Sensing – New Insights into Grassland Science and Practice

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Volume 26

Grassland Science in Europe

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Proceedings of the 21st Symposium of the
European Grassland Federation
Online
Hosted by Universität Kassel, Germany
17-19 May 2021

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UNIKASSEL VERSITÄT | ORGANIC AGRICULTURAL SCIENCES

Published by

The Organising Committee of the 21st Symposium of the European Grassland Federation,
Universität Kassel, Grassland Science and Renewable Plant Resources,
Steinstrasse 19, 37213 Witzenhausen, Germany

e-book ISBN: 978-3-00-068789-1

Abstract submission and evaluation by

Editing and production by

Universität Kassel,
Grassland Science and Renewable Plant Resources
Steinstrasse 19,
37213 Witzenhausen,
Germany
www.uni-kassel.de/agrar/gnr

Distributed by

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Estimating grassland biomass using multispectral UAV imagery, DTM and a random forest algorithm

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Abstract

A prerequisite for efficient pasture management is the regular estimation of the dry matter yield (DMY) by means of a rising plate meter (RPM). With the latest generation of unmanned aerial vehicles (UAV) equipped with a real-time kinematic (RTK) positioning system and a multispectral camera, it should be possible to measure sward heights and to estimate dry matter yields. To investigate this possibility, we developed an algorithm enabling a digital terrain model to be calculated from the digital surface model of grassland. DMY is estimated using a random forest estimator. Initial estimates at a previously unseen site achieved a root-mean-square error (RMSE) of 332 kg DM ha^{-1}. The results demonstrate that UAVs enable DMY predictions with an accuracy level close to RPM measurements. The underlying algorithm will be further developed and adapted to a wider variety of pasture types and meadows.

Keywords: grassland, machine learning, random forest, NDVI, remote sensing, dry matter yield

Introduction

In Switzerland, more than 70% of the utilised agricultural area consists of grasslands with a very diverse species composition and a heterogeneous growth pattern. A prerequisite for efficient grazing management is the regular estimation of the dry matter yield (DMY) by manual measurements of the sward height using a rising plate meter (RPM). With the latest generation of unmanned aerial vehicles (UAVs) equipped with a real-time kinematic (RTK) positioning system and a multispectral camera, it should be possible to measure sward heights and to estimate DMY over large areas with high accuracy (Viljanen *et al.,* 2018). However, to date, such approaches have required manual georeferencing with complex data processing. The calculation of a digital terrain model (DTM) based on a digital surface model (DSM) could help to overcome the limitations of manual georeferencing. This would make it possible to measure the vegetation height without prior marking of the area of interest with ground control points (GCPs) and subsequent referencing of the image, resulting in a significant improvement in the degree of automation. In this paper, we present an algorithm to calculate a DTM based on a DSM of pastures and meadows allowing DMY to be estimated based on a random forest model.

Materials and methods

DMY was calculated using a random forest estimator. To provide the model with robust data and to make it as reliable as possible to reflect seasonal growth patterns, swards of intensively managed meadows (experimental plots with a size of 4 m^2, 45 plots x number of overflights: n = 1026) at two different locations were flown over weekly with a UAV (DJI P4 Multispectral) from April to October 2020. Data from two additional sites of pastures from commercial farms (where partial areas of 30 m^2 were evaluated, 38 plots x 4 overflights: n = 152) were used as training data. In total, the training data set thus comprised 1178 polygons from four different sites and two utilization types (grazing and mowing). After flying over the meadows with the UAV, the DMY was determined by cutting (cutting height: 5 - 7 cm), weighing and drying sward samples (target variable). The model was tested with test data (n = 106) not included in the training data set from independent sites.

The pictures were taken without ground control points and were stitched to a 3-D model with Agisoft (Agisoft Metashape, 2020). We used a calibrated reflectance panel (MicaSense) with a nominal reflectance of 0.6 to radiometrically correct reflectance. The gain settings captured from the sunlight sensor were not used for radiometric calibration. A pixel size of 4 cm was chosen for the 3D model (DSM) and a pixel size of 3 cm for the orthomosaic with the five channels blue, green, red, red edge and near-infrared.

Based on the DSM, a DTM was generated with a kind of 'digital mower' making ground control points obsolete. The missing data were first interpolated and then the minima in the DSM were searched through a minimum filter of 1.5 on 1.5 metres. The DTM was subsequently smoothed with a two-dimensional Gaussian filter of 4.5 on 4.5 metres. The difference between the DSM and the DTM resulted in the sward height per pixel. To counteract divergences in the DTM, especially in areas with more complex topographies, the calculated sward height per pixel was smoothed again. For flat meadows this step seems redundant and the re-smoothing hardly changed the distribution of the grass height. Finally, the calculated average sward height for each plot was used for further calculations (Figure 1).

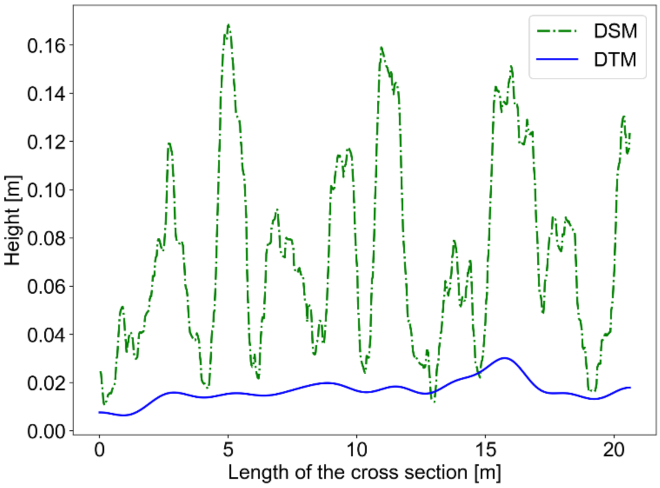

Figure 1. Example of a digital terrain model (DTM) calculated on the basis of an automatically generated digital surface model (DSM).

Results and discussion

To evaluate the DTM, meadows at three different locations (Figure 2) were flown over before and immediately after cutting. The difference between the two flights represents the average height of the swards. The R-squared value of 0.9 indicates that the results of the digital mower were a good representation of the sward heights measured in the field.

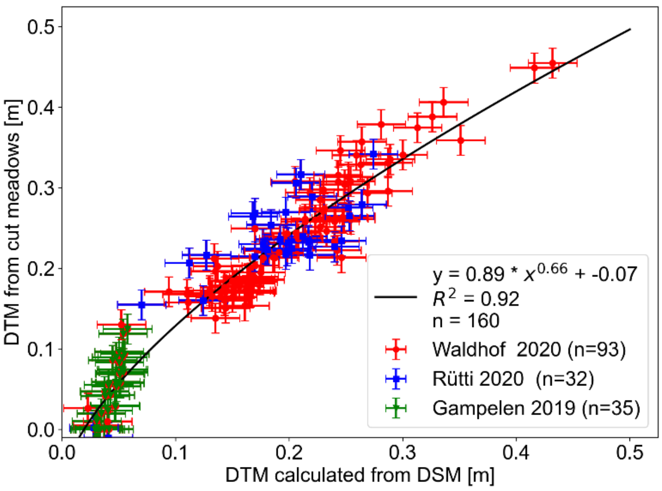

Figure 2. Evaluation of the 'digital mower' at three different locations in 2019 and 2020.

The DMY data was incorporated into the model as target variable. Based on the 3D model (DTM and DSM) and the images from the multispectral camera, 42 input variables were available for modelling the DMY.

The random forest model considers 14 input variables to estimate the target variable DMY: Average sward height, standard deviation of the average sward height, maximum and minimum sward height, normalized difference vegetation index (NDVI), green normalized difference vegetation index (GNDVI), soil-adjusted vegetation index (SAVI), green chlorophyll index (GCI), red chlorophyll index (RCI), normalized difference red edge (NDRE), excess green index (EGI), excess red index (ERI), months of data collection and shutter speed. In this model, average sward height (17%), SAVI (14%), NDVI (14%), GCI (13%) and month (9%) are the most important input variables. The high relevance of the average sward height in the model is explained by the saturation effect that occurs in the vegetation indices: above a certain biomass, the vegetation indices are no longer accurate representations. In our dataset, saturation becomes apparent from around 2500 kg DM ha^{-1}. As a consequence, the indices for a biomass of 2500 kg DM ha^{-1} hardly differ from those for 4000 kg ha^{-1} (i.e. NDVI 0.9 and 0.95, respectively). This limitation of the vegetation indices is already well described in the literature, for example by Prabhakara *et al.* (2015).

The test results of our model yielded a root-mean-square error (RMSE) of 332 kg DM ha^{-1} and a residual standard error of 335 kg DM ha^{-1}. The mean error of -90.21 kg DM ha^{-1} indicates that the model tends to underestimate ground truth. Schori (2020) tested RPM over several years at different sites in Switzerland. The author concluded that RPM estimates grass biomass well ($R^2 = 0.77$). However, despite these high R-squared values, the residual standard error was 272 kg DM ha^{-1}.

Conclusions

Our results show that it is possible to estimate the DMY of pastures and meadows with a commercially available UAV, although the accuracy of the estimate with the available training data is slightly lower compared to that of a manual measurement with a RPM. To enable the digital mower to work, minima must be present within the area. However, with our intensively managed plots (cuts every four weeks, annual yield ≥12 Mg ha^{-1}), we were able to find enough minima to model the DTM at any given time. To further reduce the estimation error, training data will be supplemented with additional data from swards with greater botanical heterogeneity and extended to the DMY range < 1000 kg ha^{-1} in the future.

Acknowledgements

This work was kindly supported by data supplied by Agroscope.

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