Improved Estimation of Leaf Nitrogen Concentration in Rice at Early Growth Stages with Spectral Mixture Analysis of Unmanned Aerial Vehicle Imagery

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Abstract : The accurate assessment and timely monitoring of nitrogen status in rice is crucial to optimize nitrogen fertilizer management and reduce environmental pollution. In recent years, unmanned aerial vehicle (UAV) remote sensing has become a promising technology for crop monitoring. Previous studies have shown that the sensitivity of vegetation indexes (VIs) to leaf nitrogen concentration (LNC) in rice is poor for early growth stages (e.g., tillering and jointing) due to the large proportion of complex background materials between discontinuous rice canopies. The spectral mixture analysis (SMA) is an effective approach to deriving the abundance of each canopy component (e.g. rice plant) in a pixel. However, how to use SMA to improve the estimation of LNC from UAV imagery remains unclear. In this study, we combined UAV-based VIs and abundance information from SMA to improve the estimation accuracy of LNC in rice for the early growth stages. We conducted seven field campaigns to collect UAV-based multispectral images and concurrent field samples for LNC determination at tillering (TS), early jointing (EJ) and late jointing (LJ) stages over two consecutive years of 2018 and 2019. The images at the original spatial resolution of 2.7 cm were also degraded to a range of resolutions up to 18.9 cm. The three components (i.e., wet soil, duckweed, and rice) were extracted as endmembers within each plot from the multispectral images. We evaluated the relationships of LNC with VIs of all pixels, VIs of green pixels only, and VIs of all pixels multiplied by the abundance of rice component, respectively. The results demonstrated that the best-performing VI ($CI_{red\text{-}edge}$) incorporated with abundant information at the original spatial resolution exhibited a better relationship with LNC (TS: R^2=0.71; EJ: R^2=0.69; LJ: R^2=0.68) than those of all pixels (TS: R^2=0.32; EJ: R^2=0.42; LJ: R^2=0.51) or green pixels (TS: R^2=0.65; EJ: R^2=0.61; LJ: R^2=0.60). While degraded to the lowest spatial resolution, the relationships for the abundance incorporated $CI_{red\text{-}edge}$ (TS, R^2=0.68-0.71) was more stable than those for green pixels (TS, R^2=0.53-0.65). These findings suggest the SMA approach is useful for improving the estimation of LNC and is less affected by the spatial resolution of images. This study represents the significant advances in the application of SMA to LNC assessment and implies the SMA approach has great potential in nitrogen status monitoring over large areas with high resolution satellite images.

Keywords: unmanned aerial vehicle; leaf nitrogen concentration; spectral mixture analysis; $CI_{red\text{-}edge}$