Int J Appl Earth Obs Geoinformation 66 (2018) 27–36

Contents lists available at ScienceDirect

Int J Appl Earth Obs Geoinformation

journal homepage: www.elsevier.com/locate/jag

Research Paper

Monitoring growth condition of spring maize in Northeast China using a process-based model

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ARTICLE INFO

Keywords:
Process-based model
Spring maize
Northeastern China
Growth condition

ABSTRACT

Early and accurate assessment of the growth condition of spring maize, a major crop in China, is important for the national food security. This study used a process-based Remote-Sensing-Photosynthesis-Yield Estimation for Crops (RS-P-YEC) model, driven by satellite-derived leaf area index and ground-based meteorological observations, to simulate net primary productivity (NPP) of spring maize in Northeast China from the first ten-day (FTD) of May to the second ten-day (STD) of August during 2001–2014. The growth condition of spring maize in 2014 in Northeast China was monitored and evaluated spatially and temporally by comparison with 5- and 13-year averages, as well as 2009 and 2013. Results showed that NPP simulated by the RS-P-YEC model, with consideration of multi-scattered radiation inside the crop canopy, could reveal the growth condition of spring maize more reasonably than the Boreal Ecosystem Productivity Simulator. Moreover, NPP outperformed other commonly used vegetation indices (e.g., Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI)) for monitoring and evaluating the growth condition of spring maize. Compared with the 5- and 13-year averages, the growth condition of spring maize in 2014 was worse before the STD of June and after the FTD of August, and it was better from the third ten-day (TTD) of June to the TTD of July across Northeast China. Spatially, regions with slightly worse and worse growth conditions in the STD of August 2014 were concentrated mainly in central Northeast China, and they accounted for about half of the production area of spring maize in Northeast China. This study confirms that NPP is a good indicator for monitoring and evaluating growth condition because of its capacity to reflect the physiological characteristics of crops. Meanwhile, the RS-P-YEC model, driven by remote sensing and ground-based meteorological data, is effective for monitoring crop growth condition over large areas in a near real time.

1. Introduction

China is the world's second-largest corn planting and consuming country. In recent years, the planting area, output, and yield of corn have increased by 5.57×10^3 km^2, 4.63×10^9 kg, and 6.24 kg/km^2 per year, respectively. Since China became a member of the World Trade Organization in 2001, the fluctuation of grain yield in China has been one of the most important factors affecting the international food market. In 2012, the planting area and output of maize accounted for 31.5% and 34.9% of China's total grain crop acreage and output, respectively, which ranked first among the three most important crops (i.e., rice, wheat, and maize). Therefore, China should adopt the strategic approach of accurate monitoring and early evaluation of the growth conditions of grain crops.

Since 1970s, the United States and the European Union have established crop monitoring systems based on remote sensing technology. Moreover, studies on crop growth condition using remotely sensed images have been conducted extensively in Canada, Japan, and Brazil. In 1980s, Chinese remote sensing agricultural monitoring systems, including monitoring crop growth condition and forecasting yield, were established by the China Meteorological Administration, China Academy of Sciences, and Ministry of Agriculture of China (Li, 1993; Sun, 1996; Shao et al., 2001; Wu, 2000, 2004). In recent years, many studies on monitoring crop growth condition have been performed on the aspects of indices selection (Banerjee et al., 2015), theoretical procession (Launay and Guerif, 2005; Ma et al., 2008; Zhao et al.,

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https://doi.org/10.1016/j.jag.2017.11.001
Received 7 February 2017; Received in revised form 25 October 2017; Accepted 6 November 2017

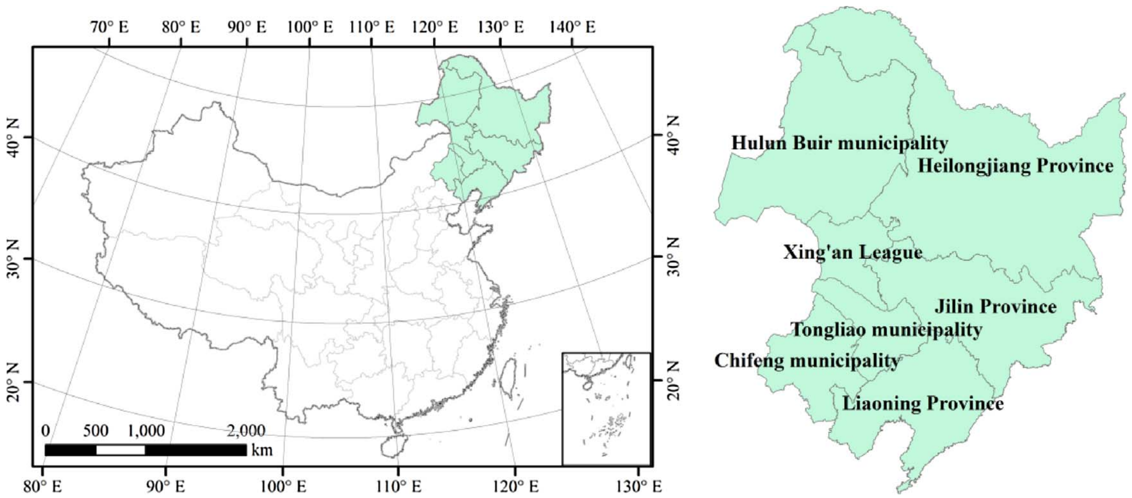

Fig. 1. Study area of Northeast China.

2013), and its quantification (Gornott and Wehsung, 2016).

According to differences in data sources and research techniques, the methods of monitoring crop growth condition can be classified into three categories. The first category monitors the crop growth condition sporadically using instantaneous satellite data. This method monitors crop growth condition based on vegetation indices at a specific developmental stage with high spatial resolution or hyper-/multi- spectral remote sensing data, such as Landsat TM data (Boschetti et al., 2007), RapidEye data (Shang et al., 2015), ground-measured hyperspectral data (Zhang et al., 2005), and Moderate Resolution Imaging Spectroradiometer (MODIS) data (Son et al., 2013). However, the critical developmental period for a certain crop might be missed using instantaneous remote sensing data. The second category monitors crop growth condition sequentially using time series remote sensing data with medium or low spatial resolution. This method can monitor growth condition directly throughout the entire crop growth period from sowing, to seedling emergence, to physiological maturity, and harvest, and it can further identify differences in growth condition between current and historical situations (Tottrup and Rasmussen, 2004; Zhao et al., 2009; Yan et al., 2009; Yang et al., 2015). This method can serve a statistical basis for forecasting crop yield by building a relationship between vegetation indices at a specific developmental stage and harvest yield (Mkhabela et al., 2011; Duveiller et al., 2012; Bolton and Friedl, 2013; Kowalik et al., 2014). However, limited by the spatial and temporal resolutions of the data and by the effects of cloud contamination, it is difficult to monitor crop growth condition continuously in a specific region. The third category monitors crop growth condition using a process-based crop growth model. This method can continuously simulate growth condition at both point and regional scales by integrating meteorological and remote sensing data. At present, several crop growth models (e.g., CERES-Wheat, WOFOST, and SUCROS) have been used successfully to simulate crop growth condition at the regional scale using satellite data (Launay and Guerif, 2005; De Wit and van Diepen, 2008; Ma et al., 2008; Zhao et al., 2013).

Vegetation indices based on satellite data have been used for monitoring, forecasting, and early evaluation of the crop growth condition and yield in previous studies, especially the Normalized Difference Vegetation Index (NDVI) (Groten, 1993; Kogan et al., 2003; Esquerdo et al., 2011) and Enhanced Vegetation Index (EVI) (Zhang and Zhang, 2016). Recently, it was found that EVI is more effective in monitoring vegetation growth compared to NDVI (Zhang and Zhang, 2016) because NDVI could be saturated in areas of dense canopy or high leaf area index (LAI) (Huete et al., 2006; Rocha and Shaver, 2009). However, most vegetation indices are calculated based on spectral observations, which means they largely reflect the traits of the vegetation surface rather than inherent characteristics of the crops (Raghavendra and Mohammed Aslam, 2016). Net primary productivity (NPP) of vegetation can represent the ability to absorb carbon and is widely used for carbon cycle research (Choudhury, 2000; Riedo et al., 2000; Mekonnen et al., 2017). The NPP also represents the above ground biomass. Therefore, a new method of applying NPP was proposed to monitor and evaluate crop growth condition in this study. The time series of NPP for spring maize in Northeast China was simulated using a process-based Remote Sensing-Photosynthesis-Yield Estimation for Crops (RS-P-YEC) model (Wang et al., 2011). As an important application of the RS-P-YEC model, the growth condition of spring maize was monitored using the time series of NPP at an early stage, i.e., from early May to mid-August. Meanwhile, the spatiotemporal characteristics of the growth condition were evaluated by comparison with the past 5- and 13-year averages, 2009 (the year of worst condition), and 2013 (the year of best condition).

2. Study area, methodology, and data

2.1. Study area

The area of Northeast China concerned in this study includes Liaoning Province, Jilin Province, Heilongjiang Province, and four municipalities in eastern Inner Mongolia (Chifeng municipality, Tongliao municipality, Hulun Buir municipality, and Xing'an League), comprising a total area of about 1.24×10^6 km^2 (Fig. 1). The study area is within a region of temperate monsoon climate with warm, rainy summers and cold, dry winters. The accumulated temperature of consecutive daily air temperatures ≥ 10 °C is about 2000–3600 °C d per year. Annual rainfall decreases from 1000 mm in the east of study region to 300 mm in the west, transiting from humid and semi-humid to semiarid regions. About 60% of the annual rainfall is concentrated during July to September. Sunshine is about 2500 h annually with an increasing trend from east to west. Overall, Northeast China is a region very suitable for planting spring maize because of its favorable meteorological conditions. Currently, it is the largest corn production base in China, contributing about 30% of the planted area and 33.5% of the total yield nationally. As such, changes in acreage and yield will have direct impact on both national economy and the livelihoods of the people of China.

2.2. Methodology

2.2.1. A process-based remote sensing model

The RS-P-YEC is a process-based remote sensing model built on the