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Optimizing winter wheat leaf area index estimation across growth stages using UAV data

Winter wheat (*Triticum aestivum L.*) is a significant grain crop in Europe, with its production playing a crucial role in food security. Monitoring the growth status and predicting the yield of winter wheat is essential due to the potential impacts of climate change on crop stability. The leaf area index is a critical parameter for assessing vegetation health and crop yield. Traditional methods of estimating leaf area index, such as direct measurement, are precise but labour-intensive and unsuitable for large-scale monitoring. Remote sensing techniques, particularly those involving unmanned aerial vehicles (UAVs), offer high spatial resolution and temporal flexibility, making them ideal for estimating leaf area index over field scale. Therefore, this study aims to optimize the accuracy of leaf area index estimation for winter wheat across different growth stages by integrating UAV-derived spectral data and plant height measurements.

The study was conducted in Alnarp, Southern Sweden, over three winter wheat fields. Field data included leaf area index and plant height. UAV flights captured multispectral images, and these images were processed to generate reflectance maps and digital surface models for height estimation. Normalized Difference Red Edge Index (NDRE) and Chlorophyll Index (CIrededge) with Red Edge were two vegetation indices computed from the UAV data. The data were analysed using machine learning models, specifically the Random Forest algorithm, to establish regression models for leaf area index estimation. The NDRE emerged as the most effective single feature for leaf area index estimation, with an R^2 of 0.64 for testing data. The addition of wheat height features improved model performance in general, particularly for the combination of crop height and CIrededge, achieving an R^2 of 0.82 for testing data. Growth stage-specific models indicated that CIrededge and NDRE were the most effective features for both vegetative (from tillering to booting) and productive stages (from ear emergence to dough development), with R^2 values of approximately 0.86 and 0.84 for testing data, respectively.

In conclusion, the findings proved that using CIrededge and plant height data can estimate the leaf area index in winter wheat most accurately. The study also discussed the challenges of radiometric calibration and the limitations of using the red edge band, which showed weak correlations with the leaf area index. Additionally, the study emphasized the impact of weather conditions on capturing drone images and estimating plant heights and listed some future study directions on solving model overfitting problems.

Keywords: Leaf area index, multispectral UAV, winter wheat, machine learning, random forest

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