Estimation of winter wheat leaf area index at different growth stages using optimized red-edge hyperspectral vegetation indices

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Abstract. Leaf area index (LAI), as one of the most important indicators in vegetation growth monitoring, has been widely used in crop growth monitor and yield estimation. Previous studies focused on LAI retrieval for whole growth stages, this study inversely LAI at five main growth stages using widely-acknowledged vegetation indices and their optimized red-edge transformations. We used hyperspectral data to analyse relationships between LAI and vegetation indices. Partial least square discriminant analysis (PLS-DA) was used in this study to distinguish the best indices for distinct growth stages. The results show that LAI retrieval at various growth stages have distinct results. The best fitted indices for different growth stages are not fixed. The best indices for five stages are OSAVI$_{red1}$, SR$_{red1}$, SAVI$_{red2}$, SAVI$_{red2}$ and OSAVI$_{red1}$ with $R^2$ value of 0.20, 0.50, 0.49, 0.72 and 0.23, respectively. Most vegetation indices show better performance in milky stage than other four stages this may due to the high vegetation cover in this stage because leaves rise to maximum. Indices composed of red-edge exhibited better relationships with LAI with higher $R^2$ and lower RMSE. Indices combined reflectance at 740 nm are capable of inversing LAI at stem elongation, anthesis and milk development stages. Indices with 705 nm showed better results in jointing and ripening stages. The results indicate that: 1) specific vegetation indices for distinct growth stages lead to better estimation than inversing LAI for whole growth stages; 2) indices take advantage of red-edge showed better potentials in estimating high LAI than traditional visible wavelength.

1. Introduction

Leaf area index (LAI) is defined as half leaf area per unit ground area[1]. LAI plays an essential role in indicating crop growth condition.

Near infrared band and red band are the top two sensitive band to LAI. Ubiquitous vegetation indices are based on these two bands. Besides, red edge region was also used because it contributes to promoting LAI retrieval accuracies due to its higher sensitivity to vegetation characteristics such as chlorophyll [2]. Red edge region ranges from 680-750 nm[3]. Red-edge moves to long wavelength when vegetation grow fast and turn to short wavelength while the leaves turn yellow [4].
The main aims of this study are: 1) to distinguish the best fitted vegetation index for distinct growth stages; 2) to analyze the potential of red-edges in estimating LAI values.

2. Materials and methods
The study site was located at Shunyi District, Beijing, China (116°31’10”E to 116°53’26”E, 40°8’2”N to 40°14’0”N). The field site is a homogeneous winter wheat planting area. Winter wheat (*Triticum aestivum* L.) was used as the research object in this study. Field measurements were conducted in five main growth stages of winter wheat: jointing stage (April 7th), heading stage (April 20th), anthesis stage (May 3rd), milky stage (May 18th) and ripening stage (June 6th) in 2016.

Canopy spectrum were collected by ASD FieldSpec spectrometer. LAI measurements were collected from LAI 2200 (LICOR, Inc., Lincoln, NE, USA) according to standard procedures.

Five classical vegetation indices were used in this research. They are normalized difference vegetation index (NDVI), simple ratio (SR), difference vegetation index (DVI), soil-adjusted vegetation index (SAVI) and optimized soil-adjusted vegetation index (OSAVI). Also, the red-edge bands settings of sentinel-2 satellite were considered. 705 nm, 740 nm and 783 nm were selected to replace the red bands for optimized red-edge vegetation indices as VI\textsubscript{re1}, VI\textsubscript{re2}, VI\textsubscript{re3}.

3. Results and analysis
Relationships between LAI and vegetation indices for distinct and whole growth stages were analysed respectively. Determination coefficient (R\textsuperscript{2}), root mean square error (RMSE) and p-value are used to evaluate the performances of indices in this research. Partial least square discriminant analysis (PLS-DA) is used to distinguish the best fitted index for each growth stage.

For jointing stage, OSAVI\textsubscript{re1} showed the best relationship (R\textsuperscript{2}=0.20, RMSE=0.48) with LAI. Indices in this stage showed no clear association with LAI. RVI\textsubscript{re1} and SAVI\textsubscript{re2} show the best relationship (R\textsuperscript{2}=0.50, RMSE=0.77; R\textsuperscript{2}=0.50, RMSE=1.06) for heading stage and anthesis stage, respectively. In these two stages, optimized VI\textsubscript{re1} and VI\textsubscript{re2} showed better performances than normal indices while VI\textsubscript{re3} showed weak relationships. R\textsuperscript{2} showed best relationship with LAI in milky stage. Most indices had the highest R\textsuperscript{2} in this stage. The highest coefficient of determination appeared in SAVI\textsubscript{re2} (R\textsuperscript{2}=0.72, RMSE=0.70). The LAI-SVI relations are not significantly correlated in ripening stage. Optimized red-edge indices didn’t behave well in this stage. OSAVI\textsubscript{re1} had the best relation with LAI with R\textsuperscript{2} of 0.23 and RMSE of 0.84. During anthesis stage and milky stage, the relationships were relatively better. However, R\textsuperscript{2} in jointing stage, heading stage and ripening stage were low. Optimized VI\textsubscript{re1} and VI\textsubscript{re2} show better relations with LAI which indicates red-edge is sensitive to LAI variation.

4. Conclusion
In this paper, a new method to inverse LAI was proposed. Comparison among various vegetation indices on LAI retrieval during different growth stages were conducted. The results show that: 1) the best fitted vegetation indices for each growth stages are not the same because of the various interfering factors in LAI retrieval; 2) optimized red-edge vegetation indices showed better estimation at five stages than other indices.

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