Ecological Modelling 277 (2014) 1–12

Contents lists available at ScienceDirect

Ecological Modelling

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

Comparing cropland net primary production estimates from inventory, a satellite-based model, and a process-based model in the Midwest of the United States

Zhengpeng Li[a,*], Shuguang Liu[b], Zhengxi Tan[c], Norman B. Bliss[c], Claudia J. Young[d], Tristram O. West[e,a], Stephen M. Ogle[f,g]

[a] Earth System Science Interdisciplinary Center (ESSIC/UMD), 5825 University Research Court, College Park, MD 20740, United States
[b] U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD 57198, United States
[c] ASRC Federal InuTeq, Contractor to the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD 57198, United States[1]
[d] Earth Resources Technology, Inc. (ERT), Contractor to the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD 57198, United States[2]
[e] Joint Global Change Research Institute, Pacific Northwest National Laboratory, 5825 University Research Court, College Park, MD 20740, United States
[f] Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523, United States
[g] Department of Ecosystem Science and Sustainability, Colorado State University, Fort Collins, CO 80523, United States

ARTICLE INFO

Article history:
Received 17 June 2013
Received in revised form 10 January 2014
Accepted 14 January 2014
Available online 6 February 2014

Keywords:
Net primary production
Biogeochemical model
MODIS
Crop inventory
USDA Cropland Data Layer
Mid-Continent Intensive Campaign

ABSTRACT

Accurately quantifying the spatial and temporal variability of net primary production (NPP) for croplands is essential to understand regional cropland carbon dynamics. We compared three NPP estimates for croplands in the Midwestern United States: inventory-based estimates using crop yield data from the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS); estimates from the satellite-based Moderate Resolution Imaging Spectroradiometer (MODIS) NPP product; and estimates from the General Ensemble biogeochemical Modeling System (GEMS) process-based model. The three methods estimated mean NPP in the range of 469–687 $g\,C\,m^{-2}\,yr^{-1}$ and total NPP in the range of 318–490 $Tg\,C\,yr^{-1}$ for croplands in the Midwest in 2007 and 2008. The NPP estimates from crop yield data and the GEMS model showed the mean NPP for croplands was over 650 $g\,C\,m^{-2}\,yr^{-1}$ while the MODIS NPP product estimated the mean NPP was less than 500 $g\,C\,m^{-2}\,yr^{-1}$. MODIS NPP also showed very different spatial variability of the cropland NPP from the other two methods. We found these differences were mainly caused by the difference in the land cover data and the crop specific information used in the methods. Our study demonstrated that the detailed mapping of the temporal and spatial change of crop species is critical for estimating the spatial and temporal variability of cropland NPP. We suggest that high resolution land cover data with species–specific crop information should be used in satellite-based and process-based models to improve carbon estimates for croplands.

1. Introduction

The cropland net primary production (NPP) is an important component in the cropland carbon cycle because it represents the ability of the cropland to fix atmospheric carbon as biomass. Accurately quantifying the changes of cropland NPP is necessary for understanding the carbon dynamics for croplands, securing food and energy needs, and mitigating the effects of climate change. However, the global and regional NPP estimates still have large uncertainties among different methods (Ciais et al., 2010; Cramer et al., 1999; Ito, 2011). A comparison of the global NPP estimates found that simulated NPP from multiple models ranges between 39.9 and 80.5 $Pg\,C\,yr^{-1}$ for the terrestrial biosphere (Cramer et al., 1999). A recent study showed that the global NPP estimates from different methods are converging because more observational data are being used, especially spatial datasets generated from satellite remote sensing data (Ito, 2011). Differences among the global NPP estimates, however, are still about 8–9 $Pg\,C\,yr^{-1}$ between 2000 and 2010 (Ito, 2011). The carbon balance study of European croplands found that cropland NPP estimates range from 490 to 846 $g\,C\,m^{-2}\,yr^{-1}$ using different methods (Ciais et al., 2010). Such differences in NPP estimates are likely

---

* Corresponding author.
E-mail addresses: zli2012@umd.edu, zhengpengli@yahoo.com (Z. Li).

[1] Work performed under USGS contract G13PC00028.

[2] Work performed under USGS contract G10PC00044.

0304-3800/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ecolmodel.2014.01.012

to bring more uncertainties in the regional carbon budget. In a recent study of North America carbon balance, the mean carbon sink for croplands estimated from multiple terrestrial biosphere models is much lower ($-94.6\,\mathrm{Tg\,C\,yr^{-1}}$) than with inventory-based estimates ($-264.3\,\mathrm{Tg\,C\,yr^{-1}}$) and atmospheric inversion models ($-136.8\,\mathrm{Tg\,C\,yr^{-1}}$) (Hayes et al., 2012). These large differences between the estimates of cropland carbon sink may be reduced by more accurate NPP estimates for croplands.

Ito (2011) classified the global NPP estimation methods into five major categories: inventory, empirical model simulation, biogeochemical model simulation, dynamic global vegetation model simulation, and remote sensing estimation. At the regional level, three methods are commonly used to estimate the cropland NPP: crop inventory, biogeochemical model simulation, and remote sensing estimation using a satellite-based model.

NPP equals the amount of biomass that vegetation assimilates over a certain time period (Jenkins et al., 2001; Prince et al., 2001; Scurlock et al., 2002). For crops, the growing season NPP can be estimated from the crop yield data in the crop inventory with allometric and biomass conversion factors such as harvest index, root/shoot ratio, and biomass-to-carbon ratio (Hicke et al., 2004; Prince et al., 2001; West et al., 2010). Because government agencies usually maintained crop inventory and regularly updated the crop yield data, the magnitudes and interannual changes of NPP for croplands can be estimated from these inventory data. Prince et al. (2001) estimated cropland NPP using the crop yield data from the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) and found that county-level NPP varies from 200 to over $850\,\mathrm{g\,C\,m^{-2}\,yr^{-1}}$ in the U.S. Midwest. Hicke et al. (2004) analyzed the national crop yield data from NASS and found that the NPP of U.S. cropland increased from $350\,\mathrm{g\,C\,m^{-2}\,yr^{-1}}$ in 1972 to $490\,\mathrm{g\,C\,m^{-2}\,yr^{-1}}$ in 2001. This approach is limited because the agricultural inventory data are usually reported based on political boundaries and lack spatial detail within the boundaries.

Remote sensing information of the vegetation can be used in satellite-based models to estimate NPP. Field experiments have shown that the carbon assimilation rates of crops are proportional to the intercepted solar radiation (Monteith and Moss, 1977; Monteith, 1972). The intercepted solar radiation by vegetation can be estimated from the Normalized Difference Vegetation Index (NDVI) from satellite remote sensing data (Goetz et al., 1999; Prince and Goward, 1995; Prince, 1991). Gross Primary Production (GPP) can be estimated from NDVI and the Photosynthetically Active Radiation (PAR) with a conversion efficiency factor ε (Running et al., 2004):

$$\mathrm{GPP} = \varepsilon \times \mathrm{FPAR} \times \mathrm{PAR} \approx \varepsilon \times \mathrm{NDVI} \times \mathrm{PAR}, \tag{1}$$

FPAR is the fraction of PAR that is absorbed by vegetation. The conversion factor ε is the light use efficiency (LUE) factor and its value is affected by biological and environmental factors (Prince and Goward, 1995). Many terrestrial biosphere models used this approach to estimate the GPP and study the carbon balance in large regions and at the global scale (Hayes et al., 2012; Prince and Goward, 1995; Running et al., 2004; Tian et al., 2010). NPP can be calculated as the difference between GPP and the Autotrophic Respiration (AR) (Chapin et al., 2006). The Moderate Resolution Imaging Spectroradiometer (MODIS) project used this approach to generate the global GPP and NPP datasets with the Biome-BGC model (Running et al., 2004; White et al., 2000; Zhao et al., 2005). The Carnegie-Ames-Stanford-Approach (CASA) model uses a similar approach to calculate NPP directly from photosynthesis without the calculation of GPP and AR (Lobell et al., 2002; Potter et al., 1993).

Process-based models can simulate NPP based on the crop-specific characteristics and the environmental variables that constrain crop growth (Cramer et al., 1999). For example, crop-specific characteristics are represented in models by multiple crop parameters such as maximum growth rate, the shoot/root ratio and the carbon/nitrogen ratios in the crop components. These model parameters are derived from field observations and calibrated with site level biometric measurements. Environmental variables influencing growth, such as temperature, precipitation, and nutrient limits, are usually estimated from climate, soil, and management data. Multiple models are based on this approach: the CENTURY model developed by Parton et al. (1993); the denitrification–decomposition model developed by Li et al. (1997); the Environment Policy Integrated Climate model developed by Izaurralde et al. (2006); and the Erosion-Deposition-Carbon-Model (EDCM) developed by Liu et al. (2003).

In this study, we estimated NPP for croplands in the Midwest of the United States with three methods: crop inventory, a satellite-based model, and a process-based model. We assessed the estimates of cropland NPP per unit area and the total cropland NPP from these methods to answer three questions:

(i) What is the NPP for croplands in the Midwest estimated from different methods in 2007 and 2008?
(ii) What is the spatial and temporal variability of the NPP for croplands, and what are the major driving factors of this variability?
(iii) What are the differences between the NPP estimated by each method and what are the causes of these differences?

2. Materials and methods

2.1. Study area

The study area is the Mid-Continent Intensive Campaign (MCI) region of the National America Carbon Program (NACP) (Ogle et al., 2006). The MCI region encompasses 678 counties from 11 states in the Midwestern United States (Fig. 1). The MCI region covers multiple major land resource areas (MLRA) and has large variation in climate, soil, and cropping systems. An MLRA is a region that has similar climate, soil, and land use systems as defined by the USDA (USDA, 2006).

The northwestern part of the MCI region including North Dakota and South Dakota is in the Northern Great Plains Spring Wheat Region (USDA, 2006). The mean annual precipitation varies from 355 to 535 mm and the mean annual air temperature varies from 5 to 7 °C. The dominant soil type is Mollisols and the major cropping system is dry-farmed spring wheat. The northeastern part of the MCI region including northern Minnesota, northern Illinois, and most of Wisconsin is in the Northern Lake States Forest and Forage Region (USDA, 2006). This region has a mean annual precipitation from 660 to 865 mm and a mean annual air temperature from 4 to 7 °C. The dominant soil type is Histosols and other major soil types include Alfisols, Spodosols, Entisols, and Mollisols. This region has large forest areas and the major cropping systems are corn and wheat.

Most of the central part and large fraction of the southwestern part of the MCI region is in the Central Feed Grains and Livestock Region. This region includes southern Minnesota, Iowa, Illinois, and northern Missouri (USDA, 2006). This region has the most favorable climate and soil for agriculture. The mean annual precipitation ranges from 815 to 990 mm and the mean annual air temperature ranges from 8 to 12 °C. Major soil types include Mollisols, Entisols, Alfisols, Entisols, and Inceptisols. The major cropping systems are continuous corn and a corn–soybean rotation. Most of the corn and soybeans in the United States are produced in this region.

The western part of the MCI region including part of South Dakota and Nebraska is in the Western Great Plains Range and Irrigated Region (USDA, 2006). This region has a mean annual precipitation from 330 to 560 mm and a mean annual air temperature