Feasibility study of using non-calibrated UAV-based RGB imagery for grassland monitoring: Case study at the Rengen Long-term Grassland Experiment (RGE), Germany

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Abstract: The monitoring of grassland ecosystems is an important task for providing spatial information on (i) biomass yield, (ii) quality, and (iii) floristic composition. Due to the heterogeneity and the spatial variability of grassland ecosystems, data acquisition on controlled factorial field experiments is of key importance for the interpretation of the spectral response of grassland. The Rengen Grassland Experiment (RGE) in Germany is such an effort for a long-term field experiment since 1941. The research focus of the present contribution is on the evaluation of low-cost UAV- or RPAS-based RGB-imaging to monitor the well-known impact of fertilizer nutrients on yield, quality, and floristic composition of grassland. Major research interest of the study is on the combined analysis of non-calibrated spectral RGB and canopy height data derived from UAV RGB imagery. To derive spatially mean plant height, the concept of multi-temporal crop surface models (CSM) was applied for the RGE. Additionally, a non-calibrated RGB vegetation index was calculated. Both parameters were evaluated against field measurements. The results indicate that the CSM-derived plant height performs very well against rising plate meter (RPM) measurements ($R^2=0.89$) and the RGB-VI are matching the pattern of NDVI values calculated from fieldspectrometer measurements ($R^2=0.7$). Finally, a new Grassland Index, the GrassI, is introduced combining plant height and VI data from the UAV imagery to distinguish between the different long-term fertilizer treatments. These first results indicate the potential of non-calibrated low-cost UAV-based RGB imaging to monitor the above mentioned spatial information of grassland ecosystems.

1 Introduction

The monitoring of grassland ecosystems is an important task for providing spatial information on (i) biomass yield, (ii) quality, and (iii) floristic composition. Due to the heterogeneity and the spatial variability of grassland ecosystems, data acquisition on controlled factorial field experiments is of key importance for the interpretation of spectral response of grassland. The Rengen Grassland Experiment (RGE) in Germany is such an effort for a long-term field experiment (SCHELLBERG et al. 1999) The research focus of this contribution is on the evaluation of low-cost UAV- or RPAS-based RGB-imaging to monitor the well-known impact of fertilizer nutrients on grassland ecosystems (HEJCMAN et al., 2007). More information on the RGE are available under http://www.lap.uni-bonn.de/forschung/forschungsprojekte/DDV%20Rengen.

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In agronomic investigations, it is shown that the approach of multi-temporal *Crop Surface Models* (CSM) is very suitable to derive crop plant height and crop biomass by using terrestrial laser scanning (TLS) or UAV-based RGB imaging (BENDIG et al. 2013, BENDIG et al. 2014, GEIPEL et al. 2014, HOFFMEISTER et al. 2010, TILLY et al. 2014). The first hypothesis for this study is that the UAV-based CSM approach is transferable to grassland ecosystems and the CSM-derived plant height can be used as a measure to estimate yield. The second hypothesis is that the CSM-derived plant height in combination with spectral analysis will provide information on quality and floristic composition. To prove the two hypotheses, multi-temporal UAV campaigns were conducted in combination with intensive field measurements at the RGE in 2014.

2   Study Area and Methods

The Rengen Grassland Experiment (RGE) is located 4 km northeast of the county city of Daun in the Eifel region and was established in 1941. The experiment comprises 55 plots in total, including ten replicates of the following fertilizer applications: Ca, CaN, CaNP, $CaNPK_2O$, $CaNPK_2SO_4$, and five unfertilized plots, as described in SCHELLBERG et al. (1999). Through the long-term application of these fertilizers, distinct plant communities have developed in the different plots (cf. CHYTRY et al. 2009), which vary in their morphological and optical properties. The current research was carried out within the DFG funded project "Detecting the response of plant functional traits to nutrient status in grassland by spectral reflectance measurements" (http://www.lap.uni-bonn.de/forschung/forschungsprojekte/Spectral%20Response%20of%20Traits), co-ordinated by the Crop Science Group of Bonn University.

In parallel to the UAV campaigns, (i) continuous destructive plant samplings were taken, (ii) standing biomass was quantified, (iii) floristic composition was determined, and (iv) non-destructive hyperspectral canopy reflectance was measured for the RGE in 2014. In this study we only focus on plant height and VIs. Plant height was measured in the field with a rising plate meter (RPM) on six dates between April and July 2014 (April 16th, April 25th, May 16th, May 25th, June 5th, June 23rd). At the same dates, the spectral reflectance of the different plant communities was measured in three replicates per plot (3 by 5 m) from nadir and at 1.5 m height above canopy with an ASD FieldSpec-3. Based on these measurements, the narrow-band normalized difference vegetation index (NDVI) was calculated according to Rouse et al. (1974):

$$NDVI = (R800 - R670) / (R800 + R670)$$

Multi-temporal UAV campaigns were flown over the RGE in 2014 on nine dates according to the field measurements (±3 days) during the first growth in 2014 (March 20th, April 6th, April 16th, April 26th, May 18th, May 27th, June 8th, June 26th, July 2nd) using a DJI Phantom 2 quadrocopter as a low-cost (< €600) and low-weight (< 1.1 kg) UAV. The payload of the Phantom 2 was estimated to be approx. 300 g by comparing camera with gimbal equipped versions. The flight endurance with one battery (LiPo 5600 mAh) is approx. 20 min. A standard RGB digital compact camera, a Canon Powershot 110, was mounted with a low-cost camera mount to the UAV. The Canon Powershot 110 was equipped with a Canon Hack Development Kit (CHDK) via SD card to enable continuous image series. Speed and aperture were fixed before take-off and the zoom

lens was set to 35 mm. The images are saved onboard on the SD card of the camera. The complete UAV imaging system is less than €800. In Fig. 1 (left), the Phantom 2 with the mounted Canon Powershot 110 is shown in air. The right picture gives an impression of the system in operation on the RGE. The diagonal length of the Phantom 2 is about 35 cm excluding the propellors.

Fig.1: *left* DJI Phantom 2 with the mounted Canon Powershot 110; *right* the UAV imaging system in air at the RGE

During the growing season in 2014, the RGE was multi-temporally monitored with the UAV imaging system. For each campaign, continuous RGB images were captured from a flying altitude of approx. 20 m above ground producing a large set of multiple overlapping images, each containing at least 15.000 pixels for each of the 25 plots. No detailed flight pattern was planned. The UAV-based imaging system was randomly and manually maneuvered over the experiment producing a large amount of multiple overlapping images. The latter were important to derive CSMs with Structure for Motion (SfM) techniques to receive spatially explicit plant height information at a spatial resolution of < 1 cm (Bendig et al. 2013). For SfM analysis, the Agisoft PhotoScan was used, and for computing of mean plant height per plot from the multi-temporal CSMs the ArcGIS software was applied.

Additionally, from a higher altitude above ground (approx. 50 m), images were taken covering the whole RGE to spatially derive a RGB-VI, calculated from the non-calibrated red, green, and blue reflectance. A recently developed RGB-based VI was applied:

$$\mathbf{VI_{RGB} = ((G*G)-(R*B)) \, / \, ((G*G) + (R*B))}$$

(Bendig et al. 2015, in review; Bendig 2015, in print)

For the second hypothesis of this contribution, the combination of CSM-derived plant height (CSM-PH) and the non-calibrated VI_{RGB} is addressed by introducing a **new Grassland Index**, **the *GrassI***:

$$GrassI = CSM\text{-}PH + VI_{RGB}$$

The idea of this new *GrassI* is the usage of structural and physiological information. While CSM-PH is relative low in the early growing stages, the *GrassI* is more dominated by the VI_{RGB}. In contrast, it is well known that with increasing plant height the NDVI or RGB-based VI are saturating (Hunt et al. 2013, Li et al. 2010). The latter effect is corrected in the *GrassI* by PH which dominates the calculated *GrassI* as taller grasses grow.

Furthermore, ground control points were installed and georeferenced with a RTK-GPS. This is of key importance because the accuracy of the UAV's GPS is not sufficient to derive a high precision georeference of the overlapping images. Consequently, in this study the georeference was improved during the SfM analysis.

3 Results

The comparison of the field measurements with the UAV-based imaging analysis were conducted at plot level. The field measurements represent mean plot values. Both, the UAV-derived data of plant height and VIs at a very high spatial resolution were summarized with zonal statistics for each single experimental plot covering an area of 3 by 5 m. An inside buffer of 0.2 m is created to exclude existing border effects between differently fertilized plots. The spatial resolution of the UAV imagery to compute the CSMs is < 1 cm while it is approx. 2 cm for the VI_{RGB}-analysis. In Fig.3 (left) an RGB image covering the investigated 25 plots of the RGE is shown. The black polygons represent the single plots whereas the red inside buffer polygons of the plots were used to compute mean values. The VI_{RGB} were calculated per pixel (Fig.3: *right*) and then summarized for the red inside buffer polygons for further evaluation against ground truth data.
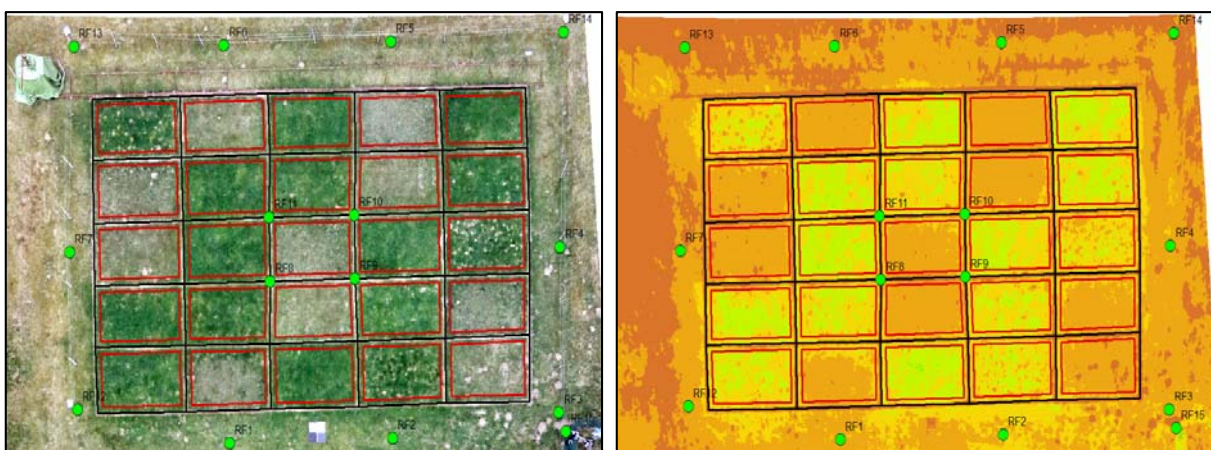

Fig.3: *left* RGB image (April 6th, 2014) of the investigated RGE experiment; *right* pixel-based VI_{RGB}-values; black polygons: plot border; red polygons: inside buffer plot polygons

The coefficient of determination (R^2) was computed in MS Excel for the CSM-derived PH and the VI_{RGB} by using the field measurements of the rising plate meter (RPM) and of NDVI with the ASD FieldSpec-3. This was done for each single plot in a multi-temporal context for all conducted campaigns. As introduced above, the campaigns were carried out with a maximum difference of three days. In Fig.4 (left) the results are shown for plant height. A very high R^2 of 0.89 is computed indicating a strong relation between CSM- and RPM-derived mean plant heights per plot in a temporal context. However, the mean CSM-derived plant height is always higher compared to the RPM values. This is explainable by the fact that the RPM compresses the sward fairly while the measuring plate is positioned on the canopy.

The correlation between the VIs in a temporal context is lower but with a R^2 of 0.7 still high. This is remarkable due to the fact that the VI_{RGB} is based on non-calibrated UAV-derived RGB imagery. Nevertheless, it seems that there also occurs some saturation of both VIs indicated by the uneven distribution of the points in Fig.4 (right).
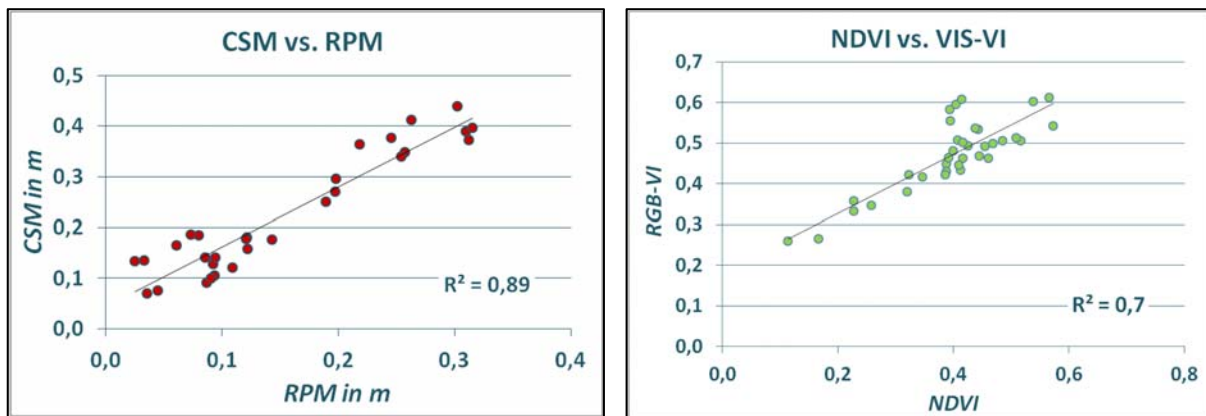

Fig.4: *left* analysis of CSM-derived and RPM-derive plant height; *right*: plot of field-measured NDVI against VI_{RGB}

Finally, the new Grassland Index, the *GrassI*, is computed only from the UAV imagery in a temporal context. Each of the five fertilizer treatments has five repetitions which were again summarized to produce a mean value for each fertilizer treatment. These mean VI_{RGB}-values are shown in Fig.5 for all five fertilizer treatments over time for the first growth at the RGE. It is clearly visible that the treatments are somehow clustered and can be separated into three groups (Fig.5). (i) The lowest values and no characteristic differences were obtained from Ca and CaN treatments, indicating that N supply under P- and K limitations did not stimulate any significant change in canopy properties. Significantly higher values were obtained for the fertilizer treatment including phosphate (P), i.e. the CaNP-plots. Earlier studies on the RGE clearly indicate that P is strongly limiting plant growth (Hejcman et al., 2010). The highest values with only minor visible differences were obtained from the $CaNPK_2O$- and $CaNPK_2SO_4$-treatments. No nutrient limitation is expected in these fertilizer treatments and S might be not a limiting nutrient at the RGE.
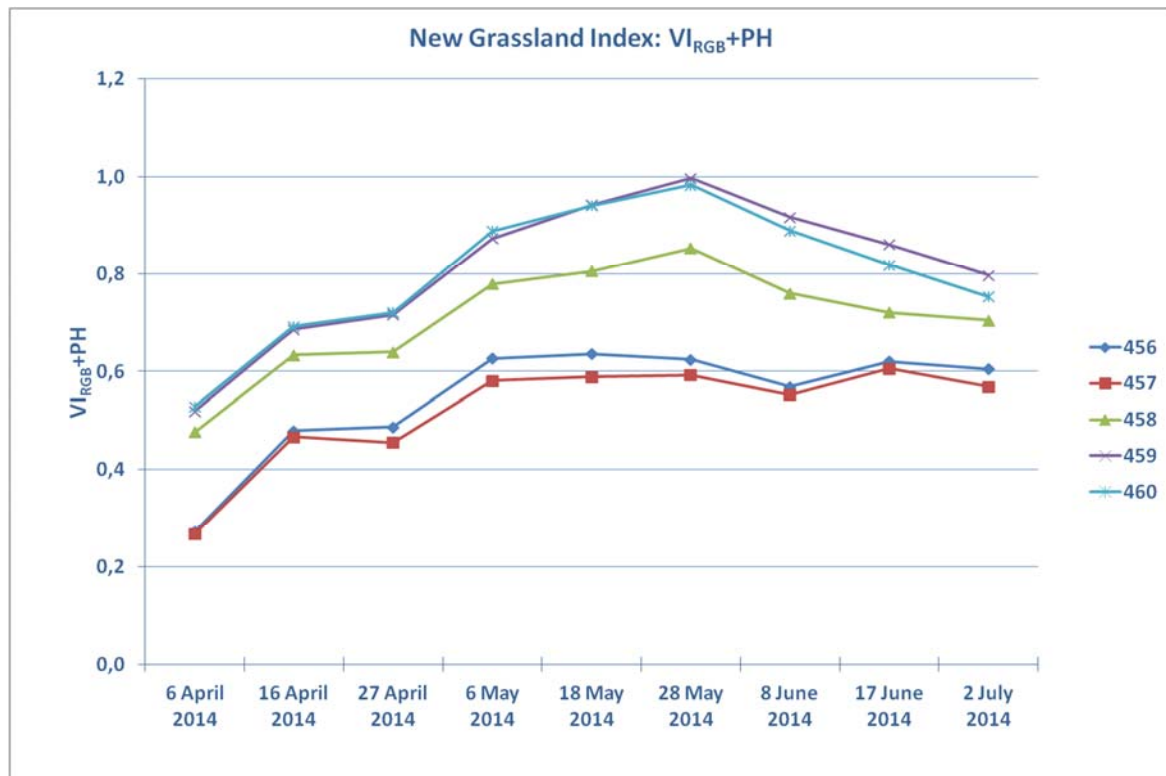
Fig. 5: Temporal development of the new *GrassI*-values for the fertilizer treatments at the RGE(456: Ca; 457: CaN; 458: CaNP; 459: CaNPK$_2$O; 460: CaNPK$_2$SO$_4$)

4 Discussion and Conclusions

It is state of the art that fertilizer applications have a significant impact on plant height, plant community composition and productivity. This is in detail documented for the RGE in a series of publications (e.g. CHYTRY, 2009, HEJCMAN et al., 2010). The mean multi-temporal plot data for plant height clearly indicate that it is possible to distinguish between most distinct fertilizer treatments in the RGE due to its differences in fertilizer dependent plant height. In contrast, treatments of similar height and structure (e.g. Ca and CaN, without P and K) exhibited similar temporal plant height patterns and could therefore not be discriminated. One major objective of this study was the combination of plant height with RGB-VI analysis. Therefore, a new VI, the *GrassI*, comprising plant height (PH) and the recently developed VI$_{RGB}$ is introduced, which combines the information content during phenological development from spectral reflectance and plant growth pattern.

The present study clearly indicates, that non-calibrated RGB images in combination with CSMs have a significant potential to spatially estimate plant height on grassland with satisfying quality. But, this approach has many other advantages and possible applications:

- It allows to distinguish between grassland types differing in canopy height as a result of other management treatments than fertilizer, for instance grazed against ungrazed areas,

conservation areas and temporarily set-aside grassland versus managed areas, drained against undrained grassland.

- We cannot yet oversee all possible applications of this technique for precision farming (PA) on grassland (SCHELLBERG & VERBRUGGEN, 2014), but standing biomass is for sure a key parameter required to respond to spatial heterogeneity within fields by new PA technologies. So far, non-destructive estimates of plant height and biomass are central but still missing in the decision making on farms. It is needed not only for decisions on grazing management but also for the calculation of nutrient extraction with harvested grass crops and nutrient balance calculation (SCHELLBERG et al., 2008).

- Further, the successful application of this approach is an important step forward in the exploration of grassland properties that are decisive for assessing ecosystem functions and services.

- As the high spatial resolution of 1 cm may not be required on practiced fields, the UAV may be positioned at higher altitudes and so cover even larger grassland areas on farms.

- The potential of this approach for a wider application lies also in its low price, easy handling of the UAV and the camera, semi-automated post-processing of the data based on comparable available software products, and on the monitoring of grassland that is difficult to access, such as coastal and riparian wetlands and protected areas.

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