JOURNAL OF ENVIRONMENTAL SCIENCES XX (2017) XXX–XXX

Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/jes

JES JOURNAL OF ENVIRONMENTAL SCIENCES
www.jesc.ac.cn

Dynamics of major air pollutants from crop residue burning in mainland China, 2000–2014

Quanfeng Jin[1,2,3], Xiangqing Ma[1,2], Guangyu Wang[4], Xiajie Yang[1,2], Futao Guo[1,2,*]

1. College of Forestry, Fujian Agriculture and Forestry University, Fuzhou 350002, China
2. Co-innovation Center for Soil and Water Conservation in the Red Soil Region of the Cross-straits, Fuzhou 350002, China
3. Li Shui Vocational Technical College, Lishui 323000, China
4. Asia-Pacific Forest Research Centre, Faculty of Forestry, University of British Columbia, Vancouver, BC V6T 1Z4, Canada

ARTICLE INFO

Article history:
Received 22 June 2017
Revised 27 October 2017
Accepted 21 November 2017
Available online xxxx

Keywords:
Agricultural pollutants
Crop residue
Straw burning
Air pollution
Temporal and spatial variations

ABSTRACT

Based on satellite image data and China's Statistical Yearbooks (2000 to 2014), we estimated the total mass of crop residue burned, and the proportion of residue burned in the field vs. indoors as domestic fuel. The total emissions of various pollutants from the burning of crop residue were estimated for 2000-2014 using the emission factor method. The results indicate that the total amount of crop residue and average burned mass were 8690.9 Tg and 4914.6 Tg, respectively. The total amount of emitted pollutants including CO_2, CO, NOx, VOCs, $PM_{2.5}$, OC (organic carbon), EC (element carbon) and TC (total carbon) were 4212.4–8440.9 Tg, 192.8–579.4 Tg, 4.8–19.4 Tg, 18.6–61.3 Tg, 18.8–49.7 Tg, 6.7–31.3 Tg, 2.3–4.7 Tg, and 8.5–34.1 Tg, respectively. The emissions of pollutants released from crop residue burning were found to be spatially variable, with the burning of crop residue mainly occurring in Northeast, North and South China. In addition, pollutant emissions per unit area (10 km × 10 km) were mostly concentrated in the central and eastern regions of China. Emissions of CO_2, NOx, VOCs, OC and TC were mainly from rice straw burning, while burning of corn and wheat residues contributed most to emissions of CO, $PM_{2.5}$ and EC. The increased ratio of $PM_{2.5}$ emissions from crop residue burning to the total emitted from industry during the study period is attributed to the implementation of strict emissions management policies in Chinese industry. This study also provides baseline data for assessment of the regional atmospheric environment.

Introduction

Biomass burning is an important source of particulate matter and gaseous pollution, thereby playing a significant role in the global atmosphere, ecosystems and climate change (Miura and Kanno, 1997; Keshtkar and Ashbaugh, 2007). Previous studies have reported that in 1979, 1990 and 2001, the annual biomass combustion worldwide was 6800 Tg, 8680 Tg and 8600 Tg, respectively (Andreae and Merlet, 2001), of which crop residue burning accounted for about 8% (Werf et al., 2010). Crop residue burning emits large quantities of gaseous pollutants, such as SO_2, NOx, NH_3, CO and VOCs (volatile organic compounds), significantly affecting regional air quality. It is unanimously agreed that high concentrations of CO, NO_X and VOC_S promote the formation of photochemical smog and haze, seriously affecting regional air quality and human health (Andreae and Merlet, 2001; Reinhardt and Ottmar, 2004; Kulle, 2008). The emission and deposition of large amounts of

* *Corresponding author. E-mail:* guofutao@126.com (Futao Guo).

https://doi.org/10.1016/j.jes.2017.11.024
1001-0742/© 2017 The Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. Published by Elsevier B.V.

NOx also promote the formation of acid rain and negatively affect soil pH and other physical and chemical soil properties (Singh and Agrawal, 2008). Additionally, EC (element carbon) has a strong influence on the absorption and scattering of sunlight, and is believed to be one of the main causes of global warming and reduced atmospheric visibility (Cao et al., 2005; Stone et al., 2010).

China is a large agricultural country with the largest mass of crop residue in the world, accounting for 17.29% of the total global mass (Bi et al., 2010) and 63.4 % of the total mass in Asia (Yevich and Logan, 2003). Residues of wheat, corn, rice, and beans are the major crop residues in China, which are generated after harvesting and before the next planting (Gupta et al., 2004). The total mass of crop residue in mainland China was estimated to be 60.6 Tg, 61.0 Tg and 62.3 Tg in 2000, 2001 and 2002, respectively (Guo et al., 2004). The utilization rate of crop residue is low, with large quantities either discarded or burned in the field (Bhatia et al., 2013). A previous study showed that the emissions of $PM_{2.5}$, BC, OC, SO_2, NO_x, NH_3, CO and VOCs resulting from the burning of crop residue in mainland China in 2007 were 13.2 Tg, 1.4 Tg, 3.0 Tg, 31.6 Tg, 23.2 Tg, 16.0 Tg, 164.9 Tg and 35.5 Tg, respectively (Cao et al., 2011). To date, studies have focused on the concentrations and total gaseous emissions from crop residue burning in a given year (Cao et al., 2008a, 2008b; Zhang et al., 2016), but dynamic analyses over a longer continuous time period are lacking. Previous studies have also tended to use a single combustion emission factor instead of specific emissions factors for different crops (Yan et al., 2006; Zhang et al., 2008), or have ignored the difference between indoor and outdoor combustion emission factors (Sahai et al., 2007), which is likely to increase estimation errors.

Based on data from China's Statistical Yearbooks and previous research, this study uses more specific emissions factors to analyze the spatial and temporal trends of pollutant emissions from crop residue burning in different regions in mainland China from 2000-2014. The main objectives of this research are to: (1) estimate the type of crops burned and their total mass from 2000 to 2014; (2) estimate the total emissions of CO_2, CO, NO_x, VOCs, $PM_{2.5}$, OC and EC from crop residue burning; (3) analyze the spatial and temporal changes in pollutants in different regions; and (4) provide a scientific basis for relevant model-based research and atmospheric pollution control policies.

1. Materials and methods

This study is based on data from 31 regions of mainland China, including provinces, autonomous regions and municipalities. Crop residues are currently used in three main ways in mainland China: natural decomposition, burning in the field, and burning as domestic fuel.

1.1. Study area

The mainland of China (Fig. 1) is located between 6°06′–53°30′ N and 73°20′–135°30′ E. China has a large population of ~1.36 billion (2014). China's crop area is about 1.5×10^9 ha, accounting for 15.63% of its total land area and about 7% of the world's arable land. Rice, corn and wheat are the dominant food crops in China, and beans, rapeseed and peanuts are the major oil crops (https://data.worldbank.org/indicator/AG.LND.A). From 2003 to 2010 China experienced 273,418 crop fires, with an average of 34,177 crop fires per year (Huang et al., 2012).

1.2. Data sources

The data used for crop residue burning is from the MODIS wildland fire data product, which is a reliable source for monitoring vegetation fires (Amraoui et al., 2015). Even when affected by natural factors, the success rate of MODIS in fire monitoring is nearly 90%. By removing the interference of noise, flares and cloud, the success rate in monitoring forest fire in different areas and seasons is as high as 100% (Zhou and Wang, 2006). This study uses MOD14A1 (daily scale at 1 km resolution) to extract the geographical coordinates and the ignition time of fire spots in mainland China from 2000 to 2014. Modis14A1 has been used in previous studies to estimate the emissions from agricultural fires in China (Liu et al., 2015, 2016). Other studies have pointed out that some agricultural fires may not be detected by MODIS sensor, but in this study, the MODIS fire product is mainly used to show the temporal and spatial distribution of agricultural fires in different regions of China; in this context, the fires "undetected" by MODIS sensors can be considered a systematic error that will not significantly impact our findings. In addition, the emissions of pollutants from crop burning are calculated based on statistical data and literature review using emissions factors and grain-to-straw ratios. The function of the MODIS fire product is to calculate the spatial weight for each region of China and to allocate the estimated emission of pollutants to each region based on the weight (for more details please see Section 0). The MODIS fire data were then overlaid on a vegetation type map (also of 1 km resolution) to identify crop fires. The vegetation type map was obtained from the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC) (http://www.resdc.cn).

Crop yield data was obtained from China's Statistical Yearbooks (2001-2015) and used to calculate the mass of crop residue with the residue-to-product ratios (RPR) obtained from previous studies (Liu and Shen, 2007; Xie et al., 2011a, 2011b) (Table 1). For the combustion efficiency of different crop residues burned in the field, this study refers to the previous study by Huang et al. (2012) (Table 1), and for the combustion efficiency of different crop residues burned as domestic fuel, an average of 92.5% was adopted based on Zhang et al. (2008).

Due to limited information on the ratio of burned crops in the field to the total amount of crop residue in China, we combined results of previous studies conducted for a specific year including 2000, 2004, 2006 and 2010 (Cao et al., 2008a, 2008b; Tian et al., 2011; Zhang et al., 2008; Peng et al., 2016) to estimate the ratio for each region from 2000 to 2014. The average annual change ratio of burned crop residue in the field was then calculated based on the value of four specific years and the ratio for 2011–2014 fixed at the 2010 value (see ratio values in Appendix 1). In addition, the ratio of crop residue burned indoors as domestic fuel to the total amount of crop residue burned each year were mainly obtained from the China Energy Statistical Yearbook (2001-2009); however, due to a lack of statistical information, the ratio between 2009-2014 was fixed at the 2008 value (see ratio values in Appendix 2).

Please cite this article as: Jin, Q., et al., Dynamics of major air pollutants from crop residue burning in mainland China, 2000–2014, J. Environ. Sci. (2017), https://doi.org/10.1016/j.jes.2017.11.024