Sensing – New Insights into Grassland Science and Practice

Book of Abstracts

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Introduction

Towards an informed grassland farming – Shortfalls and perspectives

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Abstract

Grassland in Europe provides a wide range of ecosystem services. However, the extent to which these services are provided often falls short of the expectations of agriculture and society. On the one hand, the provisioning potential of individual ecosystem services is not fully exploited, on the other hand, there are strong trade-offs between different ecosystem services. One reason for unsatisfactory performance is the lack of knowledge and information on functional relationships between management measures and ecosystem function targets. As a result, management decisions are not sufficiently targeted. New technological developments in smart farming in the field of sensor technology and information processing open up a wide range of possibilities for obtaining data to document biological production processes with a high temporal and spatial resolution. The information can be used to rationalize production processes and reduce trade-offs between different services. This paper examines the weaknesses of current grassland management practices, provides a summary of technological innovations, and analyses their potential applications using pasture management as an example.

Towards an informed grassland farming – Sensors, platforms and algorithms

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Abstract

Non-destructive monitoring of sward traits has been of management interest for more than a century. Key findings of early research works are still providing fundamental concepts for current proximal and remote sensing approaches to monitor forage mass and quality. For example, spectral absorption characteristics of plant pigments, vegetation cover, or sward height are considered in current analysis approaches. While established methods are based on vegetation indices, the latest analysis approaches, for instance those using machine learning, are considering multivariate analysis for nonlinear systems. The changing paradigm from high-cost to openly available satellite remote sensing data enables dense multi-temporal analysis. Another game changer is the use of Unmanned Aerial Vehicles (UAVs), which serve as carrying platforms for any sensing technology already being used in satellites or aircraft. Finally, combined analysis of spectral and structural canopy traits seems to provide robust estimators for forage mass and quality.

Theme 1. Biomass and quality characteristics

Drone-based remote sensing of sward structure and biomass for precision grazing: state of the art and future challenges

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Abstract

From an understanding of the ecological basis of grazing from both the perspectives of plants and herbivores, we examine why sward structure and biomass are key grassland vegetation traits for monitoring of grazing management. We review how unmanned aerial systems (UAS) have been used to measure these traits through spectral analysis and 3D modelling, and discuss how UAS remote sensing could empower disruptive innovations for grazing management based on the ecological processes of plant-animal interactions and the spatial heterogeneity inherent to pastoral ecosystems.

Remote sensing for grassland quality assessment: Status and Prospects

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Abstract

Grassland farmers face ever increasing demands on their production systems and the quality of their grassland yields. Estimating pasture quality using traditional field methods is limited as it is time consuming and costly, and requires some destructive sampling. The field of remote sensing offers alternative tools and techniques to overcome some of the limitations and thereby help farmers to receive spatial continuous and near real-time information about grassland quality parameters. This review gives an overview about recent developments in the remote sensing-based estimation of three aspects of grassland quality: feed quality, biological nitrogen fixation by legumes, and the identification of unwanted plant species.

Estimating biomass yield and growth response to temperature in red clover using terrestrial laser scanning

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Abstract

Due to its high protein content, good digestibility and its ability to fix atmospheric nitrogen, red clover (*Trifolium pratense* L.) is an important forage crop in temperate livestock production systems. Increased yield and improved adaptation of red clover would increase Europe's self-sufficiency in high quality fodder protein. The aim of this study was to assess growth dynamics and their relation to yield and flowering time in a set of 395 European red clover accessions using a high throughput field phenotyping approach. Terrestrial laser scanning implemented on the ETH field phenotyping platform (FIP) was used to track canopy height increase in high temporal resolution. Canopy height was highly heritable before the second cut (H^2= 0.93) and was predictive for biomass yield with an accuracy of R^2= 0.88. However, heritability of canopy height and predictability of biomass decreased in later cuts. Regressing short term growth rates against ambient temperature revealed a highly heritable (H^2= 0.89) genotype-specific growth response to temperature. Genotypes with a higher temperature response showed increased yield and earlier flowering. We conclude that high throughput canopy height measurements, i.e. using terrestrial laser scanning, can be applied to estimate biomass yield as well as growth response to temperature in red clover.

Using commercial field spectrometers for estimating digestibility of grasslands: an example with the Yara-N sensor

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Abstract

Mixed ley farming largely dominates the agricultural landscape of northern Sweden and leys are the major source of feed for dairy cattle. Forage digestibility is the main criterion that determines the optimal harvest date. Developing a real time and accurate tool to estimate the digestibility would increase the efficiency of the whole dairy sector. We tested how a commercially available field spectrometer (Yara N-Sensor, Yara) could be used for such a purpose. Data were collected from experimental plots with various rates of nitrogen fertilization and timothy and red clover ratios across three field seasons (2017 to 2019) and four sites in northern Sweden. Spectral data were acquired for each plot before harvesting. Collected samples were analysed for in-vitro true digestibility (IVTD) using ANKOM procedures. Different regression techniques were applied to link the spectral data with the laboratory results. The results indicate good performances for the different models for estimating IVTD (*RMSE* = 12.9 to 16.8 $g.kg^{-1}$ and R^2 = 0.88 and 0.70 for support vector machines and partial least squares, respectively). These findings suggest there is a good potential for field spectrometers such as the Yara N-Sensor for real time monitoring of digestibility.

Evaluation of remote sensing vegetation indices to estimate forage yield and quality of different fertilized grassland

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Abstract

As many studies show, spectral signatures provide detailed information on plant functional traits. Forage yield and quality are of great importance in grassland management. Therefore, we derived widely used vegetation indices from hyperspectral reflectance data and evaluated their potential for estimating yield and quality on grassland plots with different fertilization. The spectral reflectance measurements were carried out shortly before each of three harvests per year with a field spectrometer on a long-term experiment with 24 organic and mineral fertilization treatments with a four-fold repetition. Starting with a null model, the best predictors for dry matter yield (DM, kg ha^{-1}) and crude protein content (CP, g kg^{-1}) estimation were determined from selected vegetation, chlorophyll and water indices and a leaf area index using an exhaustive search algorithm on a training data set. The estimation of DM with an index combination on an independent test data set yielded $R^2 = 0.76$, the CP was estimated with $R^2 = 0.69$. Additionally, we compared the index-based results with neural net analyses using Sentinel-2 bands calculated with spectral response functions (S2-SRF) as predictors. With a variety of observations, we have shown that simple indices can differentiate forage yield and quality on grasslands evolved under different levels of nutritional supply.

Information on yield proportion of grasses slightly improves the estimate of dry matter yield based on LAI

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Abstract

Grassland yield estimates from remote sensing often rely on Leaf Area Index (LAI) or LAI-derived variables. We hypothesize that LAI may saturate at high yield levels resulting in inaccurate estimates due to plant parts contributing more to yield than to LAI, such as the stems. In a multi-site field experiment studying the effects of organic fertilization on the vegetation of moderately species-rich mountain permanent meadows, we measured dry matter yield, Leaf Area Index (with the sensor AccuPAR LP-80) and the yield proportion of grasses, legumes and forbs at the time of the first cut over three growing seasons. We evaluated the effect of the yield proportion of grasses, which were expected to provide the most relevant contribution of non-leafy plant material, on the accuracy of predicting dry matter yield by means of a linear mixed models accounting for LAI and design factors (site, year and site x year). Including the yield proportion of grasses into the statistical model allowed to slightly improve the accuracy of the prediction from 0.615 to 0.635 R^2.

Potential of Sentinel-2 and optimal hyperspectral configuration to assess forage quality in permanent grasslands of open woodlands; preliminary results

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Abstract

We explored the capability of Sentinel-2 spectral configuration to assess crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF) and enzyme digestibility of organic matter (EDOM) in open woodlands grasslands. Canopy reflectance measured with an ASD FieldSpec Spectroradiometer resampled to the configuration of Sentinel-2 MSI bands was used to calibrate models by Partial Least Squares Regression (PLSR). Models were tested over real Sentinel-2 data. The potential of hyperspectral configuration to assess forage quality was also investigated using PLSR and waveband selection procedure. Sentinel-2 based PLSR models showed a moderate predictive ability to assess CP with R^2=0.54 and Ratio of Prediction to Deviation (RPD) =1.55 while poor results (R^2<0.50 and RPD<1.50) were obtained for NDF, ADF and EDOM. 10 nm-resolution hyperspectral configuration allowed quantitative results of CP predictions.

Remote sensing-based estimation of nitrogen fixation in organically managed legume-grass mixtures

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Abstract

Organic farmers relying on legumes as the external nitrogen source need fast measurement techniques to determine the amount of fixed nitrogen (N_{Fix}) to enable numerous management decisions. Unmanned aerial vehicles (UAVs) are tools for a non-destructive assessment of grassland traits. The aim of this field study was to provide N_{Fix} estimation models for two legume-grass mixtures through a whole vegetation period based on UAV multispectral information. Additionally, the annual N_{Fix} was calculated. The treatments consisted of two legume-grass mixtures: clover-grass (CG) and lucerne-grass (LG), and pure stands of legumes and grass of both mixtures. From the multispectral data the reflectance and texture information, together with 13 spectral indices were used for modelling. A prediction accuracy of 82% was received when all vegetation and all spectral data were used. N_{Fix} was overestimated at all cuts with the annual N_{Fix} overestimated by 13.69 kg ha^{-1} for CG and by 9.96 kg ha^{-1} for LG. Annual N_{Fix} prediction by multispectral information should be considered as a first approach for the support of farm management decisions, which still needs further improvement.

Monitoring rangeland biomass during wet and dry seasons from a video obtained with a simple digital camera

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Abstract

Photogrammetry is an image analysis that produces a 3D model of on object using a set of images taken from different positions. We tested this technique using a digital camera to produce a 3D model of $1m^2$ of Sahelian rangeland grass. In 2019 we made measurements on 3 squares of $1m^2$ (images capture and biomass measurement) in each of 10 days in the wet season and each month during the dry season. We analysed the images using PIX4D software. We extracted the volume and the colour indexes from the pix4D output. We used a random forest to predict the dry and fresh mass of the grass. The percentage of variance was 46.31% for the fresh mass and 40.46 % for the fresh mass. This tool could be used to monitor grass biomass during both wet and dry seasons and implemented in a grass observatory.

Detection of grassland mowing events with optical satellite time series data

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Abstract

Grassland management – in particular the use intensity – determines its ecosystem services, like fodder production, carbon storage, freshwater generation and biodiversity. However, large-scale and spatially explicit information on grassland use intensity is often unknown. Here, an annual time series of high-resolution optical satellite data (Sentinel-2) for the year 2019 was used to detect mowing events in southern Germany. The pre-processed satellite time series was interpolated, smoothed and filtered and the daily Enhanced Vegetation Index (EVI) was calculated. Afterwards, mowing events were detected by applying an algorithm, which locates strong minima within the EVI time series per pixel. The results were validated by comparing them to mowing events extracted from daily pictures of grassland parcels on field scale. The number and dates of mowing events showed good results as 79% of the observed harvests were successfully detected. Mowing events were missed when the dense time series was disrupted by cloud conditions as the EVI response after mowing events usually lasted not longer than 14 days. Falsely detected mowing events were mostly related to grazing activities.

Generalizability of multi- versus single-target regression for herbage mass and quality prediction from multispectral imagery

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Abstract

Empirical models to estimate herbage mass and grass quality from multispectral imagery acquired by unmanned aerial vehicles (UAVs) often generalize poorly in relation to different types of grasslands. We therefore investigated whether the generalization performance can be improved by replacing the commonly used single-target regression algorithms by corresponding multi-target algorithm adaptations which can simultaneously predict herbage mass and grass quality (dry matter percentage, crude protein, and structural carbohydrates). By additionally considering the relationships between the target variables, these multi-target algorithm variants have the potential to yield better generalization performance. We found that for Partial Least Squares, K-Nearest Neighbours, and Random Forest, the multi-target variants tended to perform better than their single-target counterparts, while for Extremely Randomized Trees mostly the opposite was true. Given the usual lack of ground-truth data for the model to learn the underlying relationships, we suggest the use of multi-target regression be considered whenever several grass parameters are estimated.

From the field to the region – monitoring pre-Alpine grassland characteristics at different spatial scales

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Abstract

Grasslands in their various forms of appearance characterize the pre-Alpine landscape. Despite the economic value and significant role of plants in grassland carbon and nitrogen cycling, spatially explicit information on grassland biomass are rarely available. This study aims to develop routines to monitor grassland traits at different spatial scales. Field sampling campaigns were conducted in April 2018 and at multiple times during the growing seasons of 2019 and 2020 to collect in-situ data of aboveground dry matter biomass (DM) from differently managed grasslands. The campaigns were partially accompanied by unmanned aircraft system (UAS) flights to acquire very high resolution multispectral imagery at the field-scale. These data were complemented by time series of Sentinel-2 (S2) imagery to address the regional scale. In a first step, we tested different statistical modelling approaches and UAS input datasets to estimate DM for the single-date acquisition in 2018. Promising results were obtained by the machine learning algorithms random forest and gradient boosting machines (cross-validated R^2 of best model = 0.71). A first multi-temporal DM model for S2 imagery was developed and used to create regional maps. In the next phase we will adapt the algorithms to multi-temporal UAS data and compare the results across different scales.

UAV to measure canopy height and plot biomass in a lucerne variety trial

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Abstract

The objective was to test the reliability of height and biomass measurements of lucerne by digital photogrammetry using an unmanned aerial vehicle (UAV). Height measurements were recorded on a variety trial involving 440 microplots of pure stand lucerne over two years from April 2019 to November 2020. For comparison, manual measurements of plant height and dry matter yield (DMY) were performed the same day as the UAV acquisitions at the end of eight growth cycles. The model Phantom 4 Advanced (DJI) with mounted RGB camera equipped with a 20-megapixel CMOS sensor was used for image acquisition. The flights occurred at an altitude of 9 m to achieve a resolution of 2 mm. When UAV heights were calculated using 100% of the pixels of the canopy height model, the correlation between heights and DMY derived from UAV acquisitions were greater than those derived from manual measurements. Regressions on the set of flights per year between UAV heights and DMY were similar with high correlation coefficients in 2019 and 2020 (0.89 and 0.96, respectively). We conclude that UAV equipped with a high-resolution RGB camera allow rapid acquisition and data treatment and predicting reliable results of canopy height and DMY for the lucerne.

Using UAV-borne imagery for plant height measurements of perennial forage species by photogrammetry

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Abstract

The choice of the pixel resolution for the production of the digital elevation model (DEM) using Structure from Motion (SfM) software can largely influence the time of data treatment and the required data storage capacity. The objective of this study was to investigate the effect of the DEM resolution on height measurements of five perennial forage species. Images were acquired with a UAV, model Phantom 4 Advanced (DJI, China). Three flights were repeated 5 days apart in June 2018 on a trial involving pure stand microplots of two grass (orchard grass and tall fescue) and three legume species (alfalfa, red clover and white clover). The flights occurred at an altitude of 9 m above the ground to achieve an image resolution of 2 mm. The DEMs were built with a pixel resolution of 2, 4 and 8 mm using the SfM software Agisoft Photoscan (Agisoft Ltd, Russia). The results were compared to the height measured manually with a ruler at the same time as UAV acquisitions. The effect of DEM resolution on height measurements differed according to the species. For the three legume species, similar and reliable regressions between manual and UAV height measurements were obtained with the three tested resolutions for the three dates ($0.88 < R^2 < 0.97$). The most reliable regressions were obtained for the orchardgrass ($R^2 > 0.81$) with a DEM resolution of 4 mm. The results obtained for tall fescue were less reliable than for the other species. The highest regressions between manual and UAV height measurements for this species ($0.56 < R^2 < 0.71$) were obtained with the lowest DEM resolution (8 mm).

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.

Remote sensing data fusion and feature selection for biomass prediction in extensive grasslands invaded by *Lupinus polyphyllus*

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Abstract

Heterogenous, extensive grasslands are at risk from the spread of invasive plant species which can pose significant impacts from the ecosystem down to the species level. The aim of this study was to develop prediction models from sensor data fusion for fresh and dry matter yield (FMY/DMY) in extensively managed grasslands with variable degrees of invasion by *Lupinus polyphyllus*. Therefore, a terrestrial 3d laser scanner and a drone based hyperspectral camera was used. VSURF, a feature selection procedure was used to remove irrelevant features and ALE (Accumulated Local Effects) plots were utilized to gain a deeper quantitative understanding of a single feature on the prediction output. Models from hyperspectral data solitarily had the lowest prediction performance, followed by models derived from 3d laser data. A fusion of both sensor systems gained the highest prediction performance. Remote sensing data fusion from complementary sensor systems in combination with feature selection can increase the biomass prediction performance as well as the simplicity and interpretability of biomass prediction models. Further, the lowest over- and underprediction was found with lupine contributions between 20 and 40%. It could be shown that the abundance of invasive species can impact the quality of remote sensing-based FMY and DMY prediction in grasslands.

Using polygon grids to upscale ultra-high resolution UAV data for monitoring pastures

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Abstract

UAV imaging provides data in ultra-high spatial resolution of smaller than 3 cm. Although such data contains valuable information such as green cover and sward height, lower resolutions of e.g. 0.5 m meet the demands of monitoring pasture biomass or quality for management purposes. In the spatial analysis workflow of field experiment data, zonal statistics are essential to analyse and summarise UAV-derived data for individual plots or repetitions. Based on this concept, Bareth *et al*. (2016) proposed using polygon grids as zones input for zonal statistics on the field level. In this contribution, we (i) introduce the UAV data acquisition of a pasture experiment of the “GreenGrass” project which is funded by the BMBF, (ii) present UAV-derived sward growth data and the RGB vegetation index (RGBVI) in ultra-high spatial resolution (< 3 cm), and (iii) upscale sward height and RGBVI data using a polygon grid of 0.5 m.

Use of Sentinel-2 images for biomass assessment in extensive pastures in the Apennines (Central Italy)

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Abstract

The monitoring of forage production is one of the most important activities for establishing correct pasture management. Since above-ground biomass estimation with in-field traditional methods is costly in time and money, remote sensing techniques have been largely utilized and improved over the last decades to monitor grass growth and forage production. In this trial, we tested the potential of satellite-based vegetation indices (NDVI, SAVI, PVR, GLI, TVI, VARIGreen) in detecting actual pasture production, in terms of fresh biomass and dry matter over extensive grazing systems. Biomass was harvested from plots of 1m^2-surface wide (8 replicates per each study site) in two areas of Tuscany (Central Italy). The vegetation indices were elaborated from Sentinel-2 satellite images, acquired in correspondence of the sampling dates, and then correlated to pasture production measured from ground surveys. Best results in estimating fresh and dry forage biomass were achieved respectively with NDVI (R^2 = *0.*59) and SAVI (R^2 =*0.49*) but also other indices calculated from bands within the visible spectrum showed similar results in above ground biomass estimation.

A tool to select the best parental genotypes by combining lab and field tests

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Abstract

Highly productive forage grass cultivars capable of withstanding water shortage without suffering huge yield penalty are a desirable outcome of any breeding programme. In this study we propose a water deprivation tolerance in combination with leaf growth under controlled conditions and plant yield under field conditions as a tool to select superior genotypes to be used as parent plants in pre-breeding. A panel of 107 perennial ryegrass ecotypes, mostly originating from Lithuania and Ukraine, were used. Leaf elongation was measured using a phenotyping platform, designed to track it with high temporal resolution. Tolerance was calculated as a measure of time span between the points when the plant reduces growth and arrests it under water stress. There was a moderate correlation (r = 0.41, P < 0.05) between leaf elongation under optimal conditions and tolerance, indicating the presence of fast growing and stress-tolerant plants in the panel. Analysis of these traits in combination with dry matter yield allowed us to pinpoint genotypes that can be used as stress tolerance donors in the crosses with superior cultivars without reducing the yielding capacity of the offspring.

Estimating standing biomass of sown biodiverse pastures using a combination of remote sensing and machine learning

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Abstract

Beef cattle production in Alentejo (Portugal) is based on a mixture of grazing and supplementation. Sown biodiverse permanent pastures rich in legumes (SBP) provide quality animal feed, offset concentrate consumption and increase carbon sequestration. Providing estimations of biomass in SBP is critical for optimizing their use by farmers. We developed data processing and calibration algorithms based on remote sensing (RS) and machine learning (ML) to estimate pasture biomass. RS data were acquired from Sentinel-2 (S2). Five additional vegetation indices were calculated from the individual bands of S2. Calibration data were collected in spring 2018 and 2019 on farms. The ML method used was random forest (RF). A multi-group cross-validation approach was used, where each group is a unique combination of farm and year; in total 9 groups were considered. We used this approach to assess the estimation error when the model is applied to a new farm and year that was not used in training. Results demonstrate good predictive capacity, with root mean squared error of 810 kg DM ha^{-1} (average biomass equal to 2,499 kg DM ha^{-1}) and an r^2 higher than 0.6. This approach can lead to expedited and low-cost mapping of biomass in SBP.

Predicting herbage yield in perennial ryegrass breeding trials using UAV derived data and machine learning

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Abstract

Several methods have been developed to estimate biomass yield in ryegrass using remotely sensed spectral and structural features. This study builds further upon procedures developed in the breeding programme of ILVO. In previous work, we focused on canopy height as the main predictor of yield. Here we investigate whether the prediction of herbage yield in perennial ryegrass can be improved using canopy height information combined with spectral bands captured using different sensors. We used six breeding trials comprising 115 diploid and 112 tetraploid varieties and populations, with a total of 468 plots. A series of UAV flights was carried out with two sensors, a 10-band multispectral and an RGB camera system. The acquired data were then used to estimate the yield of the first spring cut in May 2020. Repeated nested cross-validation allowed us to evaluate the performance of the predictive models. Three machine learning algorithms (Random Forest, Support Vector Machine and Partial Least Squares Regression) were applied, to better understand the applicability of those techniques for accurate yield assessments. This study provides new insights to ryegrass biomass estimation related to earliness and ploidy level.

Evaluation of a grassland drought index based on LAI from remote sensing and meteorological data

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Abstract

Indices based on optical satellite remote sensing imagery have shown to be suitable for quantifying drought-related yield losses. The Forage-Production-Index (FPI), combining meteorological observations and remote sensing-based LAI retrievals from MODIS, was adapted for the application in South Tyrol (NE Italy) in a mountainous, highly heterogeneous landscape. Yield measurements from field trials covering 39 environments (site x year) were used for validation, which was performed using mixed models describing the relationship between dry matter yield and FPI (or their variation with respect to a reference period) and accounting for the design effects treated as random factors. Following variants in computing FPI were applied: spectral unmixing of LAI, correction by means of Water Stress Coefficient (CWS) and aggregation scale. The prediction ability of the index was found to be low. Unmixing and correction by CWS resulted in a minor improvement in accuracy. Possible reasons for the low sensitivity are: i) insufficient spatial resolution of MODIS satellite data with respect to the complexity of land use; ii) lack of coincidence between yield at validation sites and surrounding grassland; iii) small number of validation sites, possibly not covering the whole yield variation over the area and period investigated.

Validation of a workflow based on Sentinel-2, Sentinel-1 and meteorological data predicting biomass on pastures

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Abstract

This study develops the validation of the four best promising models resulting from a workflow processing Sentinel-1, Sentinel-2 and meteorological data through 13 different machine learning algorithms that led to 124 models predicting biomass under the form of compressed sward height on square sub-samples of paddocks (i.e., pixel-based estimation with a resolution of 10 m). The training and validation data were acquired in 2018 and 2019 in the Walloon Region of Belgium with a rising platemeter equipped with a GPS. The cubist, perceptron, random forest and general linear models had a validation root mean square error (RMSE) around 20 mm of CSH. However, the information relevant for the farmer and for integration in a decision support system is the amount of biomass available on the whole pasture. Therefore, those models were also validated at a paddock-scale using data from another farm (117 CSH records acquired with a different rising platemeter) based on input variables expressed at paddock scale or predictions aggregated at paddock scale. The resulting RMSE were higher than before. To improve the quality of prediction, a combination of the outputs of the models might be needed.

Case study on monitoring sward height and available biomass with a rising plate meter on pastures of dairy farms in Southwest Germany

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Abstract

Pasture management on rural and extensive small-structured dairy farms in southwest Germany is based mainly on visual estimations or traditional management strategies. To maintain and optimize grassland management for pasture use, continuously measured data over the full vegetation period are crucial. However, the measurement of pasture characteristics can be time-consuming and challenging; therefore there is a considerable potential to use sensor-based technologies. In the present study, the potential of using a semi-automated rising plate meter to measure sward height data from pastures on four dairy farms in the Black Forest region was assessed. In addition, above-ground biomass based on grass cuts of pastures were compared to estimations of available biomass from the rising plate meter. The data revealed that pastures were overgrazed during late summer and autumn, with sward heights below 2 cm on three of four farms and the availability of pasture biomass decreased from 262 to 95 kg DM ha^{-1} in autumn. The estimations from the rising plate meter constantly overestimated the available biomass on pasture, except for measurements in late summer. We conclude that the application potential of the rising plate meter at its current state might be limited and needs further adaptation for use with heterogenous short-grass swards.

Influence of microplastics on the leaf temperatures of ryegrass

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Abstract

Production rates and global consumption of synthetic polymers have grown exponentially in recent years. Associated with environmental problems such as mismanaged plastic debris, inefficient water treatment plants or anthropogenic littering behaviour, this increase has resulted in a vast amount of all-size plastic entering the environment. Due to its subsequent resistance to degradation, plastics are persisting in the environment and can potentially influence environmental processes. Primarily microplastics (< 5 mm) are central to the debate. So far, aquatic systems have been in the focus of concern. Our knowledge on microplastics in terrestrial ecosystems, especially agricultural soils and crops, is very limited. Lab experiments have shown depression in germination of grassland plants, possibly due to changes in water availability. Therefore, the aim of this research was to investigate the influence of different sizes of microplastics simulated by Polyvinylchloride on the leaf surface temperatures of *Lolium perenne* in an outdoor pot experiment. The leaf temperature is a proxy for transpirational cooling and thus water availability. An infrared image of the plants was taken weekly, using a high definition thermographic camera. We partially observed higher leaf surface temperatures for plants with different-sized microplastics. The temperatures were significantly higher for plants without fertilizer treatment.

The potential of unmanned aerial vehicle (UAV)-based multispectral data to estimate fresh grass allowance

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Abstract

Accurate estimates of fresh grass allowance are central to improve the economic and environmental performance of pasture-based dairy farms. To accurately quantify fresh grass allowance, the total available herbage mass (HM) needs to be corrected for the occurrence of rejected patches (RP) that are formed due to selective grazing. The aim of this study was to explore whether multispectral images can be used to correct fresh grass allowance for selective grazing. To do so, we performed measurements in a grazing experiment. We used an unmanned aerial vehicle (UAV) mounted with a full colour and multispectral camera to record visible (red, green, blue) and near-infrared (NIR) wavelengths. We estimated HM using the Normalised Difference Vegetation Index (NDVI). We found a quadratic relationship between grass height (as a proxy for HM) and NDVI, which was influenced by date of measurement and grazing interval *($P<0.001$; RMSEP = 10.2%; $R^2 = 0.78$)*. We were able to identify RP by estimating threshold values in NDVI using visual interpretation of full colour images. Our results provide first indications that NDVI could be used to quantify fresh grass allowance for grazing. Further research will be required in order to develop a remote sensing method for accurate fresh grass allowance estimation under different grazing management practices.

Grass quality measurement with a handheld NIR sensor

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Abstract

There is a need to determine grass quality during the grazing season to establish optimal rations in terms of CP content and to correct for low or high N fertilization. Recently, work has been done to determine grass quality using the NIR Handheld scanner of Agrocares. Grass samples from plots in the Netherlands and Germany were scanned in the lab, fresh and dried; 5 scans per sample. The dataset with dried samples was extended with scans of dry in-stock samples and another spectral database after spectral conversion. A calibration model was built for dried samples (n>6000). A subset of 337 fresh grass samples was used to make a conversion model between wet and dry samples. The validation models for CP of dry and fresh samples had RSME values of 22.7 and 25.8 g kg^{-1} DM (R^2 = 0.68 & 0.58). Pilot use of the scanner on 10 farms took place in October 2019, measuring 5 spots directly in the field. These locations were then sampled and measured in a bucket. The results showed that CP was on average 6 and 2% lower compared to reference analysis, with a maximum deviation of 13 and 18% respectively. The results are encouraging to further expand the calibration database.

Theme 2. Biodiversity and other ecosystem services

Remotely sensed insights into grassland biodiversity

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Abstract

Given the difficulties associated with field-based data collection, the use of remote sensing for estimating environmental heterogeneity is a powerful tool since it provides a synoptic view of an area with a high temporal resolution. This paper presents, as an example, a case study applied to a grassland area and provides insights about the potential use of remotely sensed data for estimation of grassland diversity.

Grassland vegetation monitoring: scale is important

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Abstract

This paper gives a broad perspective on the key aspects of grasslands monitoring, with a focus on scale of analysis. The section ‘Monitoring of grasslands using remote sensing: key aspects’ discusses interrelated aspects important in grasslands mapping. The section ‘Classified vegetation unit’ is devoted to a brief description of classifiable units, such as species, communities/habitats or ecosystem types. Next, Unmanned Aerial Vehicles (UAVs), and aerial and satellite platforms are presented, followed by a discussion of data resolution within the context of mapping. The ‘Methods of the data collection, processing and analysis’ section encompasses field data collection, additional variables and classification algorithms. Each section provides examples of grassland mapping studies. Recommendations for practitioners from these studies are highlighted in the ‘Conclusions’ section.

Detection of mowing events from combined Sentinel-1, Sentinel-2, and Landsat 8 time series with machine learning

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Abstract

The intensity of land use in permanent grasslands affects both biodiversity and important ecosystem services. Optical satellite systems have already proven to be suitable for area-wide detection of proxies of grassland management intensity, namely mowing events. However, clouds lead to considerable gaps in time series, resulting in an underestimation of the total number of events. SAR systems like Sentinel-1 (S1) can overcome this limitation, yet the information obtained is more complex to interpret. To test the synergy and complementarity of both sensor types for mowing detection, we computed high-density SAR and optical time series over three test sites in Germany covering detailed reference data on grassland management. For the growing periods in 2018 and 2019, we tested two binary, supervised machine learning algorithms, a convolutional neural network (CNN) and support vector machines (SVM), classifying sliding windows into *mown* and *not mown*. S1 VH/VV backscatter ratio, as well as Sentinel-2 (S2) and Landsat 8 (L8) normalized difference vegetation index (NDVI), were used as input features. Both models show promising results in detecting mowing events, where SVM performed slightly better. Overall, the approach shows a high potential for routinely mapping grassland management intensity over large areas in heterogeneous environments.

Using yellowness in drone-based RGB images to map buttercup cover in an upland pasture

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Abstract

The reduction of unwanted plant species in pastures is a persistent objective of grassland management. Evaluating different management options requires the assessment of the spatial coverage of the unwanted species. Here, we evaluate the use of drone-based images to quantify the cover of buttercup (*Ranunculus acris*) in an upland pasture (1654 m asl.) in the Central Swiss Alps. Buttercup is of primary concern because it is moderately toxic and avoided by grazers. Between 2016 and 2020, we conducted a randomized complete block trial with ten different treatments (combinations of grazing, mowing, liming, herbicide and overseeding) in four repetitions. Aerial images were taken annually at the peak of buttercup flowering, with a fixed-wing autonomous drone (senseFly eBee) carrying an RGB camera (Canon S110 and from 2019, senseFly S.O.D.A.) and post-processed using Pix4Dmapper. Yellowness was calculated as the percentage of yellow pixels using optimized thresholds on the RGB channels. The correlation coefficient between the yellowness of the images and the share of buttercup estimated by an independent observer was above 0.85 for the last two years. The newer S.O.D.A. camera outperformed the S110 due to its higher resolution, which was shown to be crucial for this kind of assessments.

Mapping invasive *Lupinus polyphyllus* Lindl. in grasslands from UAV-borne remote sensing images

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Abstract

Lupinus polyphyllus Lindl. (lupine) is one of the most invasive plants in European grasslands. Information about up-to-date coverage of invasive lupine is essential for effective planning of control activities and evaluating biodiversity states of the grasslands. Thus, this study focused on developing a workflow to map lupine spatial coverage using the unmanned aerial vehicle (UAV)-borne remote sensing (RS) images instead of manual digitising of aerial images. The study was conducted at an experimental grassland setup in the UNESCO biosphere reserve Rhön in Germany. UAV-borne RGB, thermal images and their derivatives (e.g., canopy height model, texture, vegetation indices, etc.) were utilized. RS images were segmented to obtain image objects, and attributes for each image object were computed. Then image objects were classified using a random forest classification model based on objects' attributes. The mean prediction accuracy of the classification models was 89%. The classification-based lupine coverage maps showed a ±5 % disagreement in the lupine area compared to the image digitising method. Overall, the developed workflow with UAV-borne RS images demonstrated that it could be adopted for accurate mapping of lupine in grasslands in an efficient way.

Using image analysis and machine learning to estimate sward clover content

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Abstract

Incorporating white clover (*Trifolium repens* L.) into grass swards can reduce the requirement for nitrogen (N) fertilizer due to its ability to fix atmospheric N and can also result in increased dairy cow milk production through increased herbage quality. Quantifying sward white clover content is laborious and time consuming. The objective of this study was to capture images and data to train a machine learning model to estimate sward white clover content. A dataset containing 515 images of grass and grass-white clover swards and associated ground-truth data was developed. A deep learning model was trained to estimate the content and percentages of grass, white clover and weed components with good accuracy directly from Irish sward images.

First results of applying UAV laser scanning to a cattle grazing experiment

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Abstract

Remote sensing, especially from unmanned aerial vehicles (UAVs), has gained popularity for monitoring grassland growth dynamics over space and time, enabling location-specific management optimization. A new generation of LiDAR sensors mounted on UAVs could potentially overcome the drawbacks of using optical imaging as the information basis. For this study, a Riegl miniVUX-1 UAV installed on a DJI Matrice 600 pro was flown over a cattle grazing experiment. Promising initial results show a moderate correlation to rising plate meter measurements.

Assessment of rangeland condition in a dryland system using UAV-based multispectral imagery

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Abstract

Dry savannahs are water-limited and under increasing anthropogenic pressure. Thus, considering climate change and the unprecedented pace and scale of rangeland deterioration, we need methods for assessing the status of such rangelands that are easy to apply, yield reliable and repeatable results, and can be applied over large spatial scales. Global and local scale monitoring of rangelands, through satellite data and labour-intensive field measurements respectively, are limited in accurately assessing the spatiotemporal heterogeneity of vegetation dynamics to provide crucial information that detects degradation in its early stages. Fortunately, newly emerging techniques such as unmanned aerial vehicles (UAVs), associated miniaturized sensors and improving digital photogrammetric software allow us to transcend these limitations, but they have not yet been extensively calibrated with rangeland functional attributes. In our study, we fill this gap by testing the relationship between UAV-acquired multispectral imagery and field data collected in discrete sample plots in a Namibian dryland savannah along a degradation gradient. The first results are based on a supervised classification performed on the ultra-high resolution multispectral imagery to distinguish between rangeland functional attributes, with a relatively good match to the field observations. Integrating UAV-based observations to improve rangeland monitoring could greatly assist in climate-adapted rangeland management.

Permanent grassland established on eroded soils: floristic composition of different sections of a hillside after 27 years of sward naturalization following sowing

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Abstract

The objective of this study was to estimate changes in phytocenoses' floristic composition in different parts of a hillslope following 27 years of naturalization after sowing. In 1993 a mixture of perennial species was sown on a south-facing slope, soil type Eutric Retisol (slightly eroded). Seed mixture was timothy (*Phleum pratense*) 20%, red fescue (*Festuca rubra*) 20%, meadow grass (*Poa pratensis*) 20%, white clover (*Trifolium repens*) 20%, and bird's-foot trefoil (*Lotus corniculatus*) 20%. In 2020 the floristic composition of the resulting permanent grassland sward was determined. The sward composition differed between different parts of the hillslope, and relative abundance of sown species was 16.5, 27.9 and 28.3% respectively, for the summit, midslope and footslope. There was a good growth of *Festuca rubra* on all parts of the hill, but *Trifolium repens* had disappeared from the grassland of the midslope and footslope. The species that disappeared were replaced by more resistant ones and some new species. There was a trend for slightly greater sward production in the footslope of the hill, and lowest in the midslope area.

Initial evaluation of PlanetScope nanosatellite images applicability for identification of grazed plant communities

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Abstract

The aim of the research was to assess the possibility of using nanosatellite images to identify chosen plant communities in the areas of pastures grazed by Hutsul horses. The surface cover is dominated by grasses, and the species composition includes herb and weed communities. Plant communities were mapped in the field using the Braun-Blanquet approach and then matched with the PlanetScope nanosatellite images. In particular, for mapped communities we created the temporal profiles of selected vegetation indices. The obtained results are encouraging, showing possible use high-resolution satellite imagery as a tool to support more effective management of grazed areas.

Wide-area monitoring of soil moisture in peatlands using Sentinel-1 images

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Abstract

Peatland functions as an essential ecosystem that stores carbon and prevents flooding by retaining water. Monitoring of peatlands, based on remote sensing, assists in the ecological service provision for grassland and agricultural use. Soil moisture plays an important role during the hydrological cycle, and EFTAS has developed a novel approach using multi-temporal Sentinel-1 images to evaluate, model, and predict the soil moisture. Our initial test in a peatland shows promising results. The Pearson correlation coefficient between the soil moisture estimated by our model and the in-situ data is up to 0.93. We have created forward models to predict soil moisture. The lowest absolute mean error is 3.63% (volumetric water content). This work is part of the interdisciplinary research project BEWAMO funded by German Federal Ministry of Food and Agriculture.

European Monitoring of Biodiversity in Agricultural Landscapes (EMBAL)

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Abstract

The 'European Monitoring of Biodiversity in Agricultural Landscapes' project (EMBAL) is an initiative launched by the European Commission (DG Environment) which aims to provide a harmonized pan-European overview about the state and changes of biodiversity in agricultural landscapes. On the basis of the first EMBAL study (Oppermann *et al.*, 2018) and its preceding project LISA (Oppermann *et al.*, 2021) a recent contract has been assigned between 12/2019 and 10/2021 in order to consolidate and operationalize the achieved survey methodology, while proving its practical feasibility and statistical efficiency via dedicated pilot surveys on 250 sites across four bio-geographic regions within the EU. With the consolidation of the methodology and the technical workflow, this pilot project prepares the emphasized EMBAL rollout in the EU, aiming to contribute to a number of EU environmental policies (e.g. EU Biodiversity Strategy for 2030, EU Common Agricultural Policy, EU Pollinators Initiative) and to monitor their implementation and effectiveness.

Lifting the secrets of pastures: Overview of animal-borne sensors to uncover processes unobserved by classical grassland research

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Abstract

Movement and foraging behaviour of grazing livestock strongly respond to pasture vegetation while being major drivers of grassland biodiversity. However, many underlying processes of these interactions are scarcely understood. In this article we focus on how animal-borne sensors can close this knowledge gap. We conducted three grazing experiments on heterogeneous pastures in the Swiss Alps. GPS-trackers, pedometers, nose-band chewing sensors and head-collar accelerometers were fitted to cattle, sheep and goats. Sensor data were combined with classical vegetation surveys. We found that (1) animal-borne sensors allow for monitoring activities of grazing animals continuously, objectively and without disturbing their natural behaviour; (2) sensors can monitor processes not directly observable by humans or aerial systems but sensed by livestock; (3) the high temporal and spatial resolutions allow for new algorithms of data interpretation. Combining these advantages of animal-borne sensors with classical measurements revealed novel ecological relationships of livestock behaviour and vegetation diversity. For instance, we disentangled interactions of cattle movement behaviour, their spatial distribution, anatomy, trampling pressure, plant trampling-adaptation and pasture vegetation and diversity. Animal-borne sensors indicate the underlying ecological processes of pasture parameters and not only their status quo, and thereby enable a holistic research approach into grassland systems.

Springtime grazing for meadowbird conservation

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Abstract

European meadow bird populations are declining. In the Netherlands, particularly the black-tailed godwit and lapwing show reduced breeding success and limited chick survival because of increased predation, urbanization and agricultural intensification. In order to increase breeding success and chick survival, farmers are compensated for implementing conservation measures, including delayed first harvest until 1, 8 or 15 June. These measures help to create a period of rest with enough shelter against predators and sufficient food availability for the chicks. However, this delayed harvest results in a heavy grass crop, which limits chick mobility and feeding success, but also negatively affects forage quality and regrowth. In the current experiment we tested the effect of pre-grazing until 1 or 8 May on the yield, sward density (% cover at soil surface) and nutritive value of the grass harvested at a delayed harvest. Pre-grazing significantly reduced the average herbage dry matter (DM) yield from 7 t ha^{-1} to 4.6 and 3.2 ton DM ha^{-1} (1 and 8 May, respectively). The sward density after the delayed harvest was 18% higher with pre-grazing, and both the energy and protein content were higher. In conclusion, pre-grazing is a good tool to prevent some of the problems associated with delayed harvests under meadow bird conservation management.

Effects of innovative management options on perennial grassland in the mountain area of Switzerland

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Abstract

Based on a Delphi study, six innovative management options were assessed with regard to their feasibility and potential effects on the delivery of ecosystem services (ES) for the Swiss alpine region: (i) complete sward renewal through sward destruction and reseeding, (ii) virtual fencing, (iii) overseeding with different grass or legume species or mixtures without complete sward destruction, (iv) practical use of rising plate meter for yield estimation, (v) biodiversity management, and (vi) weather and grass growth monitoring to improve grassland management. We found that sward renewal has negative effects on biodiversity, carbon storage, flood control, prevention of soil erosion and prevention of loss of organic matter and therefore should not be applied in the Swiss alpine regions. Rising plate meters and grass monitoring have a positive effect on grass production without any negative consequences on other ES. Biodiversity management fits perfectly under the Swiss alpine conditions, in particular when farmers are compensated for their economic loss.

Mapping grassland management and habitats with satellite and ground level imagery through machine learning

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Abstract

Intensive grassland management is impacting Europe's semi-natural grassland habitats. Without accurate data on the extent of intensive practices, conservation efforts to reverse biodiversity loss cannot succeed. This study explores how multispectral and synthetic aperture Radar (SAR) imagery and machine learning (ML) can be used to classify management intensity in Ireland. Preliminary results using three land-use classes had overall accuracy between 85 and 91%. Class labels were derived from Eurostat LUCAS survey photographs taken in 2018. Using ML, paddocks within the improved class were identified with ~86% accuracy. Work continues on expanding the model to a regional scale and different levels of intensity. The project also explores how subjectivity in class labelling can be reduced using Deep Learning. The study demonstrates the potential of in-situ photography for validating habitats and land use studies with clear implication for future CAP monitoring.

Theme 3. Management and decision support

The role of remote sensing in practical grassland farming

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Abstract

The provision of Earth Observation (EO) technology-driven services to grassland farmers has lagged behind those provided to arable farmers. Precision Agriculture (PA) in grassland animal systems has largely focused on Precision Livestock farming (PLF) with the application of technology to grass management limited to improved record keeping and automated planning. New data in the form of European Space Agency Copernicus satellites has stimulated the market for using EO data in grassland management, and stimulated research into the monitoring of grassland types, habitats, and use. This short review looks at currently available grassland commercial PA services that utilize EO data. It explores the range of services on offer and discusses the reception and potential in the grassland management business.

A novel dynamic model for estimating standing biomass and nitrogen content in grass crops harvested for silage production

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Abstract

This paper describes a tool that enables farmers to time harvests and target nitrogen (N) inputs in their forage production, according to the prevailing yield potential. Based on an existing grass growth model for forage yield estimation, a more detailed process-based model was developed, including a new nitrogen module. The model was tested using data from an experiment conducted in a grassland-rich region in central Norway and showed promising accuracy with estimated root mean square error (RMSE) of 50 and 130 g m^{-2} for dry matter yield in the trial. Three parameters were detected as highly sensitive to model output: initial value of organic N in the soil, fraction of humus in the initial organic N in the soil, and fraction of decomposed N mineralized. By varying these parameters within a range from 0.5 to 1.5 of their respective initial value, most of the within-field variation was captured. In a future step, remotely sensed information on model output will be included, and in-season model correction will be performed through re-calibration of the highly sensitive parameters.

Movement behaviour of cattle analysed with GPS data as affected by three different grazing intensities

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Abstract

In order to achieve a sustainable improvement in livestock grazing systems with their long European tradition, there is a need to improve understanding of behaviour of cattle on pasture. Maintaining the botanical and structural balance of heterogeneous pastures is becoming significant especially in the context of climate change. In this study, the long-term cattle grazing experiment 'FORBIOBEN' with its three paddock-scale grazing intensities (GI) [moderate (M), lenient (L), very lenient (VL)] each replicated thrice, is used to investigate movement and diurnal patterns of cattle behaviour in relation to the grazing intensity and season. The study took place in the spring and autumn grazing events during four periods between May 2017 and July 2020. Nine pregnant suckler cows were equipped with GPS collars, which record both position and activity of the animals at minute intervals. A strong diurnal pattern became evident with a shift in the activity peaks during the autumn period. The highest effort in walking was found in M compared to L and VL for three grazing periods. We discuss these results against the background of the suitability of cattle tracking for pasture management and vegetation parameters (herbage on offer, herbage allowance, variability of herbage on offer).

Detection of *Senecio jacobaea* in drone images, using a machine-learning approach

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Abstract

Senecio jacobaea (S.j.) often grows in extensive grassland and poses a threat to farm animals due to toxic substances. Effective weed control requires site-specific counter measures targeting the toxic plants. This requires precise knowledge of the locations of the S.j. Here we present an approach adapted from success with *Colchicum autumnale*. When the flowers were blooming, the fields were mapped using a consumer-grade camera mounted on a drone. The resulting images can then be stitched together to obtain an orthomosaic of the whole field. The S.j. flowers were located in the images using a convolutional neural network with a U-Net architecture. The relatively low number of labelled ground truth images was compensated by applying image augmentation techniques during the training of the neural network. On the test dataset, 95% of the predicted S.j. flower locations were correct (precision), and 70% of the true locations were found by the detector (recall).

The effect of virtual fencing technology on grazing behaviour: differences in herbage consumption

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Abstract

Virtual fencing (VF) technology applies stimuli to control grazing livestock without physical barriers. VF is a promising innovation in grazing livestock management, as it allows remote monitoring of animal movements and improved pasture utilization. This study aimed to determine whether the application of novel VF technologies in cattle grazing systems affects grazing animal forage intake. For this, 24 heifers (Simmental, age average: 462 days, live weight average: 396 kg) in 6 experimental groups were equipped with NoFence VF collars (® Nofence, AS, Batnfjordsøra Norway). Control groups had only physical fences (PF) and received inactive VF collars. In 3 periods of 12 days, one control and treatment group each were grazed on adjoining paddocks (866.5 ± 32.7m^2) for 5h daily. Forage biomass samplings were done on days 1, 8, and 12 of each period in both paddocks. Herbage dry matter accumulation was determined by manual clipping near the soil surface. Data analysis showed that sampling time affected dry matter availability and, thus, herbage intake (HI) ($P<0.001$). However, there was no significant difference in HI between treatments. Therefore, it can be concluded that the VF technology did not affect HI of grazing heifers, even though it was previously unknown.

Monitoring of water content in legume seed production after crop desiccation using multispectral UAV images

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Abstract

In seed production, a low water content of the crop before the harvest is of great importance. Pre-harvest crop desiccation devitalises the vegetation and consequently lowers the water content of plants to minimize machine load and drying costs. Simple and fast procedures which provide near real-time information about the current crop status are essential for the further success of seed production. The major aims of the study were (i) to determine the effects of three different herbicides used for crop desiccation in the seed production of birdsfoot trefoil (*Lotus corniculatus*) and snow clover (*Trifolium pratense ssp. nivale*). Subsequently we determined (ii) whether remote sensing technologies can be used to display the differences between the treatments. We performed the herbicide applications two (*L. corniculatus*) / three (T. *pratense ssp. nivale*) days before threshing, with a control plot serving as reference in both crops. A multispectral camera, mounted on an unmanned aerial vehicle was used to acquire spectral images from the plots before the herbicide application and before threshing. We harvested green-material and seed samples from all plots and analysed them for residual moisture content. Simple vegetation indices showed very promising results when comparing them with dry matter content of the plant biomass.

Training cattle with virtual fences on permanent pastures

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Abstract

Grazing animals, especially dairy cattle, have long been a feature in the cultural landscape of Central Europe. Smart farming technologies are one way to improve pasture management. In this study, the virtual-fencing technology (Nofence) was used to manage heifer grazing in an attempt to establish a training protocol. The heifers had not experienced virtual fencing previously. Training took place on small paddocks (1000 m^2). Two treatments (four heifers per group) were compared in three repetitions (each of 12 days). One virtual-fence-line, which is set up by GPS coordinates (the collars send acoustic signals followed by an electric impulse as a warning if the animals approach the line), separated the pasture of the virtual-fence-group into accessible or non-accessible areas. The control group had a physical-fence-line. Each repetition followed the next successively on different paddocks with a new group. Training was divided into three sections: visual support of the virtual fence by a physical barrier (first 2 days), only virtual border without visual support, moving the virtual-fence-line (on day 8). Results showed that each heifer was able to learn the virtual fencing cues. The main aspects of cattle behaviour on pasture were not affected by the physical/virtual-fence-line.

Assessing feed efficiency in grazing dairy cows through infrared thermography and behaviour sensors

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Abstract

Genetic selection for feed efficiency is hindered by the cost and difficulty of measuring individual feed intake. The objective was to explore the use of phenotypic proxies, namely surface temperature (ST), rectal temperature (RT), feeding behaviour and physical activity, to predict feed efficiency variables, i.e. feed conversion efficiency (FCE) and residual feed intake (RFI), in grazing dairy cows. Two groups of 14 Holstein and 14 Swiss Fleckvieh dairy cows were investigated during two mid- and one late-lactation period. During 7-day measuring periods, feeding and rumination behaviour, activity and individual herbage intake using the n-alkane marker technique of each cow was recorded. The ST was recorded indoors, once for each measurement period after morning milking at multiple body locations with a thermal camera. Estimated average within-herd feed efficiency was 0.78 (*SD = 0.17)* for FCE and -1.18 (*SD = 1.96*) for RFI with no significant difference (*P > 0.05*) between the breeds. FCE and RFI were best explained by maximum right front feet ST (R^2 *= 0.34*) and time interval between 2 consecutive foot strikes (R^2 *= 0.17*), respectively. The relationships were weak to very modest; however, they might be further improved by including other features such as milk and blood variables.

Automated detection of grazing behaviour with a collar-based monitoring system

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Abstract

Monitoring the health and welfare of dairy cows in grazing situations is time consuming. Most monitoring systems available on the market were developed for use with housed cattle and attain low accuracies when used on pasture. Changes in grazing behaviour may serve as an indicator for heat and also health issues. Recording the grazing behaviour automatically with a monitoring system enables a reliable detection of oestrus and early identification of health disorders, and it provides supporting information for managing pasture-based dairy farms. Therefore, in this study, different prediction models for the automated detection of grazing behaviour were evaluated. Eight dairy cows were equipped with a monitoring system containing a three-dimensional accelerometer and a gyroscope. Ground Truth data were obtained from labelled video recordings. A Random Forest prediction model trained on an orientation-independent feature set and a window size of 5 s without overlaps achieved the highest accuracy. This model detected grazing with a sensitivity, specificity, and accuracy of 91.8%, 92.7% and 92.2%, respectively. The model confused grazing with walking, and by walking while chewing. To obtain the total feeding time and to reduce the misclassification with walking (plus chewing), another model for the detection of chewing while standing and walking is needed.

Using LiDAR derived Digital Terrain Models and field data to quantify riverbank erosion and nutrient loading rates

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Abstract

Nutrient and sediment loss from agricultural land is one of the major contributing factors in declining water quality. This research aims to quantify sediment and nutrient loading rates due to riverbank erosion using airborne LiDAR and field-collected data for sites in the Blackwater catchment, Northern Ireland. Using 2014 and 2020 LiDAR Digital Terrain Models, image differencing was performed in ArcMap to determine volume changes in riverbank elevation to quantify erosion rates. This was supported by cores of bank material, which were collected in situ for analysis of bulk density and total extractable phosphorus to determine sediment and phosphorus loading rates. We conclude that LiDAR and the collection of basic field data represent an innovative means to quantify erosion and nutrient loading rates without needing intensive time-consuming field surveys.

Using GPS sensors to estimate automatically the time dairy cows spend on pasture

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Abstract

Since 2007, use of the 'Pasture Milk' labelling specification has grown further in Europe. It requires the cows to spend a minimal duration on pasture. Our objective was to develop and test an algorithm that estimates the time dairy cows spend outside the barn (T-Out), through an automatic detection of the barn, using a clustering method analysing the data recorded by embedded GPS sensors. Eight Holstein cows were equipped with a GPS collar during 56 days while having free-access to pasture at least 10 h/d. The reference T-Out (T-Outref) was calculated with a RFID antenna at the building entrance. The classification of T-Out as more (or less) than 6 h/day of pasture, as required for the French 'Pasture Milk' specification, matched the classification given by the T-Outref for 100% of the data. No effect of the number of cows equipped with a sensor has been observed on the estimation of average T-Out. However, when too few cows are equipped, the estimation of the whole herd's T-Out will be biased because some cows tend to stay in the barn. The estimation of T-Out using GPS collars seems promising to objectify the 'Pasture Milk' specification.

Use of drones with infrared cameras to search for fawns before mowing – experiences from practice

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Abstract

First cuts of grassland and fodder crops coincide with the birth time of roe deer fawns. While older fawns on plots can escape from the mower, younger fawns lack the escape behaviour and can be injured or killed. The aim of the study was to collect the information such as detection success and labour input for detection of fawns before mowing by using drones with infrared cameras. The data were recorded by nine drone users during the season 2020. The searched area varied between 0.3 and 38 ha per plot with overall 581.4 ha on 161 plots. Fawns were found or seen on 48 plots. In total, 88 fawns were found (of which 40 could be caught) by search, 8 were seen and escaped during mowing, and 10 were found injured or killed during or after mowing. Field time (time from arrival until departure from the plot) needed per ha and team (2-5 people) to search the plots varied between 0.05 and 1.49 h (0.36±0.25 h; mean±SD). Most of the fawns could be found using the drones with infrared cameras. However, this did not enable all fawns to be rescued on mown plots.

Testing the validity of a precision dairy ear sensor technology in recording grazing time

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Abstract

Commercially available smart farming technologies, e.g. ear tags that collect behavioural patterns, claim to provide economic benefits to livestock production and improvements in animal welfare. As these technologies are mainly applied to confined systems, this study aimed to validate them by visual observations to investigate their suitability for grazed grassland. A total of 24 Simmental heifers were randomly assigned to six experimental groups. These groups were then assigned into two fencing-system treatments (virtual fencing vs. physical fencing) which were compared in three successive periods of 12 days each. An ear sensor (CowManager™, Harmelen, the Netherlands) providing information on cattle activity was attached to the animals before the start of the experiment. For each period, two groups of four animals were grazed in two 1000 m^2 paddocks and grazing behaviour was observed visually for 4 h daily. Data obtained from ear sensors on grazing activity were predicted from the data based on visual observations in a generalized least square model. The relationship between observation data and sensor data was significant (P<0.0012) with a root mean square error = 39.72 and R^2_{adj} = 0.09. The ear sensor proved unreliable, and uncertainty in the prediction calls for further evaluation in the model.

Identifying areas of homogeneous grassland management based on iterative segmentation of Sentinel-1 and Sentinel-2 data

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Abstract

Remote sensing data in combination with image segmentation approaches have been shown to be valuable for identifying homogeneous areas such as agricultural land parcels. However, these approaches have not been widely explored for their usefulness in identifying homogeneous areas of grassland management under different management intensity levels. We present an unsupervised Bayesian segmentation approach for the combined analysis of Sentinel-1 and Sentinel-2 monthly composite data aiming to identify homogeneously managed grassland parcels, which was tested on an area of about 50 ha. We applied a segmentation refinement procedure with Sentinel-1 data in the first iteration and used Sentinel-2 data in the second iteration to delineate smaller areas within the identified segments. The approach led to promising results in intensively managed grassland areas with many mowing events. The results were also plausible under agriculturally extensive use. However, in semi-natural managed areas and in regions with varying environmental influences the identification of segments was prone to errors. The results show the potential of image segmentation in a grassland context, especially when management data are not available but needed. Our approach, although tested on a small scale, is applicable to larger regions.

Estimating grassland biomass from Sentinel 2 – a study on model transferability

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Abstract

Satellite-supported information services support farmers in a variety of ways to make management decisions. However, most satellite-based information services focus on arable land and are not yet available for grassland. An important aspect in the development of such information services is the correct derivation of green leaf area and aboveground dry biomass from satellite data. This derivation forms the technical basis for all subsequent analyses and management recommendations calculated by satellite-based information services. In a previous study, green leaf area and dry biomass were already successfully derived for a grassland site using two alternative modelling approaches – an empirical model based on random forest decision trees and the radiative transfer model SLC. For operational use in information services, transferability of the methods used in different areas is necessary. In this study we calculated DBM with both models and compared the results to DBM data provided by a combine harvester. The spatial heterogeneity within the fields was well captured by both models. Both models calculated significantly lower DBM than was measured with the combine harvester.

Tools for information to farmers on grasslands yields under stressed conditions to support management practices – the GrasSAT project

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Abstract

In order to manage grassland areas properly, and mitigate or avoid stress, precise information about grass growth conditions is needed. The main objective of the GrasSAT project is a fully operational system in the form of desktop and mobile applications, to provide a complementary tool for managing grassland production, mainly for medium and large farms in Poland and Norway. Combining the effectiveness of the application with the support of external advisers is the key to improve grass production management. The methodology for monitoring grass growth conditions and yield forecast will be based on synergistic use of remotely sensed data, process-based grassland models and reference in-situ data, indispensable for elaborating reliable models characterizing plant development. Using remote sensing to estimate the expected yield of a grassland site can help farmers to prepare for importing forage and to detect areas with high water stress. In addition, process-based models can help estimate the impact of a drought or freezing event on the yield. The project assumes the use of ground data for the calibration of satellite data.

Accuracy improvement of Rising Plate Meter measurements to support management decisions in the Black Forest region

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Abstract

Yield monitoring during the growing season is of great importance for grassland farmers, but challenging so far. Grass yields are often estimated based on visual observations, especially in rural and small-scaled areas with extensive dairy farms like the Black Forest region. The Rising Plate Meter Grasshopper® (RPM) is a decision support system based on sensor technology which calculates available dry matter (DM) based on the measured compressed sward height. The accuracy of the calculation algorithm for the Black Forest region needs to be evaluated before the system can be used reliably. About 100 RPM measurements and corresponding herbage samples were taken at four test sites in the Black Forest region during the 2020 growing season. The results of the calculated DM based on the RPM-measurements show a mean deviation of 13% in comparison to the reference DM of the herbage samples. The accuracy can be improved by adapting the algorithm for this region.

Botanical composition and progress of the growing season affect assessments of herbage yield based on compressed sward height

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Abstract

Compressed sward height (CSH) measurements by means of rising plate meters are a standard management tool to assess the herbage on offer in pastures and can be used to quantify the herbage mass if a suitable calibration curve is available. In a field trial we explored the combined effect of CSH, vegetation type and progress of the growing season on herbage dry mass. Paired measurements of CSH by means of rising plate meter (Grasshopper®, True North Technologies, Shannon, IRL) and of herbage dry mass (harvest at 3 cm cutting height with electric scissors) were performed during the grazing season (end of April until mid-October) at three paddocks in the montane vegetation belt of the Alps (South Tyrol, NE Italy) managed by compartmented short sward grazing, and differing moderately in their botanical composition. General Linear Models accounting for the covariates CSH and progress of the growing season (expressed as day of the year), as well as for the vegetation type showed a significant effect of all factors. For an accurate prediction of herbage mass, a vegetation type-specific calibration, even with relatively similar vegetation types, seems to be useful.

Development of a digital tool adapted to pasture management in South-West Germany

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Abstract

Grazing is a land use that has positive animal welfare benefits. A digital management tool called Weideinformationssystem ('Pasture Information System' in English), abbreviated as WIS, was developed to optimize grazing management. Farmers can integrate their list of individual animals as well as their list of fields currently managed for grazing into the WIS. The WIS can be used to document the number of grazing animals in the field each day to meet government funding programmes and to calculate the amount of nutrients excreted by grazing animals based on standardized values. Further development steps are planned to improve pasture management in order to generate benefits in terms of meeting the documentation obligations. It should be possible to integrate into the programme yield measurements and data on animal movement or grass intake, by various sensors, in order to evaluate the data and draw conclusions for optimizing grazing management.