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Balancing straw returning and chemical fertilizers in China: Role of straw nutrient resources

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A B S T R A C T

Currently, large-scale farmland degradation resulted from the overuse of chemical fertilizers has become a major issue in China. Meanwhile, a large sum of straw nutrient resources have been lost from the farmland due to the straw removal from fields, which in return aggravated the degradation in farmland quality and long-term productive capacity of soil resources. Whether current straw management practices represent rational utilization and how straw can be used more efficiently have become the most important but least studied problems for China's green agricultural development. Based on the China's Official Statistics, we first collected a large number of data on the annual crop yields, crop sown areas and chemical fertilizer consumption of different crop types in 31 China's mainland provinces from 1998 to 2014. Straw yields and straw nutrient resources were calculated to assess the potential contribution of straw resources to chemical fertilizers. Our estimation demonstrates that straw returning to farmlands could counterbalance all of the K_2O, the majority of the P_2O_5, and a portion of the N in chemical fertilizers. Promoting the return of straw to field has a great potential to reduce the use of chemical fertilizer, air pollutant emission and environmental burden. Thus, we propose that the Chinese government should adjust the policies to take promoting straws returned to field as priority, instead of greatly encouraging straw removal from field. Innovative straw decomposing technologies and returning practices are also needed to assure China's green agricultural development and reduce environmental pollution in the future.

1. Introduction

China is one of the largest agricultural countries in the world. In 2015, the total crop yield and sown area in China amounted to 621.44 million tons (hereafter Mt) and 11,3340.5 thousand hectares, respectively [1]. Accompanied by the constant increase in crop production, the crop straw yield has grown dramatically [2]. China is now one of the most abundant countries in terms of straw resources in the world (fig. 1) [3], and the average annual increase in the rate of crop straw production was about 4% in China over the last several decades [4]. As a source of bioenergy, livestock forage and other sources of loss (including open field burning, being throwing aside, etc.), crop straws in China have long been removed from the field, which has led to a large sum of straw nutrient losses from the fields. Meanwhile, straw resource utilization policy will further be encouraged in *China's 13th Five-Year Plan Period (2016–2020)*, and the comprehensive utilization efficiency of straw will be up to 85% by applying new advanced technologies [5]. This will further aggravate straw nutrient losses from the fields.

At the same time, China is now the largest producer and consumer of synthetic fertilizers, accounting for ca. 35% of the global total consumption [6]. A tremendous amount of inorganic fertilizers (nitrogen, phosphorous and potassium) have been applied to the farmland to boost food production, despite the fact that China's agronomic nutrient use efficiency (i.e., the ration of crop yield to the amount of fertilizer applied) has gradually increased over the past 10 years [7]. As a consequence, both straw removal and the overuse of chemical fertilizers have led to soil quality degradation (i.e., the loss of soil organic matter, low soil fertility, inefficient nutrient-use, and subsequently low-yielding land) and heavy environmental impacts (i.e., agricultural non-point pollution) [8]. Policy makers are challenged by the dilemma of resource competition/allocating among various straw users to balance the economic benefits and environmental effects [9]. As one of the renewable resources with high efficiency and rationality, straw resource utilization not only meets the demands for resources as the economy grows (i.e., saving the scarce natural resources and substitution for

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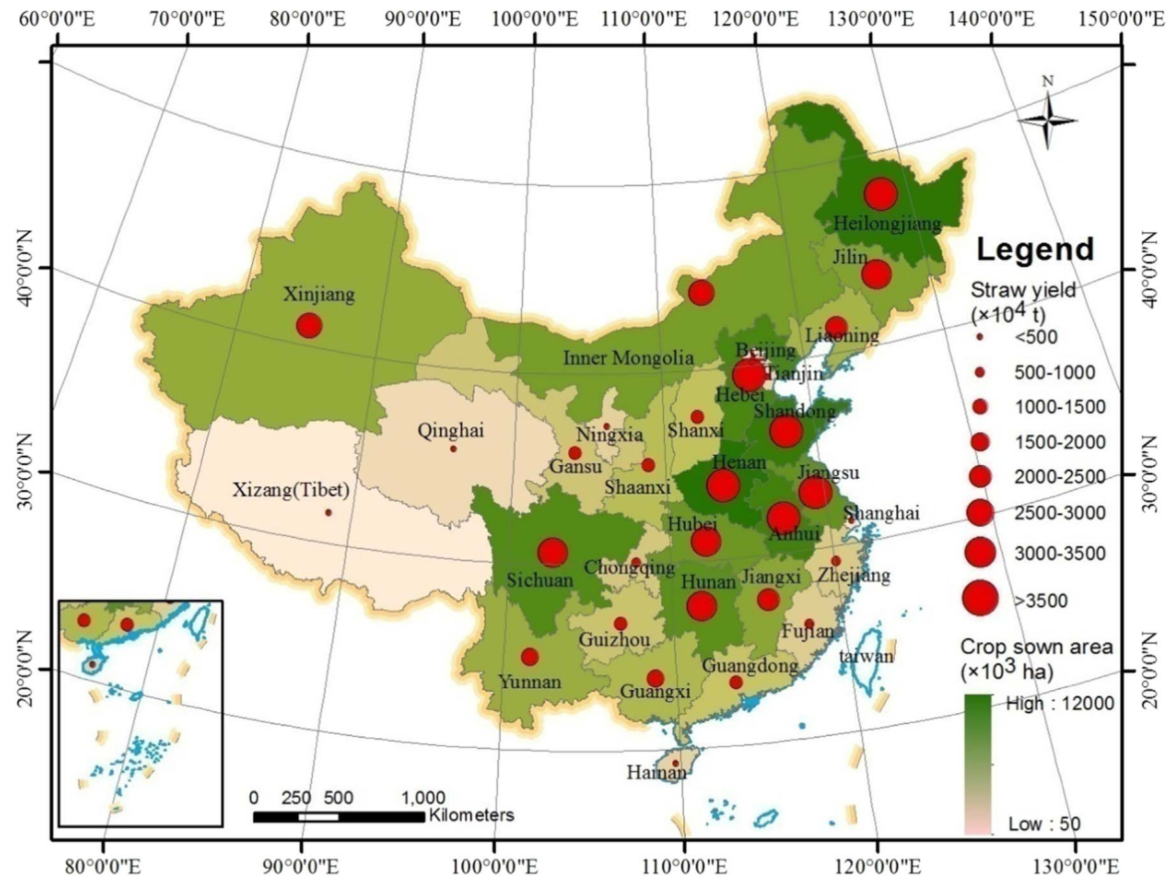

Fig. 1. Distribution of the 5-year average crop sown area and 5-year average straw yield during 2010–2014 at province level in China. The collected data include 31 provinces (Hongkong, Macao and Taiwan are not included), which were obtained from the China Rural Statistical Yearbook [14].

depleted resources), but also provide a basis for environmental protection and sustainable development of society in China [3]. Consequently, people are paying more attention to the social and economic advantages of straw utilization, and less attention to the ecological consequences of removing straw from the fields on farmland quality. In fact, the excessive removal of straw from the field has greatly resulted in field nutrient depletion and the decrease in soil organic matter content [10], and thus degraded the long-term productive capacity of soil resources [11]. From an ecosystem mass balance perspective, however, straw removal greatly disrupts the nutrient cycling of agricultural systems, and degrades the long-term productive capacity of soil since a large amount of nutrient resources are taken away from the fields [12,13]. Whether current straw management practices represent rational utilization and how straw can be used more efficiently have become the most important but least studied problems for China's green agricultural development. In this paper, we assessed the potential contribution of straw resources to chemical fertilizer consumption based on the official Chinese data of crop yield, straw yield and chemical fertilizer consumption from 1998 to 2014. The bioenergy content and pollutant emission from straw combustion were also calculated to evaluate the environmental impact of straw use for biofuel.

2. Methodology

2.1. The main crop production in China

China is one of the biggest crop production countries, producing large amounts of crop straw annually. The crops grown in China include rice, wheat, maize, soybean, peanut, canola, cotton, potato, sesame, jute, sugarcane, sugarbeet, tobacco, etc. The first 7 of these crop types comprise 96.4% of the total grain, oil-bearing, cotton, fibre, sugar, and tobacco straw yields of China in 2014. Detailed information on the chemical fertilizer consumption or straw nutrient contents of other crop types is not available in the Chinese official statistics. Hence, the main Chinese field crops selected in this study were rice (*Oryza sativa* L.), wheat (*Triticum* spp.), maize (*Zea mays* L.), soybean (*Glycine max* (L.) Merr.), peanut (*Arachis hypogaea* L.), canola (*Brassica* spp.), and cotton (*Gossypium* spp.). These 7 crops were chosen to evaluate the status of main straw resource in China.

Since Hong Kong and Macao possess limited areas of farmland and their negligible crop yields are not recorded in China's official statistics, the regions we covered in the current work contained China's 31 mainland provinces. The crop yields (10^8 t) and crop sown areas (10^3 ha) of the 31 provinces were obtained from the China Rural Statistical Yearbook [14]. The sown areas of the 7 main crops in China during 1998–2014 varied from 99.27 to 114.7 million hectares (Table S1). Among the provinces, Henan Province exhibits the largest crop yields of China, followed by Heilongjiang, Shandong and Anhui (Table S2).

The detailed data on crop yield, crop sown area, straw yield, and chemical fertilizer consumption for each crop type and province can be collected after 1998. However, the chemical fertilizer consumption (N, P, K) for each crop type cannot be obtained from the Chinese official statistics before 1998. Thus, the period investigated in this study ranges from 1998 to 2014.

2.2. Crop yield (CY)

The total *CY* in China was calculated based on the sum of the *CY* values of 7 crop types in the 31 provinces using the following equation:

$$CY_{total} = \sum CY_{ij}$$