



Using optical remote sensing LAI for semi-natural grassland yields prediction in Noteć river valley

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Abstract

The aim of the study was to evaluate the suitability of LAI calculated from satellite data (LAI-sat) for semi-natural grassland yield prediction in Noteć river valley 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 within the project GrasSAT (www.grassat.eu) on semi-natural grasslands located in Noteć river valley (Wielkopolskie region in central-western Poland). Annual yield data were collected from ca. 150 ha of semi-natural grass vegetations located on organic soils used extensively for cutting raw material for conserved fodder. 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. 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-cept than LAI-sat. The optical remote sensing LAI applied for semi-natural grassland yields prediction is an efficient method that can be used to monitor the productivity of grass communities located in riparian areas of river valleys. This can help in planning for agricultural practices, can be an efficient tool in decision support system of semi-natural grassland management, and offsetting financial risks on large scales.

Introduction

Leaf area index (LAI) is an excellent proxy for biomass estimation because it directly quantifies the amount of leaf surface area relative to the ground area, providing critical insights into the vegetation's photosynthetic capacity and overall health (Parker 2020). Since biomass is closely linked to the amount of photosynthetically active tissue, LAI serves as a reliable indicator of the total biomass present in an ecosystem (Dąbrowska-Zielińska et al. 2024). Additionally, LAI captures variations in canopy structure, density, and leaf area, which are essential factors influencing biomass accumulation. Its non-destructive

measurement and correlation with other biophysical parameters make LAI a valuable tool for accurately estimating biomass across diverse vegetation types e.g. of grassland and rangeland (Reddersen et al. 2014). 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 index within the studies investigating grassland management with remote sensing data, just like NDVI and band reflectance values. Therefore, research towards practical applications of remote sensing-based LAI is needed to support grassland and rangeland growth modelling and appropriate management decisions.

The aim of our study was to evaluate the suitability of using optical remote sensing LAI for semi-natural grassland yields prediction in Noteć river valley.

Methods

The research was carried out in the years 2020-2023 within the project GrasSAT (www.grassat.eu). Reference data were collected on six semi-natural grasslands located in Noteć river valley (Wielkopolskie region in central-western Poland, one 52°89' N, 16°45' E, two close to each other 53°07' N, 16°92' E and three also located very close to each other 53°05' N, 17°10' E). Investigated area ca. 150 ha of semi-natural grass vegetations was located on organic soils used extensively for cutting raw material two times per year for conserved fodder (hay or haylage). 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 to 3 weeks throughout the growing season. In this paper we investigated the hypothesis that the correlation between semi-natural grassland yield and different LAI obtained in-situ and from satellite is similar. The yield was represented by two indicators: aboveground fresh biomass (FM) and dry biomass (DM). On each site, the FM and DM yields were determined using quadrat frame method from the area of 0.5 × 0.5 m with four replications. 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

The analysis has shown that there is a high correlation between all the in-situ grassland yields and the optical indicators of LAI. The correlation between LAI and FM is similarly for LAI-cept and for LAI-sat ($r = 0.904$ and $r = 0.905$, respectively). In the case of correlation between LAI and DM the LAI-cept is slightly better than LAI-sat ($r = 0.936$ and $r = 0.904$, respectively). In general our results indicate that linear relationships between LAI-sat or LAI-cept and the studied semi-natural 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 semi-natural grassland biomass reaches ca. 1000 g m⁻² of FM or 200 g m⁻² of DM (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 semi-natural grassland biomass 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. In such situation a combination of both, cover to mass can be used, like is commonly used in Australia at high and/or stoloniferous spreading pastures (Barnetson et al. 2021).

Discussion

Our study has shown that LAI-sat can be used to predict yield of semi-natural grassland yields in river valleys in decision support systems for its 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. Interesting findings regarding pasture yield estimation were presented by Barnetson et al. (2021), suggesting the need to measure the biomass structure, i.e. height or density. In the case of coastal grassland and inland woodland pasture, they developed deep learning predictive models of pasture yield from field measurements and both remotely piloted aircraft systems and satellite imagery.

The accuracy between LAI and FM or DM was slightly higher for LAI-cept than for LAI-sat, but the correlation between the in-situ grassland yield and the optical indicators of LAI was very high ($r > 0.90$). This result confirms the findings of other authors, e.g. Klingler et al. (2020) or Dąbrowska-Zielińska et al. (2024), who generally observed a significant influence of the seasonal changes of the canopy structure and morphology on the estimation accuracy. The optical remote sensing LAI applied for semi-natural grassland yields prediction is an efficient method that can be used to monitor the productivity of grass communities located in riparian areas of river valleys. This can help in planning for agricultural practices, can be an efficient tool in decision support system of semi-natural grassland management, and offsetting financial risks on large scales. The remote sensing-base LAI estimated by using Sentinel-2 is also of major importance for optimal semi-natural grassland growth modelling.

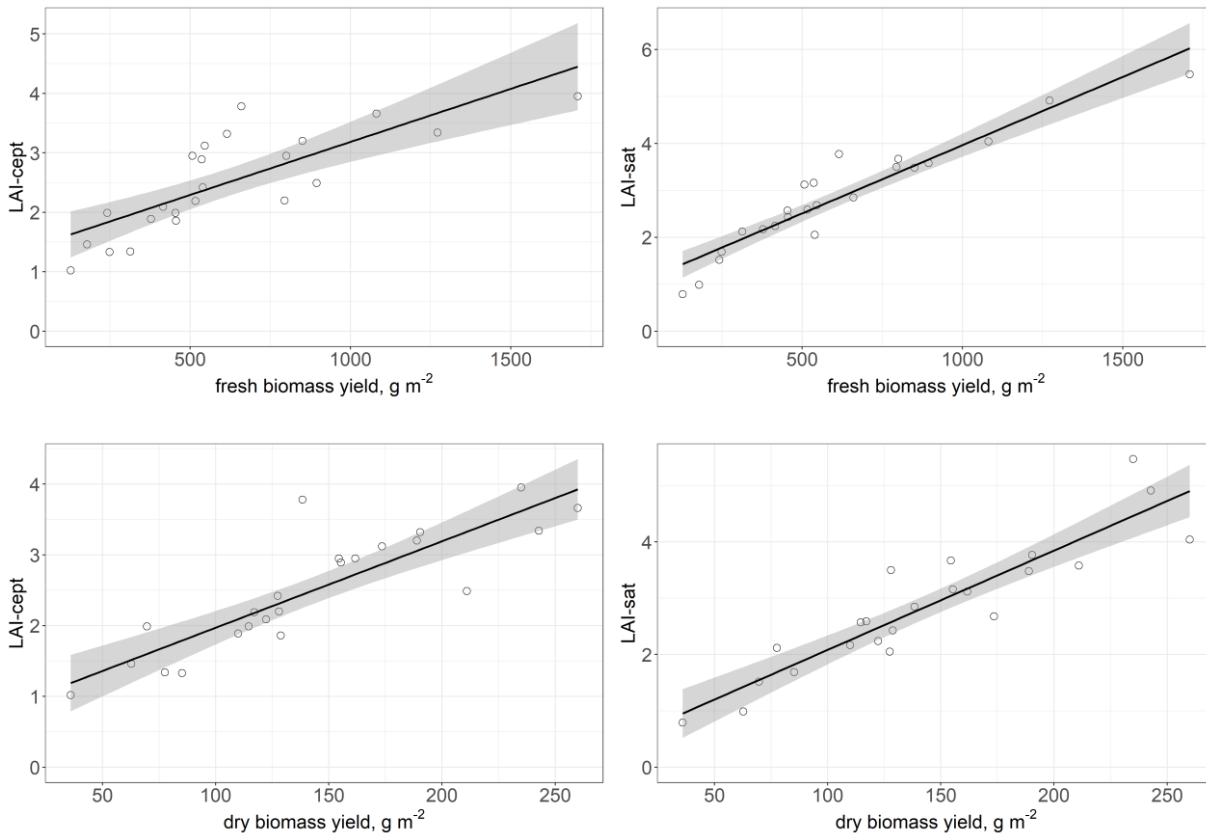


Figure 1. Correlation between in-situ measured LAI (left) and sensing-based LAI (right) and fresh biomass yield and dry biomass yield on semi-natural grassland in Noteć river valley

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