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Application of chlorophyll-related vegetation indices for remote estimation of maize productivity

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ABSTRACT

Crop gross primary productivity (GPP) is an important characteristic for evaluating crop nitrogen content and yield, as well as the carbon exchange. Based on the close relationship observed between GPP and total chlorophyll content in crops, we applied a model that relies on a product of chlorophyll-related vegetation index and incoming photosynthetically active radiation for remote estimation of GPP in maize. In this study, we tested the performance of this model for maize GPP estimation based on spectral reflectance collected at a close range, 6 m above the top of the canopy, over a period of eight years from 2001 through 2008. Fifteen widely used chlorophyll-related vegetation indices were employed for GPP estimation in irrigated and rainfed maize, and accuracy and uncertainties of the models were compared. We also explored the possibility of using a unified algorithm in estimating maize GPP in fields that are different in irrigation, field history and climatic conditions. The results showed that vegetation indices that closely relate to total canopy chlorophyll content and/or green leaf area index were accurate in GPP estimation. Both green and red edge Chlorophyll Indices, MERIS Terrestrial Chlorophyll Index as well as Simple Ratio were the best approximations of the widely variable GPP in maize under different crop managements and climatic conditions. They were able to predict daily GPP reaching 30 gC/m^2/d with RMSE below 2.75 gC/m^2/d.

1. Introduction

With the rising demand for agricultural products and commodities all over the world, croplands play an increasingly important role in global ecosystem balance, as well as human sustainable development. It is reported that approximately 24% of Earth's terrestrial surface is occupied by cultivated systems (Cassman and Wood, 2005). Gross primary production (GPP) of crops is the rate at which a cropland captures and stores carbon as biomass. Crop GPP has been estimated to contribute 15% of global carbon dioxide fixation through photosynthesis (Malmstrom et al., 1997). Therefore, there is a growing interest in crop GPP estimation especially on a regional and global scale, particularly in maize croplands that almost dominate agricultural land use in the north-central USA. An accurate and synoptic quantification of spatially distributed GPP of maize is essential for monitoring crop growth and carbon exchange of this region.

Field studies use tower eddy covariance systems to calculate seasonal and inter-annual dynamics of GPP in crops. Such micrometeorological approaches provide reliable and accurate estimates of GPP, based on measurements of the entire net CO_2 flux between the land surface and the atmosphere (e.g., Verma et al., 2005). However, it measures CO_2 fluxes over a limited area, although at a high temporal resolution. The up-scaling beyond these small footprints is needed for regional and global carbon budget evaluations as well as for estimating crop yield. Since crop productivity is a result of the interaction of solar radiation with plant canopy, remote sensing technique can be used as an expedient tool for GPP estimation over large areas.

The GPP estimate is based on a concept originally developed by Monteith (1972), suggesting that the GPP of stress-free plants is linearly related to the product of the incoming photosynthetically active radiation (PAR_{in}), the fraction of PAR absorbed by photosynthetically active elements of plants ($fAPAR_{green}$) and efficiency of converting absorbed radiation to biomass, light use efficiency (LUE):

$$GPP \propto LUE \times fAPAR_{green} \times PAR_{in} \quad (1)$$

Chlorophyll is a very important leaf pigment for absorbing radiation for photosynthesis. Total canopy chlorophyll (Chl) content was defined as the product of leaf chlorophyll content and total leaf area index, LAI (Ciganda et al., 2009; Gitelson et al., 2005), which seems the most relevant community property of vegetation productivity (e.g., Whittaker and Marks, 1975). The recent studies have

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