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# Use of Digital Camera to Assess Nitrogen Status of Winter Wheat in the Northern China Plain

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## ABSTRACT

The most widely used methods to assess the nitrogen (N) status of winter wheat (*Triticum aestivum* L.) are the determination of plant total N by combustion, the testing of nitrate in the leaf tissue and the use of SPAD readings. However, due to their labor requirements or high costs these methods can hardly be applied to the huge wheat

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growing areas of the Northern China Plain. This study therefore examined an alternative method to measure the N status of wheat by using a digital camera to record the visible green light reflected from the plant canopy. The experiment was conducted near Beijing in a multi-factorial field trial with three levels of N. The intensity of green light reflected from the wheat canopy was compared to the total N concentration, to the nitrate concentration of the basal stem, and to the SPAD readings of leaves. The results show significant inverse relationships between greenness intensity, canopy total N, and SPAD readings at booting and flowering. At booting, sap nitrate $<2000\,mg\,L^{-1}$ was inversely related to greenness intensity and to sap nitrate concentration in the basal stem. At sap nitrate $\sim 2000\,mg\,L^{-1}$, the greenness intensity reached a plateau. At booting and flowering, significant inverse relationships between greenness intensity and shoot biomass were found. The results show the potential of the new method to assess the N status of winter wheat.

*Key Words:* Greenness intensity; Nondestructive measurements; Photography.

## INTRODUCTION

Winter wheat (*Triticum aestivum* L.) is one of the most important crops in the Northern China Plain and is usually fertilized with large amounts of mineral nitrogen (N) to achieve high grain yields. In recent years, increasing concern about the nitrate concentration of the groundwater stimulated research to improve N fertilizer management in this region.[1] To this end several methods such as the testing of sap nitrate in the basal stem and of soil Nmin levels have been employed to better match N demand and N supply.[2,3] Plant total N concentration has often been used to assess the N status of crops but is time consuming and does not reflect well excessive N supply. As a nondestructive and rapid method, SPAD readings have been recommended to determine the N status in winter wheat.[4,5] The shortcomings of this method are that the SPAD chlorophyll meter only allows to measure a small part of a leaf and a large number of random observations are usually needed to obtain a representative average value. Also the measurements are subject to operator bias in the selection of leaves and for the monitoring of large areas, the collection of SPAD meter data is too time consuming.

Alternatively, the testing of sap nitrate in the basal stem has been found to allow a reliable assessment of the N status of wheat. This method has also been used to predict yield and grain quality of wheat in field trials but has not been widely accepted by farmers because of the complexity of the method which involves a cutting of the stem combined with the use of chemical reagents or strips.[6] Therefore, a rapid and inexpensive method to monitor a crop's N status in the field would be of great value to make wheat production in the Northern China Plain more environmentally sound.

The canopy color of crops reflects their N status. In corn it has been shown repeatedly that N deficient plants reflect more light over the entire visible spectrum than N sufficient ones.[7,8] It has been proven that differences in light reflectance are usually largest for wave bands between 550 and 600 nm. Research on soybean indicated that the light reflectance from leaves of plants grown at three different N rates differed most near 550 nm.[9] On the other hand, the green light reflected from plants and detected by the human eye has a peak wavelength of 550 nm. This greenness is generally recognized as an indication of the N status in many crops.[8] It shows the potential to use the light reflectance in the visible spectrum, especially in the green band, to determine the N status of crops.

The development of low-cost color digital cameras that use charge coupled device (CCD) arrays to capture images allows measurement of the intensity of light reflected on a plant canopy. Adamsen et al.[10] used a color digital camera to measure the greenness of a wheat canopy at the plot level by calculating the ratio of green (G) to red (R). Dymond and Trotter[11] used a CCD array to obtain color images of forest and pasture targets from aircraft. They were able to calibrate the camera system and used it to evaluate the bi-directional reflectance properties of different targets. Lukina et al.[12] used digital images captured by a color digital camera to estimate the vegetation coverage and biomass of wheat.

The objective of this study was to determine the feasibility of using a color digital camera to detect the N status of winter wheat and to compare it to the total N concentration, to the nitrate concentration of the basal stem sap and to SPAD readings.

## MATERIALS AND METHODS

The properties of the loamy soil (0 to 0.3 m) at the experimental site of Dongbeiwang, near Beijing, in northwestern of the Northern China Plain were a bulk density of 1.33 g $cm^{-3}$, pH 8.0, 17.3 g organic carbon $kg^{-1}$, 52.5 g $CaCO_3$ $kg^{-1}$, 34.6 mg Olsen-P $kg^{-1}$, and 125 mg $NH_4OAc$-K $kg^{-1}$.

The field experiment comprised a winter wheat/summer maize double cropping system, which involves planting and harvesting of one wheat and one maize crop each year. In this experiment, the first crop was summer maize, which was sown in June 1999 and harvested in September. From October 1999 to September 2001, two winter wheat/summer maize rotations followed. All results presented in this article were obtained in the 2000/2001 winter wheat growing season.

The $3 \times 2 \times 3$ factorial split–split block experiment with four replications contained (i) three methods of irrigation as main plots of $60 \times 30$ m comprising sub-optimal irrigation as a control, conventional irrigation at 384 mm split into four applications, and optimized irrigation at 310 mm split into six applications; (ii) two straw levels as sub-plots of $60 \times 15$ m consisting of plus and minus straw recycling to the soil; and (iii) three levels of N application as sub-sub-plots of $20 \times 15$ m comprising an unfertilized control, conventional N fertilization, and optimized N fertilization. Conventional N application as typically practiced by farmers in the Northern China Plain consists of 150 kg N $ha^{-1}$ as $NH_4HCO_3$ before sowing and an additional 150 kg N $ha^{-1}$ as urea at booting. The optimized N fertilization treatment took into consideration the mineral N (Nmin) target value (split for three growth stages) for the envisaged yield and the Nmin level in the soil profile before sowing, at regreening and at booting.

Before the sowing of winter wheat in 2000/2001, 55 kg P $ha^{-1}$ were applied as triple superphosphate (TSP) to all plots. Winter wheat, variety Jingdong 8, was sown in mid October 2000 at an amount of 187 kg $ha^{-1}$ with a row spacing of 15 cm and harvested in mid June 2001. During the 2000/2001 winter wheat growing season, eight contrasting treatment plots were selected for the measurements reported in this article (Table 1). Their Nmin levels (0–0.9 m soil depth) before sowing and the N rate applied are shown in Table 2.

Soil Nmin and plant total N analyses were done before sowing, at regreening [156 days after sowing (DAS)], booting (184 DAS), flowering (203 DAS), and after harvest (242 DAS). Five soil cores were taken from each plot and pooled at 0–30, 30–60, and 60–90 cm depth intervals. Subsequently, these samples were sieved, extracted by 0.01 mol $L^{-1}$ $CaCl_2$ solution and $NH_4^+$-N and $NO_3^-$-N were analyzed by Continues Flow Analysis (TRRACS 2000).

Plant SPAD readings were taken with a Minolta SPAD®-502 chlorophyll meter[13] on 19 April (booting stage) and on 7 May, 2001 (flowering stage). For this purpose 30 first fully expanded leaves were randomly selected and measured to obtain an average value of each plot. At the same time, the aboveground plant biomass was harvested in 1 $m^2$ sampling areas per plot, dried to constant weight at 70°C, and analyzed for total N using the Kjeldahl method. At booting, the nitrate

***Table 1.*** Treatments of the soil fertility experiment selected for the nitrogen monitoring study in winter wheat of the Northern China Plain.

| Treatment | Irrigation | Straw | N fertilization |
|---|---|---|---|
| 1 | Optimized | Without straw | Continuous 4 crop seasons, no N fertilizer |
| 2 | Optimized | Without straw | Continuous 3 crop seasons, no N fertilizer |
| 3 | Optimized | Without straw | Continuous 2 crop seasons, no N fertilizer |
| 4 | Optimized | Without straw | Current season no N fertilizer |
| 5 | Optimized | Without straw | Conventional N fertilization |
| 6 | Optimized | Without straw | Optimized N fertilization |
| 7 | Optimized | With straw | Optimized N fertilization |
| 8 | Conventional | Without straw | Conventional N fertilization |
| 9 | Conventional | Without straw | Optimized N fertilization |

***Table 2.*** Initial levels of mineral nitrogen (Nmin) and N application rate ($kg\,ha^{-1}$) in the treatments selected for this study on winter wheat of the Northern China Plain.

| Treatment | Nmin before sowing | Basal fertilization | Topdressing at regreening stage | Topdressing at shooting stage | Total N supply |
|---|---|---|---|---|---|
| 1 | 52 | 0 | 0 | 0 | 52 |
| 2 | 64 | 0 | 0 | 0 | 64 |
| 3 | 96 | 0 | 0 | 0 | 96 |
| 4 | 103 | 0 | 0 | 0 | 103 |
| 5 | 473 | 150 | 0 | 150 | 773 |
| 6 | 112 | 0 | 17 | 47 | 176 |
| 7 | 112 | 0 | 15 | 49 | 176 |
| 8 | 461 | 150 | 0 | 150 | 761 |
| 9 | 116 | 0 | 17 | 66 | 199 |

concentration of the plant sap was tested with a Reflect Meter (Merck Co., Darmstadt, Germany). At maturity, in each plot three separate subsamples (each of size $3\,m^2$) were harvested to determine grain and straw yield.

The digital pictures of the winter wheat canopy were obtained with an Olympus 2100L Digital Camera on 19 April (booting) and 7 May 2001 (flowering). To work at a comparable solar angle and light intensity, all images were taken between 12:00 and 13:00 on clear days at 1.2 m above the ground and at an angle of 60°. Image resolution was 1024 × 768 pixels of 8 bit for red, green, and blue. Subsequently, the images of size 2.39 MB were transferred in TIFF format to a computer and processed with Adobe Photoshop® to extract color information.

## RESULTS

At booting significant inverse relationships were found between greenness intensity and canopy total N (Fig. 1) and between greenness intensity and SPAD readings (Fig. 2). For the relationship between sap nitrate with the greenness intensity, the latter reached a plateau when the sap nitrate concentration was above 2000 mg $L^{-1}$ (Fig. 3A). At a sap nitrate concentration <2000 mg $L^{-1}$, however, the greenness intensity of the wheat canopy's image decreased with increasing nitrate concentration (Fig. 3B).

Significant inverse relationships were also detected between greenness intensity and shoot biomass at booting and flowering (Fig. 4). Canopy biomass decreased with increasing greenness intensity. The larger the biomass of wheat, the less green light was reflected from the canopy. At flowering, most of the color intensity came from canopy light reflectance, whereas at booting a large proportion of the color intensity came from soil reflectance.

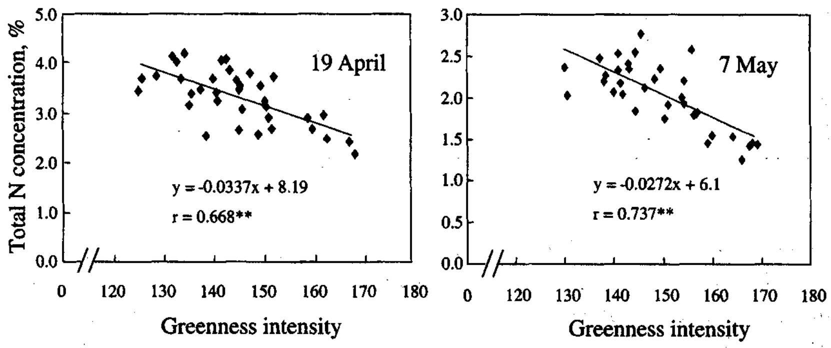


***Figure 1.*** Correlation between total N concentration and greenness intensity of a wheat canopy at booting and flowering on 19 April and 7 May 2001 ($n = 36$).

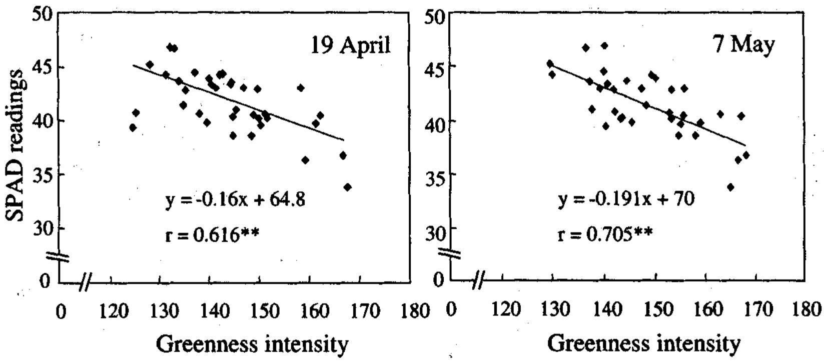


*Figure 2.* Correlation between SPAD readings and greenness intensity of a wheat canopy at shooting and flowering on 19 April and 7 May in 2001 ($n = 36$).

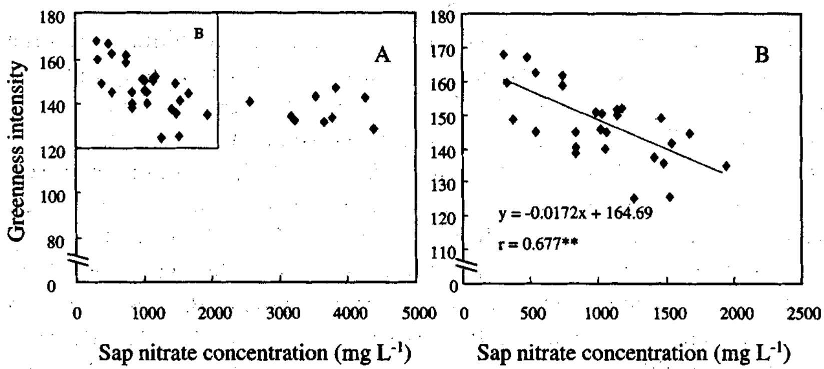


*Figure 3.* Relationship between greenness intensity of a wheat canopy and the sap nitrate concentration in the basal stem at booting (Fig. B shows a detail of Fig. A at a nitrate concentrations below 2000 mg $L^{-1}$; $n = 36$ for A and 27 for B).

## DISCUSSION

The results of the digital image analysis technique correlated well with the other methods used to assess the N status of wheat. Significant correlations were found between the greenness intensity of the canopy image and plant total N concentration, sap nitrate, and canopy biomass. The correlation coefficients ($r$) ranged from 0.6 to 0.8. This shows the potential of using a color digital camera as a near-ground remote sensing

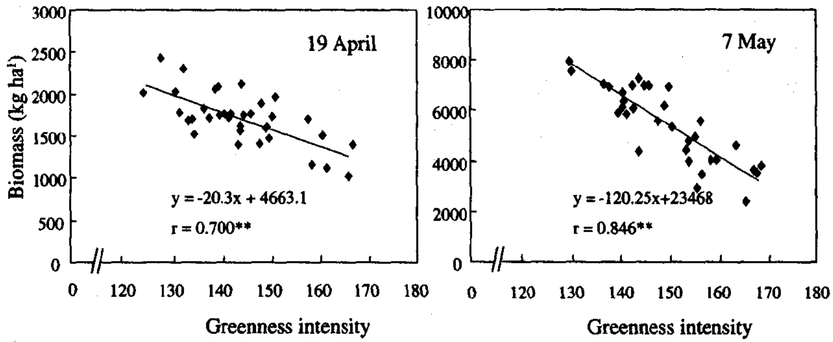


***Figure 4.*** Correlation between canopy biomass and greenness intensity at booting and flowering of wheat on 19 April and 7 May 2001 ($n=36$).

tool to detect the N status of wheat. Moreover, this technique shows the potential to estimate canopy biomass without destructive sampling. The results also suggest that the relative value of the R, G and B intensity or the G/R, G/(R + G + B) ratio need to be considered for a more reliable assessment of the N status of wheat. Adamsen et al.[10] used a green (G) to red (R) ratio to measure the greenness of a wheat canopy and showed good correlations between G/R ratios with SPAD readings. In the study presented here the correlations of the absolute G value with the SPAD readings were higher than with the G/R ratio or the G/(G + R + B) ratio (data not shown). But in another experiment, the G/(G + R + B) ratio was more reliable than the G value (data not shown). This needs to be verified in further studies before more definitive conclusions can be drawn.

A canopy's greenness intensity as recorded by the digital image processing method is affected by many external factors. Soil reflectance, especially on light colored soils, the cloudiness of a particular day and the angle of view from which an image is taken are known as potential errors affecting the comparability of reflectance measurements over time and space. The limitation of such measurements to closed canopies can minimize the first source of error, whereas the control of light intensity and consistency in the angle of view depends on environmental conditions and the care of the operator. Nevertheless, even if these factors are controlled, simple field measurements of reflectance to monitor a crop's N status as presented in this study will only be successful as long as chlorophyll formation is dependent on N alone. With rapidly increasing resolution and data storage capabilities the use of digital images to assess a crop's N status will likely grow in the near future. Some recent camera systems even allow to directly record the near-infrared (NIR) spectrum of reflected light, which is much less dependent on external errors and will therefore facilitate the monitoring of N in crop canopies at the field level by simple photometric methods.

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