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Review

Current status and environment impact of direct straw return in China's cropland – A review

Hui Li[a,*], Mingwei Dai[a], Shunli Dai[b], Xinju Dong[c]

[a] School of Resources and Environment, Anhui Agricultural University, Hefei 230036, Anhui, China
[b] College of Engineering, Anhui Agricultural University, Hefei 230026, Anhui, China
[c] Department of Chemistry, Western Kentucky University, Bowling Green 42101, KY, USA

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ABSTRACT

With the development of grain production technologies and improvement of rural living standard, the production and utilization of straw have significantly been changed in China. More than 1 billion tones of straw are produced per year, and vast amount of them are discarded without effective utilization, leading various environmental and social impacts. Straw return is an effective approach of the straw utilization that has been greatly recommended by government and scientists in China. This paper discussed the current status of the straw return in China. Specifically, the production and models of straw return were explored and their environmental impacts were extensively evaluated. It was concluded that straw could be positively effective on the improvement of the soil quality and the grain production. However, it appeared that the straw return also had several neglect negative effects, implying that further research and assessment on the returned straw are required before its large-scale promotion in China.

1. Introduction

As a biggest traditional agricultural country in the world, China has a huge amount of various crop straw with the yield of 1.04 billion tones in 2015, which accounts for nearly one-third of the global production (Han et al., 2002; Li et al., 2017). Crop straw has been used as domestic heating, cooking, livestock feeding, building and industrial raw materials in rural areas in China for a long history (Lu, 2015). With the dramatic increase of the crop production during the past few decades, and the economic and social improvement in rural areas, more and more straw has been replaced by daily fossil fuel energy sources (Qu et al., 2012). More than 30% crop straw was burned in the field after harvest in most eastern and southern areas in China (Wang and Zhang, 2008), emitting large amount of gaseous and particulate pollutants and leading greater environmental and social impacts (Chen et al., 2017a; Poetter et al., 2014; Sun et al., 2016; Wang and Zhang, 2008; Yang et al., 2013; Zhang et al., 2017a, 2016; Zhou et al., 2017). Therefore, it is an urgent issue in China to find an environment-friendly, high efficient, low costly and less secondary polluted approach for straw utilizations (Qu et al., 2012).

Nowadays, Chinese government has paid much attention to the straw utilization, and has officially and strictly banned the direct straw burning, which has been implemented in April 2014 (Hong et al., 2016). Nonetheless, the latest data from the ministry of environmental protection indicated there were 3744 straw combustion sites involving 15 provinces detected by environmental satellites during April 2017, implying that the integrated utilization of straw still did not achieve the desired results. Straw burning has been regarded as the easiest and fastest approach to dispose agricultural waste and satisfies the time limitations for double/triple crop system (Yu et al., 2017). However, the direct combustion of crop straw emits various pollutants such as fine particulate matter (PM_{10} and $PM_{2.5}$, i.e. particles smaller than 10 or 2.5 μm), polycyclic aromatic hydrocarbons (PAHs), and other gaseous pollutants (Chen et al., 2017b; Li et al., 2007; Lu and Zhang, 2010; Subramanian, 2014; Zhang et al., 2011). Therefore, the proper disposal of crop straw has become an urgent concern for not only the air quality, but also the effective beneficial utilizations of these valuable resources (Yang, 2017).

Five main utilization approaches for straw have been proposed by the Ministry of Agriculture, ie. used as fuel, fertilizer, feed, industrial raw material, and base material. Among of them, the straw return to soil as fertilizer is and will continue to be the most widely adopted approach in China. About 32% of the total straw has been returned to soil (Bi et al., 2008), and this number has been gradually increased in recent years.

Straw contains abundant organic matters, potassium, phosphorous,

* Corresponding author.
E-mail address: zhpaper@126.com (H. Li).

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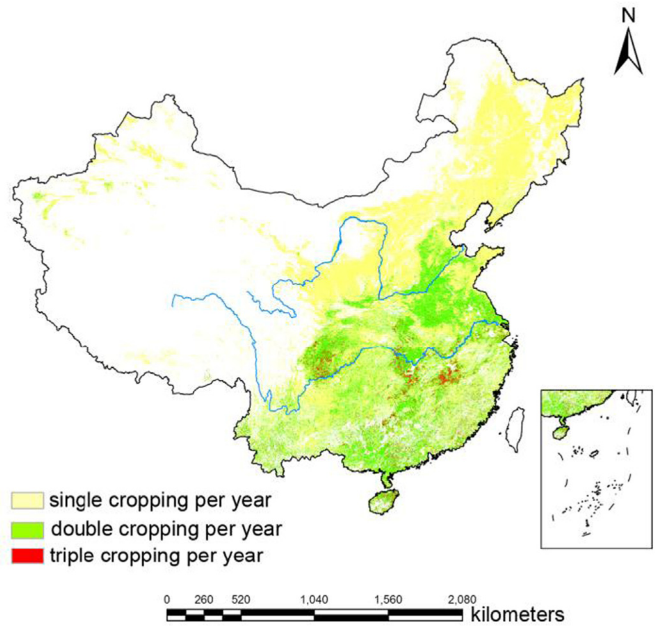

Fig. 1. The cropping systems in China (Modified from Liu et al., 2013b).

nitrogen and other trace elements, which is considered to be desirable fertilizer for crop growth. Numerous individual studies have been conducted that the straw return is beneficial for the improvement of soil properties, and thus increases the productivity of agriculture by 1.7–145.8% (Zeng et al., 2002). However, in comparison with other countries, the majority farm land in China is the double-cropping system or even the triple-cropping system, as shown in Fig. 1, implying that crop straw need to be quickly handled after harvest. This is conflicted with slow biodegradation of the returned straw, leading some unfavorable effects during this implementation and impacting the traditional management mode. There exists poor understooding on negative effects of the straw return in China. This paper summarized the open published investigations on the integrated impact of the straw return to the soil, addressing the effects of the straw return on soil properties, nutrients, SOC (Soil organic carbon), emission of GHGs (Greenhouse gases), etc. in details.

2. Production and utilization of straw in China

Crop straw or crop residue is defined as the stalk or stem of crop that are left in the field after harvest. It is a most important component of biomass resources in China (Li et al., 2017). Some open published statistics numbers showed that about 72.2% of biomass energy resources is supplied by crop straw in China (Zeng et al., 2007; Zheng et al., 2010). Up to now, there was no direct Chinese official statistics on yields of crop straw, estimated by various scientific approaches, such as field survey, straw/grain ratios, remote-sensing, GIS approach (Geographic information system), etc. (Dai et al., 2016; Li et al., 2017; Qiu et al., 2014).

Table 1 shows that more than 550 million tons straw per year is produced in China during the past decade, and the total output of the crop straw varies considerably by the different evaluation methods and definition of straw. Liu et al. (2008) was the first to systematically report the production data of crop straw, indicating 630 billion tons of straw has been produced in 2005 and nearly 80% from corn, wheat and rice. The latest study of Li et al. (2017) showed that the production of 5 main food crop straws in China were 598 million tons using the region specific crop-to-residue index (CRI) method.

Large amount of straw are available for agriculture and industry. Since 1950s, the Chinese government has implemented great effort on the comprehensive utilization of crops, such as the straw burning, anaerobic digestion, gasification, briquette, liquefaction and carbonization. However, most utilization approaches have not achieved desired results, and there are still some straw burned outdoors, which has caused a series of problem to the environment. Many researches showed that the major measure to promote straw as industrial supplies was less profitable and impeded by the high cost on straw collection and transport.

3. Model of straw return in China

Straw return has been regarded as an environment-friendly approach for the straw utilization due to its positive effects on the soil fertility and the crop yield. Thus, it has been extensively applied by the government and scientists (Zeng et al., 2002; Zhang et al., 2017c). It has been highly recommended in China and other developed countries due to the prohibition on the burning straw (Jiang et al., 2012). About 61.5% of rice straw was plowed into the field in Japan (Matsumura et al., 2005). The U.S. Department of Agriculture recommended that more than 30% soil surface should be covered with straw, and actually

Table 1
The estimated yield of crop straw in China.

Number of crop	Production (million tons per year)	Time/year	Methods	Ref.
5 Main food crops	598.00	2014	straw/grain ratios	(Li et al., 2017)
All the crops	630.00	1995–2005	straw/grain ratios	(Liu et al., 2008)
10 crops	600.00	2000–2003	straw/grain ratios	(Cao et al., 2008)
All the crops	622.00	2002	straw/grain ratios	(Zeng et al., 2007)
All the crops	592.57	2003	straw/grain ratios	(Cao et al., 2006a)
All the crops	762.00	2006	straw/grain ratios	(Gao et al., 2009)
All the crops	554.10	2000	straw/grain ratios	(Gao et al., 2001)
All the crops	652.02	2004	straw/grain ratios	(Wang et al., 2008)
All the crops	651.92	2006	straw/grain ratios	(Jianchun et al., 2012)
All the crops	679.22	2001	straw/grain ratios	(Hai-bo et al., 2008)
All the crops	741.53	2011	straw/grain ratios	(Guo and Huang, 2016)
7 main crops	559.28	1998	straw/grain ratios	(Yin et al., 2017)
7 main crops	703.30	2014	straw/grain ratios	(Yin et al., 2017)
9 main crops	778.00	2011	straw/grain ratios	(Zhang et al., 2017b)
All the crops and some common secondary agricultural processing residues	850.83	2010	straw/grain ratios	(Ji, 2015)
All the crops	728.00	2004	GIS approach	(Long et al., 2013)
9 main crops	806.90	2009	straw/grain ratios	(Jiang et al., 2012)
10 main crops	939.29	1998	straw/grain ratios	(Liao et al., 2004)
All the crops	729.00	2010	remote-sensing	(Qiu et al., 2014)
All the crops	841.83	2008	straw/grain ratios	(Bi et al., 2008)