Applied Geography 79 (2017) 212–222

Contents lists available at ScienceDirect

Applied Geography

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

Mapping cropping intensity trends in China during 1982–2013

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ARTICLE INFO

Article history:
Received 3 August 2015
Received in revised form
5 January 2017
Accepted 6 January 2017
Available online 19 January 2017

Keywords:
Cropping intensity
MODIS
China
Continuous wavelet transform
Spatiotemporal continuous datasets

ABSTRACT

Long range continuous monitoring information of cropping intensity is useful for sustainable agricultural management but still limited. This study filled this information gap through delivering spatiotemporal continuous datasets of cropping intensity in China during the past 30 years. Cropping intensity data were derived by a wavelet features-based method based on the long-term weekly global EVI2 (Enhance Vegetation Index with two bands) at 0.05° spatial resolution (5 km) from 1982 to 1999 and 8-day composite 500 m Moderate Resolution Imaging Spectroradiometer (MODIS) surface reflectance products from 2001 to 2013. The remote-sensing estimated images in 2013 agreed well with field survey data (overall accuracy = 91.63%) and the national agricultural census data ($r^2 = 0.89$). Results revealed that the cropping intensity remarkably increased during 1982–1999 but slightly declined during 2001–2013. The overall cropping intensity increased from 1.34 in the 1980s to 1.41 in the 1990s, and then dropped to an average of 1.36 after 2000. From 1982 to 1999, approximately 93,225 km^2 single-cropped areas changed to double-cropping, primarily those located in the North China plain. However, 39,883 km^2 double-cropped areas were turned back into single-cropping areas from 2001 to 2013, principally located in the North China plain, the Middle-lower Yangtze River plain, and the hill regions of the southern Yangtze River. This reverse trend of cropping intensity was due to combined effects from the corresponding reverse variations in agricultural population, increasing agricultural mechanical power, positive agricultural policy. The agricultural duty free policy has only immediate effects on stabilizing cropping intensity in croplands with more favorable biophysical conditions.

1. Introduction

Asia is home to the most intensively farmed cropland on earth in order to meet the growing demand for agricultural products with limited room for expansion (Gray et al., 2014; Plourde, Pijanowski, & Pekin, 2013). For example, agriculture in China feeds 33% of the world's population with only 7% of the world's arable land (Piao et al., 2010). Multiple cropping is widely utilized to increase food production in Asian countries. However, intensification might have significant environmental and social impacts, which need careful evaluation (Plourde et al., 2013; Qiu et al., 2003; Robinson, Ericksen, Chesterman, & Worden, 2015; Wang, Zhang, & Fu, 2016). Timely and spatially continuous information of cropping intensity (CI) is required for sustainable agricultural and environmental management (Challinor, Parkes, & Ramirez-Villegas, 2015; Iizumi & Ramankutty, 2015). However, there are a limited number of cropping intensity datasets and crop-specific information in current global land cover products (Iizumi & Ramankutty, 2015; Qiu, Qi, Tang, Chen, & Wang, 2016a, 2017; Wang et al., 2016).

Considerable remote sensing-based research efforts have been undertaken to characterize agricultural intensification, especially cropping intensity (Ding et al., 2016; Gray et al., 2014; Jain, Mondal, DeFries, Small, & Galford, 2013; Wang et al., 2016; Yan et al., 2014). On a global scale, a global map of irrigated areas and rain-fed crop areas provides information on irrigation status and cropping intensity (Thenkabail et al., 2009). In the United States, the U.S.

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http://dx.doi.org/10.1016/j.apgeog.2017.01.001
0143-6228/

Department of Agriculture's (USDA) Cropland Data Layer provides a means to assess the acreage of major crops, finding evidence of increased monoculture cropping (Plourde et al., 2013). In Asia, a recent study developed 500 m Asian Cropping Intensity CI maps using MODIS images for years 2009–2012 and revealed significant challenges in mapping CI (with overall accuracy of 11%) (Gray et al., 2014). In China, 0.5° resolution distribution maps of single and multi-crop rotations in mainland China have been generated through combining agricultural census data and 1995-96 Landsat Thematic Mapper data (Qiu et al., 2003). Recently, cropping intensity in 2012 was derived from MODIS data based on the peak-detection method with reference to agro-meteorological observations (Yan et al., 2014). From 2005 to 2012, the annual agricultural intensity in mainland China at 500 m spatial resolution was obtained using an iterative moving-window method and evaluated through comparing a visually interpreted time series (Li et al., 2014).

Besides the research efforts of mapping cropping index, trends of agricultural (cropping) intensity over time have also been documented (Robinson et al., 2015). For example, cropping intensity increased from the early 1980s to the late 1990s in China based on 8 km AVHRR NDVI images (Yan, Liu, & Cao, 2005). The mean multiple cropping index over the whole of northern China increased from 107% to 115% throughout the 1980s and 1990s based on 8 km Global Inventory Modeling and Mapping Studies (GIMMS) NDVI datasets (Ding et al., 2016). Farmers moved from single-to double-cropping in order to increase yields during the 2000s in Mato Grosso, Brazil (Arvor, Jonathan, Meirelles, Dubreuil, & Durieux, 2011).

Despite these research efforts, mapping cropping intensity is relatively understudied compared to mapping the amount of cropland and irrigation (Gray et al., 2014). There are several challenges involved in undertaking these studies. First, validation and accuracy assessment conducted with ground truth datasets is arguably essential when considering the complexity of the MODIS Vegetation Indices (VI) time series across different regions. It is recognized that trajectories of MODIS Vegetation Indices time series in croplands are highly variable over large areas (Qiu, Zeng, Tang, & Chen, 2013, Qiu et al. 2017). Second, most of these datasets cannot be easily utilized to identify changes since they only provide a snapshot in time (Gray et al., 2014). Third, the inter-annual spatiotemporal trends and the influencing factors for relatively longer periods are rarely investigated (Ding et al., 2016).

Given the importance of cropping intensity in balancing the food productions and increasing demands of land for rapid urbanizations, studies on the country-wide spatiotemporal trends in cropping intensity are essential for a better understanding of food security and agriculture-related decision-making in China (Ding et al., 2016). Previous research has failed to provide temporally and spatially continuous monitoring and neglected the spatial heterogeneity of cropping intensity (Ding et al., 2016). This study aims to fill this gap by developing broad scale spatiotemporal continuous datasets of cropping intensity in China during the past 3 decades (1982–2013) based on vegetation indices time series with better spatial and temporal resolutions. We aim to answer the following questions: how did multiple-cropping croplands vary spatially and inter-annually from 1982 to 2013? Is there any overall decreasing or increasing trends? What are the primary spatiotemporal trends and the implications?

2. Data sources and methodology

2.1. Study region

China has tremendous altitudinal and climatic diversity (Fig. 1(a)). Croplands span temperate, subtropical, and tropical climates. Primary large arable lands are located in several plains: the Northeast China Plain, the North China Plain, the Middle-lower Yangtze River Plain, the Pearl River Delta Plain, and the Sichuan Basin. The mountainous and hilly areas in South China are characterized with relatively small patches of croplands. According to the distribution of farmland and its cropping intensity, climatic and topographic conditions, the whole country is subdivided into 11 regions (Fig. 1(b)). Single cropping is common in northern China, while multi-cropping rotations dominate south of 40°N (Piao et al., 2010). Triple cropping is generally practiced in tropical regions, particularly Hainan and Taiwan islands (see locations in Fig. 2(a)).

2.2. Data sources

The vegetation index (VI) time series utilized from 2001 to 2013 (2001–2013) were 8-day composite 500 m Moderate Resolution

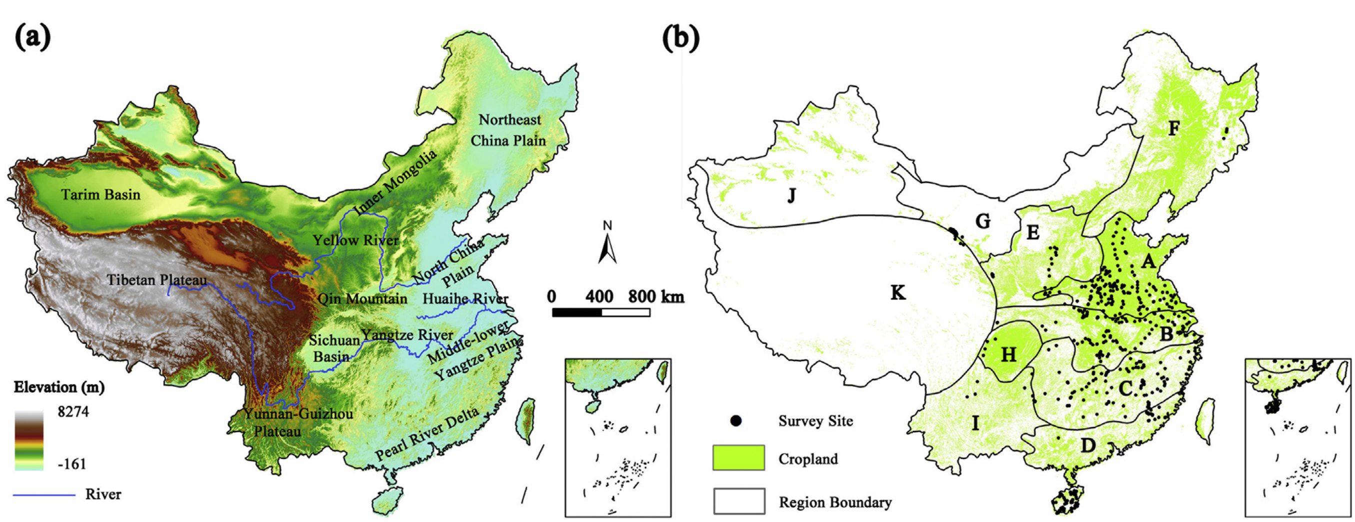

Fig. 1. The spatial distribution of elevation (a), croplands, and survey sites (b). Notes: Regions A-K represented the North China plain, the Middle-lower Yangtze River plain, the southern Yangtze hill region, the Pearl River Delta, the loess plateau, Northeast China, the Inner Mongolia Plateau, the Sichuan basin, the Yunnan-Guizhou plateau, the Tibet-Qinghai plateau, and Xinjiang region, respectively.