Use of passive sensor technologies to determine the N-status of tomato plants (*Lycopersicon esculentum* L.)

K. Nerlich[1], J. Pfenning[2], S. Graeff[1], W. Claupein[1], M. Erbs[2], H.-P. Liebig[2]

[1]Institute of Crop Production and Grassland Research
University of Hohenheim
Fruwirthstr. 23
70599 Stuttgart

[2]Institute of Special Crop Cultivation and Crop Physiology
- Vegetable Science -
University of Hohenheim
Emil-Wolff-Str. 25
70599 Stuttgart
graeff@uni-hohenheim.de
pfenning@uni-hohenheim.de

Abstract: The advantages of precision agriculture in the vegetable growing and high value crop sector may accrue to horticulturists especially with respect to meet quality standards and to carry out selective and subsequent harvesting. However, the implementation and use of site-specific sensor technologies has never been adopted for horticultural purposes in the context of nitrogen fertilization sufficiently. Suitable sensor technologies and especially crop specific calibrations to determine crop nitrogen status and adapt fertilization strategies are still missing in this area. The aim of this study was to evaluate the use of a passive sensor technology to set up suitable calibrations to determine the N-status of tomato plants cv. Vanessa, and to adapt N-fertilization rates in the early stages of a growing period based on the sensor measurements. A greenhouse study was conducted with tomato plants during three months in 06 (April-June). Three different N fertilization rates (30 kg, 60 kg, and 100 kg) were implemented. As soon as the first inflorescence of the tomato plant was visible, sensor measurements were carried out on the first expanded leaf above the inflorescence with a digital imager (Leica S1 Pro) and repeated once a week. The results of the study indicate that the fine tuning of fertilizer operations using feedback signals from the tomato plant based on sensor measurements is clearly a promising way for optimizing nitrogen fertilizer inputs in horticulture and thus enhancing crop yield and quality.

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1 Introduction

Precision agriculture (PA) aims at making cultural operations more efficient, while reducing the environmental impact and enhancing crop quality. In this framework, new sensors are implemented in order to measure soil and crop properties on-line. Sensors allow the easy acquisition of the spatial and temporal information during a cultural operation and informing about the crop's actual status to enable the adjustment of future cultural operations. Remote sensing capabilities are under development that may improve the accuracy and reduce the cost of real-time measurements of spatial variability in crop physiological status and crop quality. Despite the evident benefits of PA, its widespread adoption is constrained by concerns amongst non-adopters as to its benefit. This is especially the case for cereal production where the primary interest is in the variable application of fertilizers.

In contrast, the advantages of operating precision agriculture in the vegetable production and high value crop sector may accrue to horticulturists especially with respect to meet quality standards and to carry out selective harvesting concerning yield and fruit size as for tomato growing. Furthermore, PA is likely to have a greater profitability advantage than current farming methods for higher-value crops, because yield increases resulting from more precise input application are worth more in such cases. However, the implementation and use of site-specific sensor technologies has never been adopted for horticultural purposes sufficiently. Suitable sensor technologies and especially crop specific calibrations for adapting e.g. fertilization strategies are still missing in this area.

Tomato is an important vegetable crop where nitrogen (N) has a major influence on the productivity levels. The goal of N management should be supplying enough N to achieve maximum profit. Efficient N management in tomato production can be attained by suitable evaluation of plant nutritional status [Co 88], usually accomplished by a quantitative analysis of total N concentration. Alternatively, quick, non-destructive procedures have been proposed to evaluate tomato N status as sap nitrate [Co 88] and leaf greenness determination by the Minolta SPAD meter. Hence, the aim of this study was to evaluate the use of a passive sensor technology based on reflectance measurements of tomato plants to i) set up suitable calibrations to determine the N-status of tomato plants, and ii) to adapt N-fertilization rates in tomato plants during the growing period.

2 Material and Methods

A greenhouse study was conducted with tomato plants cv. Vanessa in climate chambers at the Institute of Special Crop Cultivation and Crop Physiology of the University of Hohenheim over three month in the 06 growing period (April-June). Three different N fertilization rates (30 kg, 60 kg, and 100 kg) were implemented. Each treatment was replicated three times. All pots were randomly arranged in a climate chamber to minimize shading effects. The temperature in the climate chamber was set to 20° C/17° C day/night (18° C ± 3° C) with a minimum of 13° C and a maximum of 24° C. The relative humidity was kept at 70 % ± 5 %.

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As soon as the first inflorescence of the tomato plant was visible, sensor measurements were carried out on the expanded leaf above the inflorescence and repeated once a week. Leaf scans were taken with a digital, light-sensitive (ISO 200–2400; spectral sensitivity of 250-1300 nm), high-spatial resolution (5140*5140 pixel) imager (S1 PRO, Leica, Germany). The imager provides an entirely digital and fully automatic process to produce highly accurate digital image data. The imager gives as output the values of trichromatic coordinates L*, a*, b* [C 86]. The imager was used in conjunction with a constant light source (Reporter 21D MicroSun, 21W, Sachtler, Germany). For each plant, scans were performed with different long-pass filters (380 nm, 490 nm, 510 nm, 516 nm, 540 nm, 600 nm) in conjunction with a LEICA Daylight Filter IRa E55 to cut all scans at 780 nm (wavelength ranges indicated with X_{780} nm). A second set of scans was taken without this daylight filter in order to scan in the near-infrared ranges, indicated with X_{1300} nm. Spectral data were studied to select feature wavelengths, that is, the wavelengths at which contrasts in spectral responses between major object categories became distinct.

Analysis of variance (ANOVA) was carried out on all crop and reflectance data using the general procedures of the Tukey minimum significant difference (MSD) test at the 5 % significance level of the Statistical Analysis System (SAS) version 6.12. Correlation and regression analyses were performed to determine the association among monitored physiological parameters, nitrogen concentration and leaf spectral reflectance.

3 Results and Discussion

Over all investigated wavelength ranges, the visible spectrum was most responsive to changes in N status of the first leave above the inflorescence. N status of fully expanded leaves ranged from 3.5 % to 7.5 % nitrogen in leaf dry matter and correlated with determined changes of the reflectance parameter b*. The correlation indicated that the b* parameter increased when tomato plants were more than sufficiently feed with N (N concentration > 6.0 %) and when N was deficient ((N concentration < 4.0 %) (Fig. 1). As the reflectance parameter a* increased under sufficient supply but decreased under nitrogen deficiency (results not shown), the nutritional status of tomato plants could be clearly discriminated.

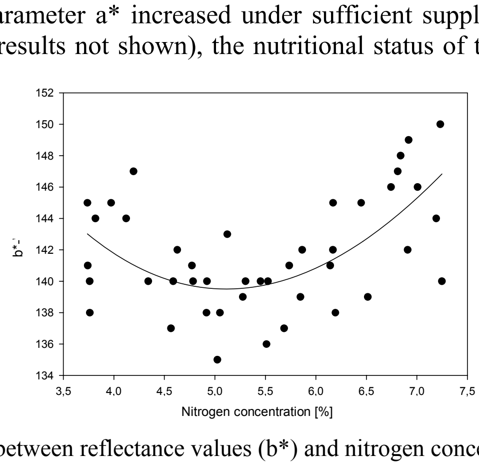

Figure 1: Correlation between reflectance values (b*) and nitrogen concentration in the first leaf above the inflorescence in the visible wavelength range 380_{780} nm..

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Furthermore, the investigation of N status of leaves above different trusses (IF) within a single plant clearly indicated differences in the reflectance parameter b*. Overall, the first leaves above youngest trusses had the highest b* value, indicating a high N demand (Fig. 2).

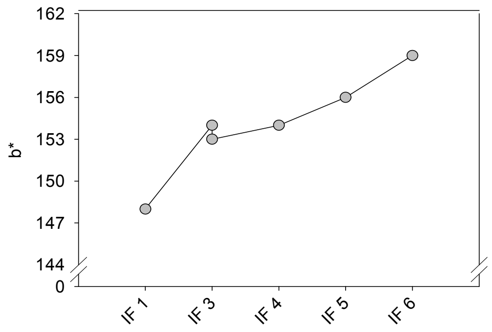

Figure 2: Reflectance change of first leaves above different trusses (IF) of a single tomato plant in the wavelength range 516_{780} nm.

The existence of values accepted as critical N concentration in the leaves above different trusses is necessary to be used as a standard or reference for the dimensioning of N fertilizer rates based on reflectance measurements. Several models for best describing crop response to N fertilization, which depends on N rates high enough to produce a clear maximum response, appropriate plant growth, N absorption rates and fruit yield exist and have led to different critical levels being the timing of N application, that is N availability, and the sink demand or dry matter yield the most sensitive parameters. To set up a nitrogen fertilization recommendation system based on reflectance measurements it will be necessary to test if N concentrations in leaf tissue of the different trusses are most responsive to total N demand of tomato and to evaluate which truss could give a valuable estimate of total N demand over the growing cycle of tomato plants.

4 Conclusion

The results of the study indicated that the fine tuning of fertilizer applications using feedback signals from the tomato plant based on sensor measurements is clearly a promising way for optimizing nitrogen fertilizer inputs. Further studies in this context are warranted.

References

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