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A Comparison of Satellite-Derived Vegetation Indices for Approximating Gross Primary Productivity of Grasslands

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Abstract

Gross primary productivity (GPP) is a key component of ecosystem carbon fluxes and the carbon balance between the biosphere and the atmosphere. Accurate estimation of GPP is essential for quantifying plant production and carbon balance for grasslands. Satellite-derived vegetation indices (VIs) are often used to approximate GPP. The widely used VIs include atmospherically resistant vegetation index, enhanced vegetation index (EVI), normalized difference greenness index, normalized difference vegetation index, reduced simple ratio, ratio vegetation index, and soil-adjusted vegetation index (SAVI). The evaluation of the performance of these VIs for approximating GPP, however, has been limited to one or two VIs and/or using GPP observations from one or two sites. In this study, we examined the relationships between the nine VIs derived from the moderate resolution imaging spectroradiometer (MODIS) and tower-based GPP at five eddy covariance flux sites over the grasslands of northern China. Our results showed that the nine VIs were generally good predictors of GPP for grasslands of northern China. Overall, EVI was the best predictor. The correlation between EVI and GPP also declined from the south to the north, indicating that EVI and GPP exhibited closer relationships in more southerly sites with higher vegetation cover. We also examined the seasonal influence on the correlation between VIs and GPP. SAVI exhibited the best correlation with GPP in spring when the grassland canopy was sparse, while EVI exhibited the best correlation with GPP in summer when the grassland cover was dense. Our results also showed that VIs could capture variations in observed GPP better in drought period than in nondrought period for an alpine meadow site because of the suppression of vegetation growth by drought.

Key Words: China, grasslands, gross primary productivity, MODIS, vegetation indices

INTRODUCTION

Grassland is one of the most widespread vegetation types worldwide, covering nearly one-fifth of the world's land surface (Lieth 1978). Natural grassland ecosystems are responsible for a substantial proportion (as much as 20% or more) of total terrestrial production and constitute a carbon sink of about 0.5 $Pg \cdot C \cdot yr^{-1}$ (Hall et al. 1995; Scurlock and Hall 1998). Ecosystem processes, including photosynthesis and respiration, are important parts of plant growth and ecosystem dynamics. Gross primary productivity (GPP), defined as the rate at which vegetation canopies fix carbon through plant photosynthesis, is an important component of the terrestrial carbon cycle (Gitelson et al. 2006). Accurate estimation of GPP is essential for quantifying plant production and carbon balance for grasslands.

Satellite-derived vegetation indices (VIs) can be used to approximate GPP at stand, regional, and global scales. A variety of VIs have been developed from satellite observations. Previous studies have estimated GPP directly using VIs, such as the normalized difference vegetation index (NDVI; Gilmanov et al. 2005) and the enhanced vegetation index (EVI; Sims et al. 2006, 2008). VIs are also the basis of some remote sensing-based GPP modeling approaches, such as the Carnegie-Ames-Stanford Approach (CASA; Potter et al. 1993), the Global Production Efficiency Model (GLO-PEM; Prince and Goward 1995), the Vegetation Photosynthesis Model (VPM; Xiao et al. 2005), and EC-MOD (a data-driven modeling approach based on eddy covariance flux measurements and MODIS data; Xiao et al. 2010).

The development and use of VIs have a history of over 30 yr. NDVI has been widely applied since 1970s (Rouse et al. 1973), using the reflectance of the red and near-infrared channels from the advanced very high resolution radiometer (AVHRR) aboard the NOAA's meteorological satellites. More VIs, such as the ratio vegetation index (RVI) and the soil-adjusted vegetation index (SAVI), have been developed using the red and near-infrared spectral bands. Other spectral bands have also been used to derive VIs. For example, in addition to the red and near-infrared bands, the enhanced vegetation index (EVI) makes use of information from the blue band (Huete and Liu 1994), and the reduced simple ratio (RSR) uses the shortwave infrared band (RSR; Brown et al. 2000). Theoretical analyses and flux measurements have shown strong linear relationships between VIs (e.g., NDVI and EVI) and GPP for a variety of ecosystems (McMichael 1999; Frank and Karn 2003; Glenn et al. 2008; Wu et al. 2008; Sjöström et al. 2009).

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