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Estimating Triticale Dry Matter Yield in Parcel Plot Trials From Aerial and Ground Based Spectral Measurements

P.O. Noack*

*University of Applied Sciences Weihenstephan-Triesdorf, Markgrafenstr. 16 , D-91746 Weidenbach, Germany (Tel: +49-9826-654242; e-mail: patrick.noack@hswt.de)

Abstract: Spectral measurement devices are a useful tool for quantifying biomass and the nitrogen uptake of plants. They are employed for site specific nitrogen application in arable farming and for crop scouting in parcel plot trials. In 2014 a plot trial with varying fertilizer types and levels has been monitored with a low-cost handheld NDVI sensor and an UAV carrying a multispectral camera. The results show that data from both spectral measurement devices was fit to estimate triticale dry matter yield with confidence levels exceeding 95%.

Keywords: spectroscopy, plant nutrition, yield estimation, UAS, biogas, nitrogen

1. INTRODUCTION

Establishing parcel plots is a common method for comparing different breeds of plants or different treatments under *ceteris paribus* conditions. They consist of several rectangular plots arranged in rows and columns. Traditionally, the development of plants from seeding to harvest is being monitored by human perception based on regular crop scouting missions resulting in scores for a selected set of target features.

Plant phenotyping is an emerging approach for assessing plant traits based on sensor values eliminating the subjective nature of human judgement. It aims at achieving highly reproducible measurements of plant properties. At the same time a sensor-based approach allows for high-throughput measurements increasing data density both in the time as well as in the spatial domain. Multi- and hyperspectral measurement devices are perceived to have a high potential for monitoring plant characteristics as the reflection of visible and near-infrared light is closely correlated to properties of plants relevant to breeding and production.

Gates et al. (1965) report that plants absorb, transmit and reflect light dependant on species and the thickness of leaves. Schmidhalter et al. (2003) have investigated the relationship between different spectral indices and biomass, nitrogen uptake and yield of wheat (*Triticum aestivum*). They found R^2-values of up to 94% when applying quadratic fits. All indices under investigation had a coefficient of determination above 0.7 when related to grain yield. Bach (1998) was able to predict corn yield in the Rhine Valley from satellite-born spectral data with “a high degree of accuracy”. Carter et al. (2001) found that reflectance of light in the far-red and green-yellow spectra is consistently related to plant stress. Lilienthal (2011) has presented a tractor-mounted hyperspectral sensing device for estimating crop parameters in parcel plot trials.

The reflectance of light from plants in parcel plot trials can be captured with different approaches one aspect being the carrier platform. Lately, unmanned aerial vehicles (UAV) carrying multispectral cameras have been proposed and utilized for capturing data in the field. Tractor-based sensor systems like the Trimble Greenseeker system or the YARA N-Sensor for site specific nitrogen fertilization are already applied in arable farming and may be suitable for assessing plant characteristics in parcel plot trials. Sensors may also be carried by humans triggering the measurements manually (handheld spectrometers).

Another aspect of measuring the reflectance of light are spectral range and resolution. Basic sensor systems directly compute spectral indices (e.g. NDVI) without revealing the underlying reflectances. Multispectral sensors or cameras acquire the reflection of several distinct, nonadjacent spectra whereas hyperspectral sensor systems seamlessly acquire reflections over a given spectrum. Passive sensor systems only measure the energy of light reflected from a body whereas active sensors emit light with a defined energy level enabling them to directly calculate the reflectance being the ratio of reflected light and the total amount of radiation.

The objective of this paper is to compare spectral measurements from a low-cost handheld device with data from a high-end multispectral camera carried by an unmanned aerial vehicle (UAS) with respect to their fitness for anticipating the biomass of small grains.

2. MATERIALS AND METHODS

After the introduction of the Renewable Energy Act (EEG) in the year 2000 the number and the size of biogas plants in Germany has steadily been growing. Biogas plants primarily serve the production of electrical energy. At the same time they produce substantial amounts of biogas slurry serving as organic fertilizer in plant production.

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2.1 Trial Description

The fertilizing effect of animal slurry has been well investigated whereas the effect of biogas slurry is not yet fully understood. The Agricultural Academy in Triesdorf (*Landwirtschaftliche Lehranstalten, LLA*) has established a long-term trial (2011-2014) with four different crop rotations and fertilizing regimes.

Table 1. Crop rotations and fertilizing regimes

Rotation	Corn-Rye	Triticale-Sorghum	Corn	Corn-Wheat-Canola
Fertilization	100% biogas slurry	50% biogas slurry/ mineral fertilizer	100% mineral fertilizer	No fertilization

The crop rotations under investigation are typical for farms operating biogas plants in the region.

Triesdorf is located in Bavaria, Germany (49.21^0 N, 10.59^0 E) in the county of Ansbach which has the highest density of biogas plants in Germany. The average annual temperature is 7,7 ^{0}C. Average annual precipitation between 1960 and 1990 was 630 mm, in 2014 the annual precipitation was 661 mm.

This paper focusses on Triticale which was sown on October 1, 2013. Four parcel blocks with randomly arranged variations with respect to fertilization were established. Each parcel plot had a length of 8.20 m and was three parcels or 4.50 m wide. Yield was determined by harvesting only the center parcel (1.50 m wide).

The nitrogen fertilization was carried out on February 23, 2014 and March 24/25, 2014. Parcels treated solely with biogas slurry received 98 kg N /ha and 42 kg N /ha respectively. Parcels receiving both organic and mineral fertilizer received 70 kg N/ha in the form of biogas slurry as a starter dressing and a subsequent fertilizer dose of 70 kg N/ha Hydrosulfan. Parcels solely treated with mineral fertilizer received two fertilizer dressings with a dosage of 68 kg N/ha Hydrosulfan.

All parcels have been treated with the herbicide Broadway on March 31, 2014. Triticale was harvested on July 1, 2014.

2.2 Measurement Devices and Data Sampling

The NDVI (*Normalized Difference Vegetation Index*) in the parcel plots under investigation has been measured with a Trimble GreenSeeker handheld device in the period between April 07, 2014 and June 30, 2014 on a weekly basis with four repetitions per parcel plot (576 samples). According to Wilkinson (2011) the sensor measures the reflection from the plant canopy at 650 nm (red) and 770 nm (near-infrared). The device features LEDs (Light emitting diodes) radiating light at the same wavelengths whenever a measurement is triggered. The resulting NDVI is calculated from the reflectances (reflection/radiation) according to the formula below:

$$NDVI = \frac{R_{770nm} - R_{650nm}}{R_{770nm} + R_{650nm}}$$

In addition, a Tetracam Mini MCA6 with ILS (*Incident Light Sensor*) carried by a geo-XR6 hexacopter UAV was operated over the trial on May 5, 2014, May 23, 2014 and June 30,2014. The Tetracam multispectral camera was configured to measure the reflection of light at 530 nm, 670 nm, 700 nm, 730 nm and 780 nm. Due to the light sensor compensating the spectral reflections for solar radiation the output is again represented as reflectances. The pictures were processed by geo-konzept GmbH, Adelschlag, Germany, resulting in multispectral digital orthophotos (DOP) and digital terrain models (DTM) extracted from pictures taken with a RGB camera (Sony a5000 alpha).

Plant heights were derived from the digital terrain model by following an approach suggested by Bendig et al. (2015). A terrain model of the soil surface was created by neglecting the areas covered by plants. After subtracting the original DTM from the soil surface model the resulting dataset contains the plant heights (*Crop Surface Model*, CSM).

After the parcel boundaries had been surveyed with a RTK-GNSS receiver (Trimble Integrated FmX Display applying Ntrip corrections), median plant heights and median reflectances for all wavelengths captured with the multispectral camera have been assigned to the parcels using Quantum GIS.

The parcels were harvested on July 1, 2014. The dry matter yield was determined by drying and related to the area harvested resulting in dry matter yield in dt/ha (decitonnes per hectare).

3. RESULTS

3.1 Dry Matter Yield

As expected dry matter yield in parcels with no fertilization clearly underperformed (Ø 72 dt/ha) when compared to the parcels which received N-fertilization (Ø 152 dt/ha). The relative ranking within the repetitions revealed that parcels treated with mineral fertilizer performed best, followed by the parcels treated with biogas slurry only (Table 2).

Table 2. Relative Treatment Ranking

Treatment	Fertilization	Rank
1	100% biogas slurry	2.0
2	50% biogas slurry/mineral fertilizer	2.8
3	100% mineral fertilizer	1.3
4	No fertilization	4.0

A comparison of the repetitions revealed that parcels which received fertilization in repetition 1 significantly produced