THE INTERNATIONAL SOCIETY OF PRECISION AGRICULTURE PRESENTS THE
13th INTERNATIONAL CONFERENCE ON
PRECISION AGRICULTURE
July 31-August 4, 2016 • St. Louis, Missouri USA

Comparison between tractor-based and UAV-based spectrometer measurements in winter wheat

M.L. Gnyp[1], M. Panitzki[1], S. Reusch[1], J. Jasper[1], A. Bolten[2,3], G. Bareth[2,3]

[1] Research Center for Crop Nutrition Hanninghof, Yara International ASA, 48249 Dülmen, Germany

[2] Institute of Geography, GIS & RS group, University of Cologne, 50923 Cologne, Germany

[3] Spatial Data Services Cologne UG (haftungsbeschränkt), 53879 Euskirchen, Germany

A paper from the Proceedings of the
13th International Conference on Precision Agriculture
July 31 – August 4, 2016
St. Louis, Missouri, USA

Abstract. *In-season variable rate nitrogen fertilizer application needs a fast and efficient determination of nitrogen status in crops. Common sensor-based monitoring of nitrogen status mainly relies on tractor mounted active or passive sensors. Over the last few years, researchers tested different sensors and indicated the potential of in-season monitoring of nitrogen status by unmanned aerial vehicles (UAVs) in various crops. However, the UAV-platforms and the available sensors are not yet accepted to monitor nitrogen status in farm practice. This study compares tractor-based spectrometer measurements with measurements from a UAV to assess the potential in estimating N uptake. Sensors on both platforms were technically identical. The UAV sensor was adapted to a UAV platform and its payload restriction. The sensors measured the reflectance in the spectral wavelength domain of 600-1100 nm and with a spectral resolution of 10 nm. Measurements were taken in a winter wheat field, which was split into 12 differently fertilized treatments. At three crop growth stages in 2015 (BBCH 31, 49, 59) crop scans were conducted, accompanied by destructive biomass samples to determine aboveground plant N uptake. Spectra from both sensing platforms showed comparable characteristics. Similar correlations between N uptake and a Simple Ratio vegetation index (SR) were observed for both platforms across the three growth stages, whereas the commonly observed saturation of the Normalized Difference Vegetation Index (NDVI) was less pronounced for the UAV based sensor with nadir view, resulting in a better correlation with N uptake compared to an NDVI calculated from tractor-based sensor spectra obtained at oblique view. The differences in explained variability between the systems were due to the different sensor viewing angles and footprints. N uptake can be monitored by spectral reflectance measurements with an acceptable accuracy for farming practice, irrespective of the platform (UAV or tractor-mounted) and the related viewing angle. Provided that crop and growth stage specific calibrations are developed, UAV-based spectral crop sensing, therefore, has the potential to supplement tractor* *based sensing where required.*

Keywords. *Crop sensing, UAV, spectrometer, reflectance, vegetation index, winter wheat, N uptake, nadir view, off-nadir view.*

Introduction

Unmanned aerial vehicles (UAVs) are able to carry optical sensors and open new opportunities in precision farming in addition to tractor-based platforms. Nowadays, UAV-service providers enter the market with applications for precision farming, such as plant growth monitoring for field crops at high spatial resolution. Most farmers, who use UAV-services, request a simple mapping of their in-field variability during the growing season. To date, common farmer's practice in terms of sensor-based monitoring of in-season plant growth and nitrogen uptake is to use tractor-mounted devices that allow variable rate nitrogen fertilization on-the-go (Lammel et al., 2001; Mistele and Schmidthalter, 2010). Using UAVs instead of tractors may be an alternative option in manually managed crops, e.g. rice, or on agricultural sites with difficult conditions, e.g. wet soils, where tractors cannot drive without causing soil compaction.

In the last few years, researchers have investigated different commercial sensors and developed or modified new sensors for UAV-platforms (Primicerio et al., 2012; Geipel et al., 2016) and the list of crops tested with UAVs is long (Salami et al., 2014). Most common UAV-based approaches in the field of precision agriculture monitor biomass, nitrogen concentration, leaf area index, water stress or plant height. Furthermore, Bendig et al. (2015) reported about a combination of UAV-derived plant height with vegetation indices for biomass prediction. However, most of those monitoring approaches are well adopted in research, but not really practiced by end-users, e.g. farmers.

Most studies focused on testing sensors for UAV-platforms, but very few compared airborne UAV-based spectrometer measurements with hand-held or tractor-based spectrometer readings from the same field. Laudien and Bareth (2006) investigated spectral measurements from an airborne and tractor–mounted spectrometer for plant disease detection. Spectral comparison between hand-held spectrometers and UAV-carried spectrometers in the visible-near infrared domain were reported with promising results for barley (Aasen et al., 2015; Bareth et al., 2015), grassland (von Bueren et al., 2015) and wheat (Burkart et al., 2014).

Often, farmers are overwhelmed with new and complex technologies in precision farming (DLG, 2013) and need very simple and user-friendly sensors instead that help to monitor plant growth and nitrogen status. Mounting existing commercially established tractor-based sensors on UAV-platforms may encourage farmers to use them in their fields. Nevertheless, farmers request a fast, cost-efficient and easy to use sensor that supports their site-specific nitrogen management and application. One way to do this is to deliver nitrogen application maps based on reflectance measurements (Link et al., 2002). Field specific data, which may be provided by a sensor or service provider, must be processed and delivered on time when the farmers need it.

The objective of this research was to assess the potential of estimating N uptake by using a spectrometer, which is well established for tractor-platforms, mounted on UAV platform and compare its performance with tractor-based spectrometer measurements.

The authors are solely responsible for the content of this paper, which is not a referred publication. Citation of this work should state that it is from the Proceedings of the 13th International Conference on Precision Agriculture. Gnyp, M. L., Panitzki, M., Reusch, S., Jasper, J., Bolten, A. & Bareth, G. (2016). Comparison between tractor-based and UAV-based spectrometer measurements in winter wheat. In Proceedings of the 13th International Conference on Precision Agriculture (unpaginated, online). Monticello, IL: International Society of Precision Agriculture.

Materials and Methods

Study Site and Field Trial Layout

A field trial in winter wheat (Triticum aestivum L.) was conducted in 2015 at the Research Center for Crop Nutrition Hanninghof, Dülmen, North Rhine-Westphalia, Germany (51°50'24''N and 7°15'07''E). The field site is flat and the dominating soil is a dark and sandy stagnic cambisol (82% sand, 12% silt and 6% clay). The climate is temperate and humid. Annual average temperature, precipitation and sunshine hours are 9.3 C°, 718 mm and 1580 h, respectively. The site serves as long-term study site for the Research Center. One winter wheat cultivar (Inspiration) was sown on October 22nd, 2014 with a seeding density of 330 seeds/m^2. The whole field received 113 kg P_2O_5/ha as triple super-phosphate and 75 kg K_2O/ha as patentkali. At first topdressing, the field was subdivided into twelve treatments (N0-N11), where ten treatments (N0-N8, N11) received increasing N rates of 0-270 kg N/ha in 30 kg N/ha increments and two treatments (N9+N10) received in total 240 kg N/ha with different splitting. Each treatment was located along a 2 m wide tramline, which was used to scan the winter wheat canopy with a tractor-based spectrometer (Fig. 1). Each plot was 11.5 m by 15 m in size, including the tramline. Destructive plant biomass samples were taken to determine plant dry matter and plant N uptake at BBCH-31, BBCH-49 and BBCH-59 in 2015 (Meier, 2001); BBCH is related to the Zadoks code, corresponding to Feeke's scale growth stages 6, 10.1 and 10.5, respectively.

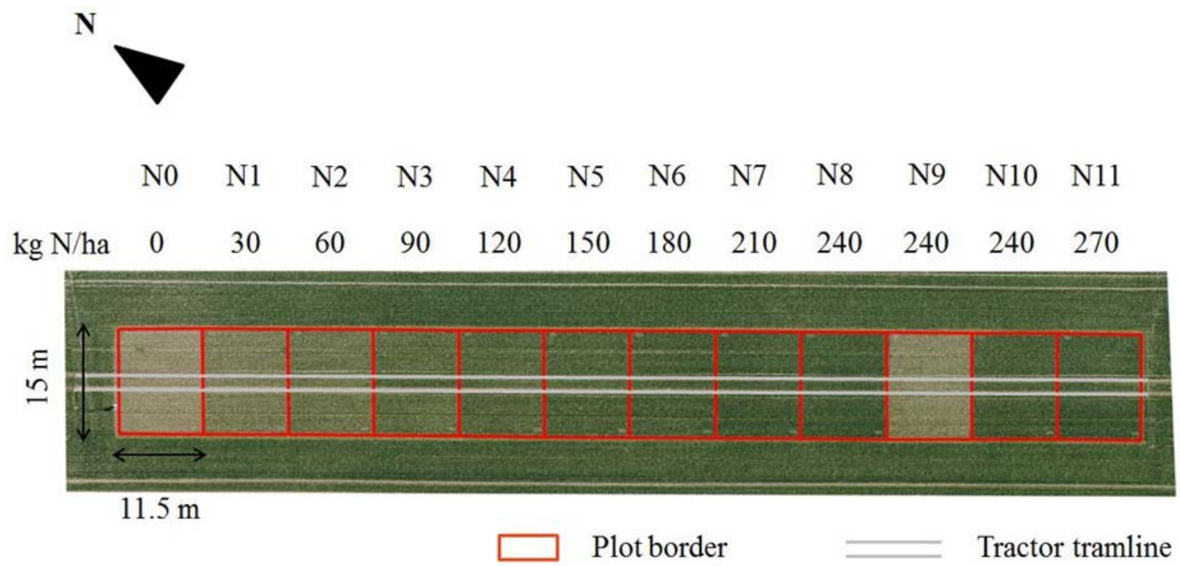

Fig 1. Trial layout of the winter wheat field with 12 treatments.

Sensor mounted on a tractor-platform

A tractor-based device including two spectrometers, manufactured by Yara International ASA, was used to measure the spectral reflectance of the crop (Fig. 2). It contained two spectrometers (AVANTES BV, Apeldoorn, Netherlands) covering the visible and near infrared spectral range from 600 to 1100 nm with a 10 nm spectral resolution. One unit pointed to the sky through a cosine-corrected diffusor to quantify the incoming irradiation (reference channel). Simultaneously, the second unit looked down at an oblique view angle of 60° into the canopy (canopy channel) and measured the canopy reflectance. To minimize solar azimuth effects that might be caused by oblique view, the system takes measurements from four directions (Reusch, 2003). Therefore, the spectrometer was connected to a four-armed light fiber and the signal was optically averaged. The fiber optics were angled into the canopy pointing in four directions, with 90° angles between each of them and at 60° from nadir. Spectral measurements were taken from a height of 2.8 m above the ground and with a sensor-canopy distance of approximately 6.3 m covering a footprint of four ellipsoids with 5.9 m². The tractor-based device can operate as long as sufficient daylight is available. Spectral data and the corresponding GPS positions were automatically recorded via a spectrometer software in a PC on the tractor. Information about treatments and growth stages were manually entered into the software. The tractor-mounted unit delivered on average 24 spectra per treatment and growth stage. The measurements were taken one day after UAV flights.

Figure 2: Sensor mounted on tractor-platform.

Prototype sensor mounted on a UAV-platform

A multi-rotor UAV-platform MK-Oktokopter (HiSystems GmbH, Moormerland, Germany) was used to carry a lightweight sensor prototype. The platform had eight engines and its total payload including the prototype amounted to 5 kg. While the heavy tractor-mounted crop sensor can be used over the day for several hours, the UAV-mounted lightweight unit can only stay in the air for 20 minutes per flight, due to battery and payload limits (Tab. 1). The spectrometers of the prototype (same unit as for the tractor based system) were protected by a small lightweight housing mounted on an active gimbal, which ensured that reference and canopy channels were on one axis (Fig. 3). The reference channel was located above the top of the UAV-platform capturing the incoming irradiation from the whole sky hemisphere through a cosine-corrected diffusor to quantify the incoming irradiation. In contrast to the tractor-mounted system, the canopy channel was connected to a single light fiber, looking down in nadir view into the canopy.

Table 1: Technical and geometric specifications of the tractor- and UAV-mounted crop sensors.

	Tractor-mounted	UAV-mounted
Spectrometer producer	AVANTES	AVANTES
Spectral range	600-1100 nm	600-1100 nm
Spectral resolution (effective)	10 nm	10 nm
View angle (canopy channel)	Off-nadir (60°)	Nadir (0°)
Sensor-canopy distance	6.3 m (oblique)	7 m (nadir)
Footprint	5.9 m²	5.8 m²
Weight (sensor + housing)	approx. 15 kg	approx. 1 kg

Spectrometer settings were adjusted in the spectrometer software on the notebook and transferred to the on-board mini PC mounted on the UAV-platform. A continuous spectra recording (one spectrum per second) was set because the wireless connection between notebook and on-board mini PC was suspended after take-off. During the flight, the on-board mini PC automatically logged spectral data, position and altitude. The MK-tool autopilot was used to set the flight waypoints. With a field of view of 22° and a speed of 2 m/s at an operational flight height of 7 m, the footprint covered an area of approx. 6 m^2, comparable to the tractor-based footprint. The UAV-carried unit delivered in average 22 spectra per treatment and growth stage.

Figure 3: Lightweight crop sensor prototype mounted on MK-Oktokopter UAV-platform.

Results and Discussion

Pre-processing of sensor readings

Sensor readings from both platforms (tractor and UAV) had 5 m position accuracy. This accuracy is sufficient for tractor-based monitoring and nitrogen fertilizer application. While the GPS position recorded on the UAV matched the sensor footprint, the GPS antenna of the tractor was located on the tractor cab (Fig. 4). Hence, the logged GPS positions for the tractor-mounted device were situated in the tramline and mismatched with the actual GPS position of the sensor footprint (Fig. 5).

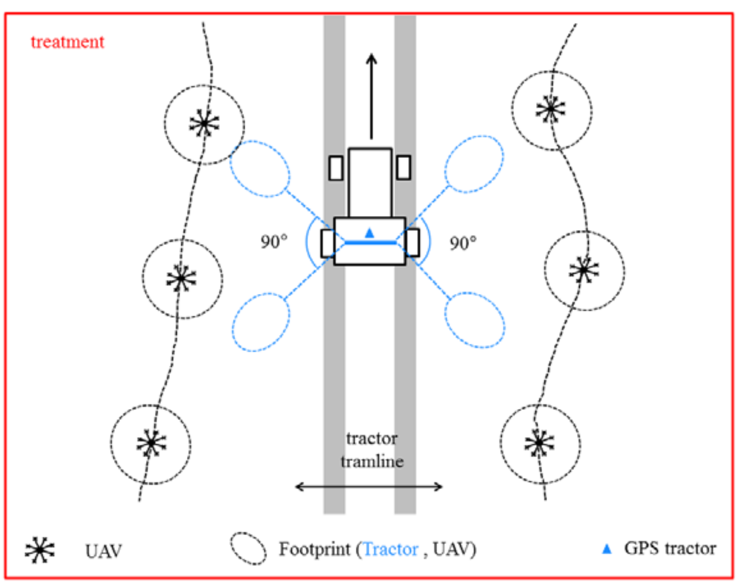

Fig 4. Footprints of the tractor and UAV platform.

The device recorded one GPS position for the tractor within the tramline with an averaged spectrum from the four optical inputs.

For a spectral comparison between the two units, the spectral readings were pre-processed using two methods:

1. Direct comparison by using the GPS positions of the UAV spectra and linking the closest spectra from the tractor to that position (spatial data processing by GIS software).

2. Indirect comparison by using each treatment as target and averaging the spectra per each sensor, treatment and growth stage (linkage to agronomic parameters, e.g. N uptake).

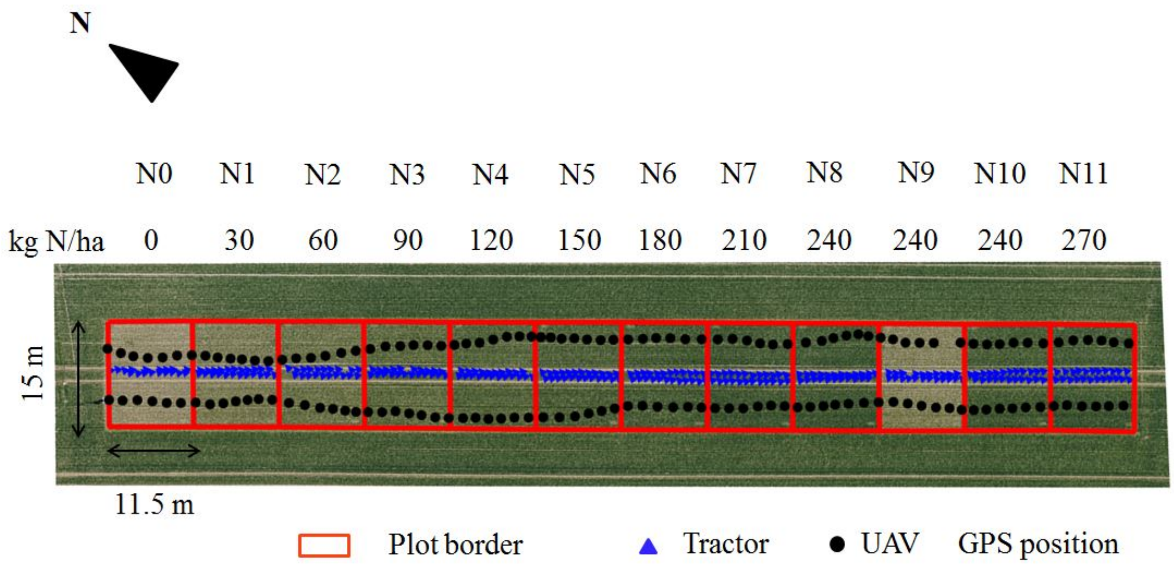

Fig 5. GPS positions for the spectral readings from both platforms.

The indirect approach allowed a linkage of spectral data with each treatment and N uptake measurement (n=36). In the direct method, spectral data with GPS positions in a distance of less than 3 m from the plot border and the tractor tramline were excluded. The valid spectra (n=497) from the tractor and UAV were linked by their GPS records using nearest neighbor method. In that case, only a spectral comparison was possible without a linkage to N uptake. The direct method allowed it to establish a relationship between the spectral measurements from both platforms.

Spectral comparison between the tractor-based and the UAV-based sensor

For the spectral comparison, the spectra taken by the tractor-based and UAV-based spectrometers were averaged per treatment and growth stage. Noisy spectral bands at wavelengths of 600-640 nm and 1070-1100 were excluded. Figure 6 shows the acquired spectra of both systems for selected N treatments (N0, N3, N6 and N9). The UAV-taken spectra have on average 20% lower absolute reflectance values (maximum reflectance of 37%) compared to the tractor-taken spectra, which reached maximum reflectance values of 57%. Those lower reflectance values were most likely caused by the nadir view angle (Gnyp et al., 2015) of the UAV-platform. In contrast, using the oblique view, the tractor has taken more vegetation into account. An off-nadir view favors capturing higher intensity of reflected light from the canopy (Aparicio et al., 2004; Samborski et al., 2009). Hence, more spectral information was gathered from the vegetation and less from the soil background by the tractor-carried sensor due to its oblique view.

In addition to nitrogen input treatments the growth stage significantly influenced the spectral values for both platforms. Increasing nitrogen inputs and progressing crop growth resulted in lower reflectance in the visible light range and higher reflectance in the near infrared domain.

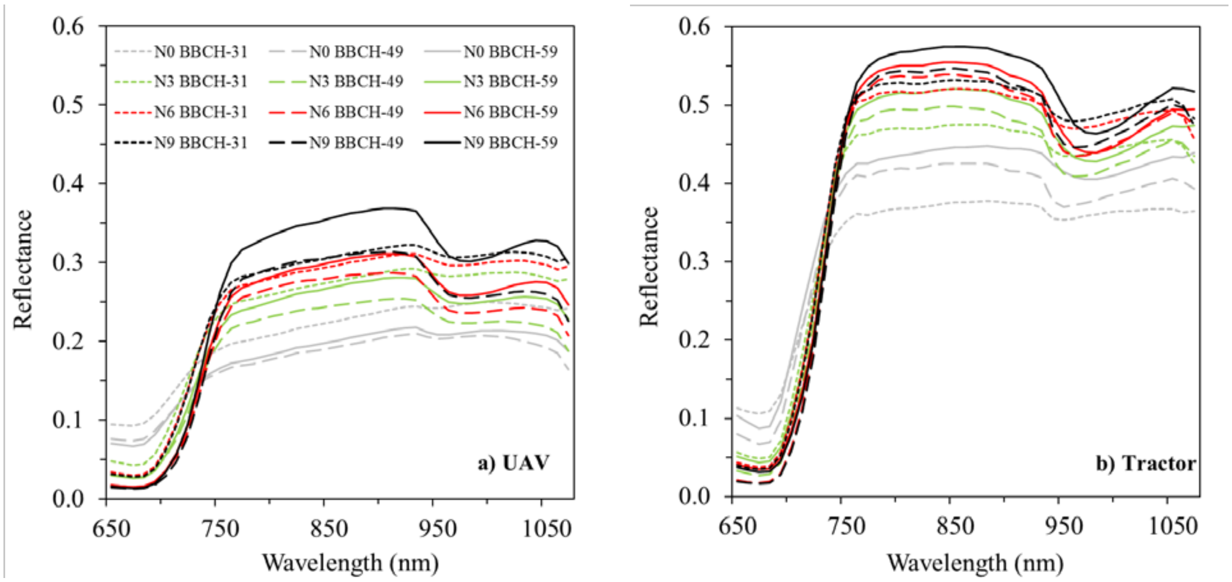

Fig 6. Spectral comparison between UAV-based and tractor- based spectral data for four selected nitrogen treatments (N0, N3, N6 and N9).

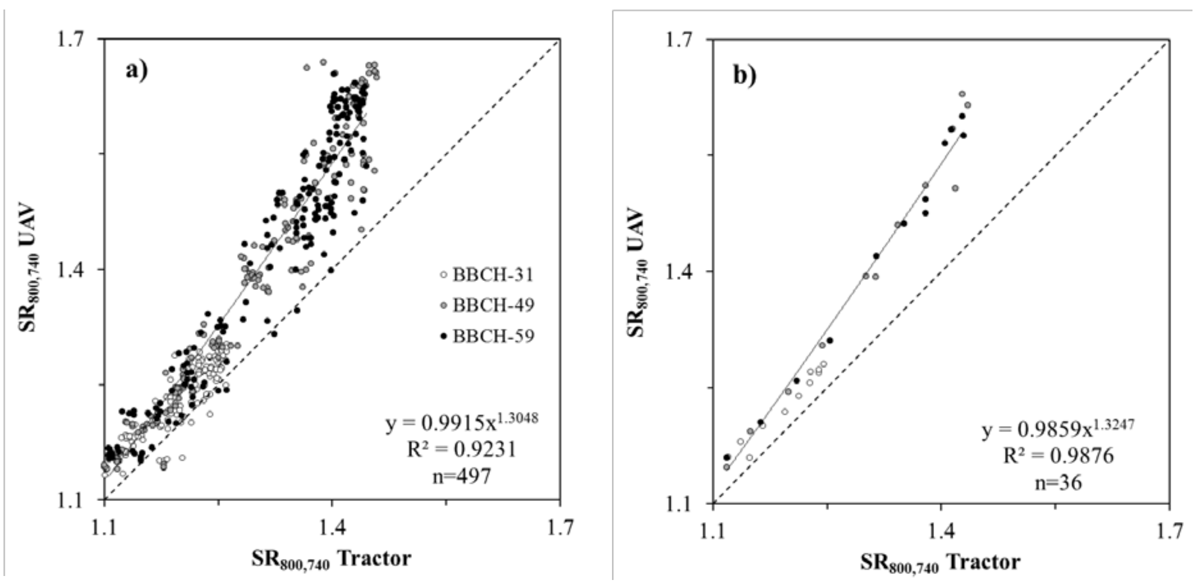

Fig 7. Relationship between SR $_{800,740}$ calculated from tractor and SR $_{800,740}$ calculated from UAV data. a) Direct comparison of SR values for all readings and b) Indirect comparison of averaged SR values per treatment and growth stages.

To investigate the relationship between the spectral measurements from the tractor-and UAV-platform, a Simple Ratio (SR) vegetation index based on wavelengths at 800 and 740 nm was calculated. This index was identified as the optimal wavelengths combination for determining N uptake in wheat (Reusch, 2005) and performed well in estimating N uptake in wheat for off-nadir and nadir measurements (Gnyp et al., 2015). A non-linear relationship between the SR values of the two sensors (tractor-based, UAV-based) was observed (Fig. 7).

Both sensors obviously distinguished between the differently fertilized treatments (Fig. 8). Increasing nitrogen input and progressive growth stage resulted in rising SR values for both platforms. $SR_{800,740}$ values from the UAV-mounted spectrometer were higher than those measured by the tractor-mounted system, with the difference increasing at later growth stages. The highest SR values were observed for the N9 treatment which had received a total nitrogen rate of 240 kg/ha. The most visible influence of growth stages on SR values occurred between the first (BBCH-31) and second measurement (BBCH-49) when the crop was growing most intensely and canopy closure was not fully reached, while the differences of measured SR values between the second (BBCH-49) and third scan (BBCH-59) were much lower.

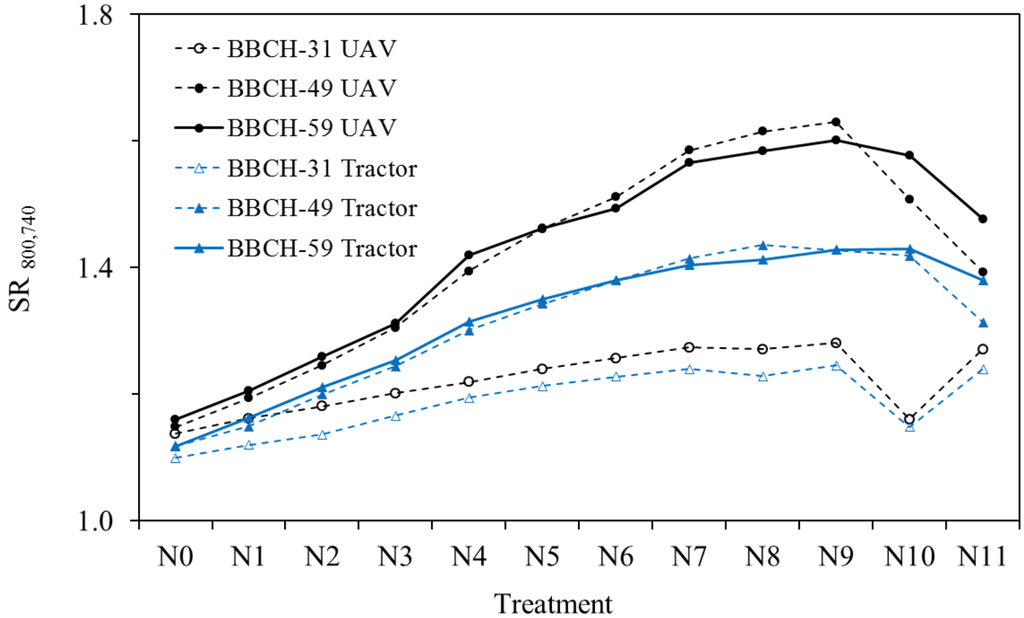

Fig 8. Calculated $SR_{800,740}$ based on the spectra from the UAV and tractor-based system for the twelve treatments at three growth stages.

Relationship between N uptake and Vegetation indices

Vegetation indices ($SR_{800,740}$ and NDVI using the reflectance in the red and near infrared) were calculated for the spectrometer readings from both platforms and related with N uptake (Fig. 9). The results revealed differences between the vegetation indices as well as a dependence on the platform. N uptake had a higher correlation to the SR index compared to NDVI, which was characterized by distinct signal saturation, especially when used with oblique view. The different viewing angles (off-nadir and nadir) and footprints (also affected by sensor-canopy distance) of the two platforms led to differences in the explained N uptake variability.

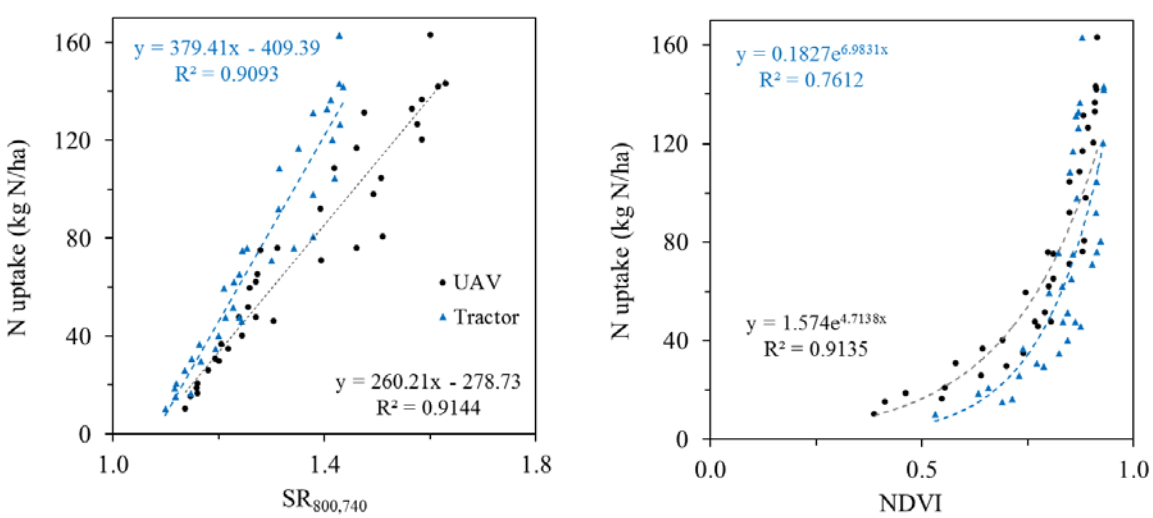

Fig 9. Relationship between N uptake and $SR_{800,740}$ derived from tractor and UAV spectrometer.

In case of the $SR_{800,740}$, the tractor and UAV sensors performed similarly in estimating N uptake up to approximately 80 kg/ha, whereas at higher N uptakes the estimate with the UAV sensor became less accurate compared to the tractor mounted system. Similar results were observed for the comparison between nadir and off-nadir measurements with a handheld spectrometer by Gnyp et al. (2015). The NDVI was characterized by a strong saturation at medium to high N uptake, of about 70 kg N/ha for the tractor mounted system and at slightly higher values for the UAV based system.

Conclusion

It was concluded that N uptake in a crop canopy can be monitored by spectral reflectance measurements, irrespective of the platform (UAV- or tractor-mounted) and the related viewing angle of the sensor. This applies particularly when using optimized wavelengths combination for N uptake measurements. Provided that crop and growth stage specific calibrations are developed, UAV-based spectral crop sensing has the potential to supplement tractor-based sensing where required.

Acknowledgements

The authors would like to express their gratitude to Klemens Brüggemann and his field team at the Research Center for Crop Nutrition Hanninghof for organizing and performing the tractor-based sensor scans, managing the field trial and taking plant samples. We acknowledge our laboratory team for their plant N analysis.

References

Aasen, H., Burkart, A., Bolten, A., Bareth, G. (2015). Generating 3D hyperspectral information with lightweight UAV snapshot cameras for vegetation monitoring: From camera calibration to quality assurance. ISPRS Journal of Photogrammetrie and Remote Sensing, 108, 254-259.

Aparicio, N., Villegas, D., Royo, C., Casadesus, J., Araus, J.L. (2004). Effect of sensor view angle on the assessment of agronomic traits by ground level hyper-spectral reflectance measurements in durum wheat under contrasting Mediterranean conditions. International Journal of Remote Sensing, 25 (6), 1131-1152.

Bareth, G., Aasen, H., Bendig, J., Gnyp, M.L., Bolten, A., Jung, A., et al. (2015). Low-weight and UAV-based hyperspectral full-frame cameras for monitoring crops: spectral comparison with portable spectroradiometer measurements. Photogrammetrie Fernerkundung Geoinformation, 2015 (1), 69-79.

Bendig, Yu., K., Aasen, H., Bolten, A., Bennertz, S., Broscheit, J., et al. (2015). Combining UAV-based Crop Surface Models, Visible and Near Infrared Vegetation Indices for Biomass Monitoring in Barley. International Journal of Applied Earth Observation and Geoinformation, 39, 79-87.

Burkart, A., Cogliati, S., Schickling, A., Rascher, U. (2014). A Novel UAV-Based Ultra-Light Weight Spectrometer for Field Spectroscopy. IEEE Sensors Journal, 14, 62-66.

DLG (2013). Nitrogen sensors (in German). DLG Merkblatt 390, pp 15-19.

Geipel, J., Link, J., Wirwahn, J. A., Claupein, W. (2016). A programmable aerial multispectral camera system for in-season crop Biomass and Nitrogen Content Estimation. Agriculture, 6 (4), 19 pages.

Gnyp, M.L., Panitzki, M. & Reusch, S. (2015). Proximal nitrogen sensing by off-nadir and nadir measurements in winter wheat canopy. In: Proceedings of the 10th European Conference on Precision Agriculture (pp. 43-50). Wageningen. Wageningen Academic Publishers.

Lammel, J., Wollring, J., & Reusch, S. (2001). Tractor based remote sensing for variable nitrogen fertilizer application. In: Horst, W.J. et al (Eds.), Plant nutrition – Food security and sustainability of agro-ecosystems (pp. 694-695). Dordrecht Klumer Academic Publishers.

Laudien, R., & Bareth, G. (2006). Multitemporal Hyperspectral Data Analysis for Regional Detection of Plant Diseases by using a Tractor- and an Airborne-based Spectrometer. Photogrammetrie Fernerkundung Geoinformation, 2006 (3), 217-227.

Link, A., Panitzki, M., Reusch, S., Lammel, J. (2002). Hydro N-Sensor: Tractor-mounted remote sensing for variable nitrogen fertilization. In: Proceedings of the 6th International Conference on Precision Agriculture (pp. 1012-1018). (unpaginated cd-rom). Minneapolis, USA.

Meier, U. (2001). Growth stages of mono- and dicotylendous plants. BBCH Monograph. Federal Biological Research Centre for Agriculture and Forestry, 158 pages.

Mistele, B., & Schmidthalter, U. (2010). Tractor-based quadrilateral spectral reflectance measurements to detect biomass and total aerial nitrogen in winter wheat. Agronomy Journal, 102 (2), 499-506.

Primicerio, J., Di Gennaro, S.F., Fiorillo, E., Genesio, L., Lugato, E., et al. (2012). A flexible unmanned aerial vehicle for precision agriculture. Precision Agriculture, 13 (4), 517-523.

Reusch, S. (2003). Optimisation of oblique-view remote measurements of crop N-uptake under changing irradiance conditions. In: Stafford, J.V., Werner, A. (Eds.) Proceedings of the 4th European Conference on Precision Agriculture (pp. 573-578). Wageningen. Wageningen Academic Publishers.

Reusch, S. (2005). Optimum Waveband Selection for Determining the Nitrogen Uptake in Winter Wheat by Active Remote Sensing. In: Stafford (Eds.) Proceedings of the 5th European Conference on Precision Agriculture. Wageningen Academic Publisher, The Netherlands, pp. 261-266.

Samborski, S.M., Tremblay, N., & Fallon, E. (2009). Strategies to Make Use of Plant Sensor-Based Diagnostic Information for Nitrogen Recommendations. Agronomy Journal, 101(4), 800-816.

Salami, E., Barrado, C., & Pastor, E. (2014). UAV flight experiments applied to remote sensing of vegetated areas, Remote Sensing, 6, 11051-11081.

Von Bueren, S.K., Burkart, A., Hueni, A., Tuohy, M.P., Yule, I.J. (2015). Deploying four optical UAV-based over grassland: challenges and limitations. Biogeosciences, 12, 163-175.