Impact of leaf area index on the grassland yield prediction

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Abstract

The aim of our study was to evaluate the suitability of LAI calculated from satellite data (LAI-sat) for grassland yield prediction based on relations between in-situ ground measured yield indicators and LAI computed from in-situ values (LAI-cept) compared to relations between those indicators and LAI-sat data. The research was carried out in the years 2020–2023 on permanent grasslands located in dairy farms in central-western Poland. In each grassland, ground measurements were carried out in a representative 30 m×30 m plot every 2–3 weeks during the growing season. Fresh and dry matter yield was determined from biomass samples collected using a quadrat frame. Additionally, compressed sward height was measured using a Jenquip EC20 plate meter. LAI-cept was measured using AccuPAR LP-80 ceptometer and LAI-sat was obtained from platform Weekeo based on Sentinel-2 satellite images at 10 m pixel resolution. Statistical analysis has shown that all the tested relations had high correlation coefficients. The accuracy between LAI and FM or DM was slightly higher for LAI-sat than for LAI-cept. We conclude that LAI delivered from satellite data can be used to support grassland farmers to make proper management decisions.

Keywords: leaf area index, grassland, yield prediction, remote sensing

Introduction

The leaf area index (LAI) is one of the key biophysical metrics to characterize grassland vegetation growth. LAI can be measured using ground-based methods, but these approaches are time-consuming, labor-intensive, and difficult to apply at a regional scale. In the last few decades, remote sensing-based approaches, which are endowed with high temporal resolution and the capacity for large-scale observation, are increasingly used to estimate LAI. As reported by Reinermann *et al.* (2020), LAI is one of the most widely used indices within the studies investigating grassland management with remote sensing data, like NDVI and band reflectance values. Therefore, research towards practical applications of remote sensing-based LAI is needed to support appropriate grassland management decisions. The aim of our study was to evaluate the suitability of LAI obtained from satellite data for the grassland yield prediction based on relations between LAI in-situ and ground measured yield indicators.

Materials and methods

The research was carried out in the years 2020–2023 as part of the project GrasSAT (www.grassat.eu). Reference data were collected on 22 permanent grasslands selected in 10 medium and large dairy farms in the region of central-western Poland (Wielkopolskie voivodship). As suggested by Crabbe *et al.* (2019), on each site, a 30 m×30 m plot was randomly selected for in-situ ground measurements to encapsulate the resampled 10 m × 10 m spatial resolution of the Sentinel-2 imagery, allowing for a 10 m radius buffer around the 'central pixel' location for uncertainty in spatial registration of the image pixels. Field measurements were carried out every 2–3 weeks throughout the growing season. In this paper we report our investigations of the hypothesis that the correlation between grassland yield and different LAI obtained in-situ and from satellite is similar. The yield was represented by three different indicators: aboveground fresh biomass (FM), dry biomass (DM) and compressed sward height (CSH). On each site, the FM and DM yields were determined using the quadrat frame method from the area of 0.5×0.5 m with four replications. The CSH was measured using Jenquip EC20 alu plate meter. LAI at the ground level (LAI-cept) was determined with AccuPAR LP-80 ceptometer (using effective plant area index $L_e=\Omega L$ where Ω refers to a clumping index resulting from the non-random distribution of canopy elements). The remote sensing-based LAI (LAI-sat) was obtained from platform Weekeo based on a neural network that utilizes the surface reflectance of Sentinel-2A bands. The relationships between the in situ LAI-cept and biomass and the LAI-sat data were determined. The correlations were tested using the Pearson's *r* coefficient in the R statistical environment and modelled using simple linear regression with confidence interval displayed around the regression line (Wickham, 2016).

Results and discussion

The analysis has shown that there is a high correlation between all the indicators of grassland yield and the optical indicators of LAI (r>0.85). The correlation between LAI and FM is closer for LAI-sat than for LAI-cept (r=0.947 and 0.865, respectively). Similarly, the correlation between LAI and DM is slightly better for LAI-sat than for LAI-cept (r=0.929 and 0.885, respectively). The strength of correlation between CSH and LAI-sat or LAI-cept is at a similar level (r=0.856 and 0.856, respectively). In general, our results indicate that linear relationships between LAI-sat or LAI-cept and the studied grassland yield indicators are high. However, the scatter plots illustrating these relationships suggest that yield estimation using optical LAI indicators is most precise before the accumulation of grassland biomass reaches ca. 550 g FM m^{-2}, or 150 g DM m^{-2}, or before the average CSH is around 13 cm (Figure 1). All these threshold values are consistent with one another. Above these thresholds, the studied LAI indicators seem to be less responsive to the accumulation of grassland biomass or the CSH increase, which is indicated by the wider points dispersion and the weaker trend of increase in the plots. This is related to the change in the structure of aboveground biomass due to the transition from the vegetative to the generative growth stage in grasses and other plants. Another reason is foliage overlapping that makes some leaves invisible to the optical sensors.

Our study has shown that LAI-sat can be used to predict yield in decision support systems for grassland management, but the precision of this prediction can be further improved in future research. However, as reported by Reddersen *et al.* (2014), models for predicting biomass of extensively managed grassland using exclusive LAI were barely suited to predict biomass accurately, but can be improved significantly when combined with waveband selected common vegetation indices. We further propose that for tall and dense swards, the relationship between the yield and LAI-sat is modelled using a two-segment regression line (Muggeo, 2008), with the first segment steeper than the second one, and the breakpoint (yield indicator value where the two segments are connected) located near the above-mentioned threshold values.

Conclusions

The results shows that there is a high correlation between optically assessed LAI and FM, as well DM yields or CLS. The strongest correlation coefficient values were obtained for LAI from satellite, with slightly weaker correlation values received for LAI *in situ*. We concluded that remote sensing-based LAI is suitable to predict grassland yields and support grassland management decisions.

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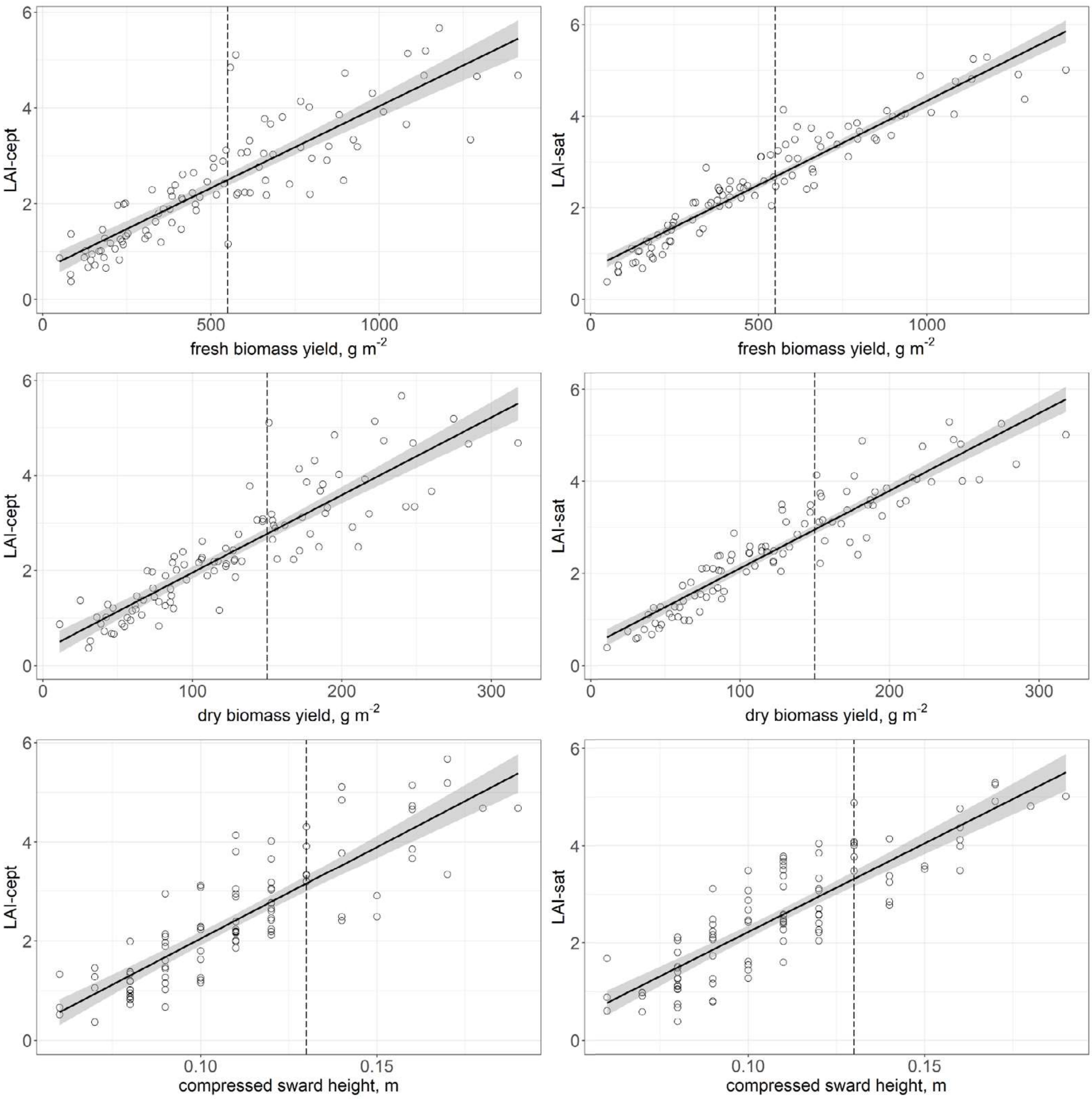

Figure 1. Correlation between in-situ measured LAI (left) and sensing-based LAI (right) and fresh biomass yield, dry biomass yield and compressed sward height on grassland (vertical long-dashed lines illustrate threshold values).

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