and Cameras (Lee and Lee, 2013).

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Since digital cameras precisely record the appearance of photographic subjects in a non-destructive manner, they can be considered as proximal sensing devices to provide an alternative and inexpensive method for characterizing crop stand parameters (Sakamoto et al., 2012). There have been some efforts to use digital cameras for estimation of nitrogen status in wheat (Li et al., 2010), corn (Rorie et al., 2011), and rice (Lee and Lee, 2013).

The basic assumption in using the crop sensors for nitrogen fertilization is that nitrogen of a crop has the strongest effect on the crop attributes assessed by the respective sensor. However, there is an evidence that these crop attributes can be affected by other environmental factors such as water supply (Clay et al., 2006).

By reviewing the literature, information about effect of drought stress on the measurements of nitrogen status using digital cameras was not found. Therefore, the objective of this study was to investigate the possibility of using a RGB camera for assessing nitrogen and water supply in winter wheat.

2 Material and Methods

During the 2012 growing season, a field experiment was conducted at the Bundessortenamt Marquardt experimental station, Potsdam, Germany (52°27' N, 12°57' E). The experiment was designed as a randomized split block design with two replications. Treatments on winter wheat (cv. Cubus) consisted of four N fertilization rates (0, 60, 120 and 240 kg N ha^{-1}, in total) and two water regimes (irrigated (Irr) and non-irrigated (NIrr)). During the growing season, the non-irrigated plots received 272 mm of precipitation, while the irrigated plots received an additional 20 mm of irrigation on two dates (18 April and 29 May).

Soil moisture was assessed by TDR soil moisture probes (ECH2O, Decagon Devices, Inc., Pullman, WA, USA). The sensors were positioned at a depth of 15 cm in irrigated and non-irrigated soils.

Above ground biomass sampling was performed three times (at weeks 19, 21 and 23 of the year 2012). The fresh biomass was put into plastic bags, immediately weighed, and then oven dried at 75 ºC for 24 h. The shoot fresh biomass (FB) and the shoot dry biomass (DB) (g m^{-2}) were recorded. The plant samples were chopped and the N content (% dry weight) was measured by the standard Kjeldahl method in laboratory. Crop yield and final biomass were also recorded during the harvesting time.

Digital images of winter wheat canopy were acquired by a Canon camera model EOS 550D with a resolution of 18.0 megapixels. Medium resolution of the camera was used. The resulting images had a size of 3456 × 2304 pixels at Program AE shooting mode of the camera. The camera was set to automatically adjustment f-stop and shutter speed, however, focus was set manually. The colour images were recorded in JPEG format and downloaded to a desktop computer for subsequent processing.

The images were taken looking vertically downward from a height of 1.8 m, which resulted in a rectangular area of 1.5 × 1.0 m on the ground. The photos were recorded at different plant growth stages including: stem elongation, booting stage, Inflorescence emergence, heading, flowering, and development of fruit.

To extract crop coverage and colour indices from the digital images, image processing was performed using MATLAB software (Version 7.13, R2011b, Mathworks Company). For segmentation of the green plant against background, a by a mask (M) (binary image) was derived from the difference between green (G) and the red (R) band of each image together with the threshold t:

$$M = \begin{cases} 1 & \text{for} \quad (G - R) \geq t \\ 0 & \text{for} \quad (G - R) < t \end{cases} \tag{1}$$

Crop coverage (CC) was defined as the proportion of plant pixels in an image:

$$CC = \frac{\sum M}{n \cdot m} \tag{2}$$

where n and m are number of rows and columns of pixels.

Various colour indices were obtained from plant part of the images defined by the mask M:

Rm = *R***M*; *Gm* = *G***M*; *Bm* = *B***M*; *GMR* = *Gm* – *Rm*; *GMB* = *Gm* – *Bm*; *RMB* = *Rm* – *Bm*; *NGMR* = (*Gm* – *Rm*)/(*Gm* + *Rm*); *NGMB* = (*Gm* – *Bm*)/(*Gm* + *Bm*); *NRMB* = (*Rm* – *Bm*)/(*Rm* + *Bm*).

where R, G and B are the intensity levels of the red, green and blue channels, respectively. The values were then averaged for each image.

Hue, Saturation (SAT) and Intensity (INT) were also calculated according to Tang et al. (2003):

$$\text{Hue} = \begin{cases} \theta & \text{if } B \leq G \\ 360 - \theta & \text{if } B > G \end{cases} \tag{3}$$

$$\theta = \cos^{-1}\left\{\frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)^2+(R-B)(G-B)]^{1/2}}\right\} \tag{4}$$

$$\text{SAT} = 1 - \frac{3}{(R+G+B)}[\min(R,G,B)] \tag{5}$$

$$\text{INT} = \frac{1}{3}(R+G+B) \tag{6}$$

The data obtained from the measurements and the image processing were analyzed using analysis of variance (ANOVA) and the means were compared at 5% level of significance using the Tukey range test in SAS software (version 9.3, SAS Institute, Inc., Cary, N.C., USA). Regression and correlation analysis were done using MATLAB software (Version 7.13, R2011b, Mathworks Company).

2 Result and discussion

The statistical analysis results indicated that there were strong significant differences among the N supply levels and between the irrigation regimes in the case of crop yield and final straw of the crop ($p<0.01$). The differences of N supply levels for fresh and dry biomass and also plant N content were highly significant ($p<0.01$)

in all three times of biomass sampling. However, the differences of irrigation regimes for these crop properties were mostly insignificant ($p>0.05$).

According to the soil water retention curve for sand, a volumetric water content of 10% was considered as field capacity and about 3% as permanent wilting point (Ehlert, 1996). Results of soil water content showed that the lowest readings (around permanent wilting point) were observed between days 235 and 245 after sowing (weeks 22 and 23 of the year) for non-irrigated part of the trial field. During this period, leaf rolling was also observed in the plants of non-irrigated part. Therefore, in spite of having a relatively wet vegetation season for the year 2012 in northeast Germany, a mild drought stress was observed.

Statistical analyses of the data showed that the effect of nitrogen supply on all the colour indices (except Bm) was significant at 1 % level for all the growth stages considered. In addition, the analyses showed that among the indices, Rm, RMB, NRMB, Hue and INT were less sensitive to water supply.

Time course of the crop coverage (as an example of the colour indices) is shown in

Fig. **1**.

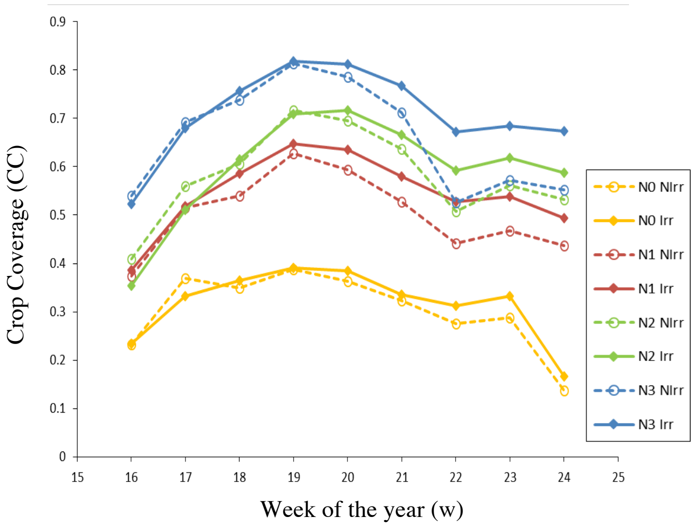

Fig. 1. Time course of crop coverage for irrigated (Irr) and non-irrigated (NIrr) wheat crops growing under 4 levels of nitrogen supply (N0=0, N1=60, N2=120, N3=240 kg N/ha)

According to the statistical analyses and time course of the colour indices, all the indices were affected by both N and water supplies. However, Rm, RMB, NRMB, Hue and INT were less sensitive to water supply. Li et al. (2010), Wang et al. (2013) and Lee and Lee (2013) showed that CC estimations obtained by digital cameras were good indicators for detection of nitrogen status in wheat and rice.

The three above studies did not consider effect of other plant stresses such as drought stress on the results. Based on the results obtained in the current study, the values of CC and other indices can be affected by drought stress. Therefore, in the case of drought stress, these indices can become less reliable for site-specific N management.

The indices Rm, RMB and Hue were less affected by water supply and showed high differences among nitrogen supply levels. Thus, they have a potential to be good indicators for detection of nitrogen deficiency.

As it is seen in Table 1, CC, NGMR and Hue had a strong positive correlation, while Rm, Gm, GMB, RMB, NGMB, NRMB, SAT and INT had a high negative correlation with the direct measurements of the agronomy parameters at all three times of sampling. Bm and GMR had a weak correlation with these parameters.

Among the colour indices, the strongest correlations with N content, FB and DB were obtained for Rm (rho=-0.926), Rm, GMB and RMB (rho=-0.953), and GMB and RMB (rho=-0.956), respectively (Table 1).

Table 1. Spearman's rho for correlation of direct and indirect measurements of winter wheat

variable	10.05.2012			25.05.2012			08.06.2012		
	N content (%)	FB ($g\ m^{-2}$)	DB ($g\ m^{-2}$)	N content (%)	FB ($g\ m^{-2}$)	DB ($g\ m^{-2}$)	N content (%)	FB ($g\ m^{-2}$)	DB ($g\ m^{-2}$)
N content	1	0.915^{**}	0.897^{**}	1	0.594^{*}	0.591^{*}	–	–	–
FB	0.915^{**}	1	0.994^{**}	0.594^{*}	1	0.979^{**}	–	1	0.994^{**}
DB	0.897^{**}	0.994^{**}	1	0.591^{*}	0.979^{**}	1	–	0.994^{**}	1
Height	0.918^{**}	0.950^{**}	0.930^{**}	0.575^{*}	0.905^{**}	0.936^{**}	–	0.885^{**}	0.872^{**}
CC	0.912^{**}	0.944^{**}	0.938^{**}	0.815^{**}	0.891^{**}	0.876^{**}	–	0.915^{**}	0.929^{**}
Rm	-0.926^{**}	-0.953^{**}	-0.950^{**}	-0.826^{**}	-0.885^{**}	-0.868^{**}	–	-0.851^{**}	-0.853^{**}
Gm	-0.918^{**}	-0.935^{**}	-0.935^{**}	-0.841^{**}	-0.897^{**}	-0.882^{**}	–	-0.828^{**}	-0.829^{**}
Bm	-0.468^{ns}	-0.529^{*}	-0.515^{*}	0.144^{ns}	-0.026^{ns}	-0.029^{ns}	–	0.328^{ns}	0.312^{ns}
GMR	0.253^{ns}	0.209^{ns}	0.215^{ns}	0.315^{ns}	0.326^{ns}	0.312^{ns}	–	0.679^{**}	0.674^{**}
GMB	-0.885^{**}	-0.953^{**}	-0.956^{**}	-0.812^{**}	-0.868^{**}	-0.871^{**}	–	-0.835^{**}	-0.824^{**}
RMB	-0.885^{**}	-0.953^{**}	-0.956^{**}	-0.791^{**}	-0.891^{**}	-0.897^{**}	–	-0.859^{**}	-0.847^{**}
NGMR	0.915^{**}	0.935^{**}	0.924^{**}	0.844^{**}	0.862^{**}	0.832^{**}	–	0.862^{**}	0.876^{**}
NGMB	-0.853^{**}	-0.909^{**}	-0.918^{**}	-0.812^{**}	-0.812^{**}	-0.821^{**}	–	-0.791^{**}	-0.779^{**}
NRMB	-0.871^{**}	0.935^{**}	-0.935^{**}	-0.809^{**}	-0.862^{**}	-0.868^{**}	–	-0.797^{**}	-0.791^{**}
Hue	0.871^{**}	0.935^{**}	0.935^{**}	0.797^{**}	0.894^{**}	0.906^{**}	–	0.850^{**}	0.844^{**}
SAT	-0.865^{**}	0.929^{**}	-0.932^{**}	-0.818^{**}	-0.859^{**}	-0.862^{**}	–	-0.800^{**}	-0.794^{**}
INT	-0.894^{**}	-0.935^{**}	-0.932^{**}	-0.824^{**}	-0.879^{**}	-0.859^{**}	–	-0.700^{**}	-0.712^{**}

^{ns}: No significant difference; **: Significant at the 0.01 level; *: Significant at the 0.05 level; –: Data not available

The colour indices were used to develop regression models for predicting plant fresh and dry biomasses, and also N content.

Performance of the indices for predicting the plant parameters were near to each other as demonstrated by the r^2 and RSME of the equations. However, for predicting N content, the index CC (r^2=0.94) presented the best relation (exponential). The Rm showed the weakest quality among the indices to relate the three plant parameters.

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