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The Assessment and Utilization of Straw Resources in China

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Abstract

The study was undertaken to evaluate the collectable and usable volume of existing straw resources, its suitability for different ways of utilization and fully reorganization of its development potential in China. Based on the results on the stubble heights of major crops in the Huang-Huai-Hai area (the area along the Yellow River, Huai River, and Hai River), the evaluation of the collectable and usable coefficients, and the collectable and usable volumes of various straw resources in China were worked out during 2005. The respective collectable and usable volumes of straw resources were worked out on the basis of suitability as fuel, feed, fertilizer, and base material for edible mushrooms. The total collectable and utilizable quantity of straw in China was 685 950 000 t, and the mean collection coefficient was 0.81 during 2005. The quantity of straw residue and wasted straw accounted for 19%. The collectable and utilizable quantities of grain, cash crop, and other crop straw were 492 310 000, 162 610 000, and 31 030 000 t which accounted for 71.77, 23.71, and 4.52%, respectively of the total collectable and utilizable quantity of straw. The quantity of straw which could be used as fuel was 635 000 000 t, which accounted for 92.63% of total quantity of the straw in the country during 2005. Among the total quantity of collectable and utilizable straw in China during 2005, the quantities of straw suitable and unsuitable for being processed as feedstuff were 587 640 000 and 98 310 000 t, which accounted for 85.67 and 14.33%, respectively. The quantity of straw residue returned to the field and collectable and utilizable straw for direct field restoration was 616 000 000 t, which accounted for about three-fourths of the total straw yield, while the quantity of straw for cultivation of edible mushrooms and industrial processing was about 587 000 000 t, which accounted for more than 85% of the total collectable and utilizable straw. The evaluation results indicate that the collectable and utilizable quantity of straw in China is abundant and suitable for many purposes.

Key words: China, straw resources, collectable and utilizable quantity, suitability, assessment

INTRODUCTION

China is a country with the highest straw yield in the world, and its proper utilization is an important task (Bi *et al*. 2008). The rational utilization of straw resources is involved not only in sustainable development of problems, including soil fertility, soil conservation, environmental safety, efficient utilization of renewable resources of the whole agricultural ecosystem, but also keep housing system warm and clean environment in rural areas. Thus, it is becoming an inevitable requirement for sustainable development of agriculture and social economy in rural areas of China. Till date, there are few systematic domestic studies were carried out on the efficient utilization of available straw resources. Cui *et al*. (2008) adopted the approach of document analysis supplemented by investigations in typical areas, and evaluated the theoretical resource volumes, collection coefficients, collectable and usable volumes, and

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the usable volumes as energy resources of straw resources in five major crops, *viz*., rice, wheat, corn, cotton, and rape seed in China during 2006. It made a comprehensive assessment of the proportions of the five major crops straw as fuel, fertilizer, feed, industrial raw material, and base material for edible mushrooms or as waste to be burned or discarded. Han *et al*. (2002) and Zhong *et al*. (2003) evaluated the distribution in utilization of crop straw as fuel, feed, fertilizer, and industrial raw material in China. Li (1998) evaluated the availability of straw biomass in China and divided it on the basis of ways of utilization into three groups, *viz*., industrial raw material, feed for livestock, and direct fuel or biomass energy resources. The crop straw output of China in 1995 was 6.04×10^8 t, among which the losses incurred during collection such as the straw directly returned to the field or lost during collection accounted for approximately 15.0% of the total volume. Therefore, the volume of actual straw obtained was 5.134×10^8 t. So, the assessment of collectable and usable straw volume should be based on the amount of straw resources. The domestic studies on the straw resources mainly focused on the amount and distribution of crop straw resources (Basic Industry Department of National Development and Reform Commission 2000 ; Cao *et al*. 2003; Zhong *et al*. 2003; Ministry of Agriculture of the People's Republic of China 2007; Wang *et al*. 2008a; Wang *et al*. 2008b), the comprehensive utilization of straw resources (Gao *et al*. 2001; Han *et al*. 2002; Chen *et al*. 2007; Yan *et al*. 2007; Cui *et al*. 2008), the collection and storage of straw (Yang *et al*. 2006; Xing *et al*. 2008; Zhang *et al*. 2009) as well as the burning of straw (Liu and Ji 2003; Wang *et al*. 2003; Xie and Fu 2006; Ye and Yi 2006) The evaluation of the amount of straw resources yielded different results, ranging from 6×10^8, 7×10^8 to 8×10^8 t. The consideration of the value of straw-to-grain ratio in current evaluation of straw resources is inappropriate in China. Bi *et al*. (2008) made a thorough evaluation of straw resources in China with corrected straw-to-grain ratio and showed that the gross straw output during 2005 in China was $84\,183.12\times10^4$ t. At present, there are many foreign studies for the evaluation of straw amount and utilization of straw resources. Edwards *et al*. (2005) used GIS data to evaluate the quantities of wheat and barley straw, which could be translated into electrical energy in 27 EU countries (EU had 25 participating countries and two candidate countries, that is Bulgaria and Romania, in 2005) during 2005. Summers *et al*. (2003) reported that there were internal relationships between straw yield and factors, including crop stubble height, season, region, and equipment losses, and furthermore, the ratio of straw to grain in California was 0.81-2.29 and the mean value was 1.27. There are few domestic research papers on the collectable and usable volume, suitability and other aspects of straw resources, and the existing ones do not cover all the aspects. The evaluation of suitability of the straw resources as a whole remain at the stage of perceptual knowledge, and most assessments on obtainable volume of special-purpose straw are based on perceptual knowledge. The uni-standard classification and quantitative comprehensive studies of straw resources based on evaluation of the suitability of straw are seldom seen both at home and abroad. The aim of the present study was to work out the collectable and usable volumes of various straw resources according to the definite coefficient of collectable and usable straw resources in China, and to make qualitative or quantitative evaluations of the suitability of the straw resources as fuel, feed, fertilizer, industrial raw material, and base material for edible mushrooms and their respective collectable and usable volumes.

MATERIALS AND METHODS

Determination of the collectable and usable coefficient

The collectable and usable volume of straw resources refers to the maximum amount of straw resources that could be collected from the field and utilized by people under actual cultivation management, especially for crop management practices. The evaluation of collectable and usable volume of straw resources usually do not consider the economic and technical feasibility of comprehensive utilization of straw and demand influences on the collectable and usable volume of straws, or the influences of future technical innovations on crop. All the crop straw collectable but not collected or usable but not utilized, such as straw burned or discarded in the field as well as straw covering the field for protective cultivation should be included in the collectable and usable volume of straws.

The collectable and usable volume of straw resources is usually calculated according to the gross straw output and the collectable and usable coefficient. It is expressed by the following formula:

$W_{GS}=W_S \times I_G$

Where, W_{GS} is the collectable and usable volume of straw resources; W_S is the gross straw output; I_G is the collectable and usable coefficient of straw resources.

The collectable and usable coefficient of straw resources refers to the ratio of the weight of collectable and usable straws to the gross biomass of crop stalks, i.e., the gross straw output. Crop stalk refers to the part of crops left above the ground surface after harvesting beside grains or main produce (also called economic products). The collectable and usable coefficient of straw resources is usually calculated according to the ratio of stubble height to crop height and the fall-off rate of leaves and branches. Mainly adopting the approach of field survey and document analysis, based on the results of investigations on the stubble heights of major crops in the Huang-Huai-Hai area, and referring to such data from relevant research institutes as the residual amount of straws in the field, the preliminary evaluation of the collectable and usable coefficients of various straw resources in China was carried out.

During the process of evaluation, it was noticed that besides the micro-physiognomy of farmland, field moisture capacity (mainly for rice), cultivation system, harvesting, and the need of returning straw to field that have certain effects on the collectable and usable coefficient of straw resources. But, the most influential factor is the method of crop harvesting. The investigations conducted at Jiangsu, Henan, and Shandong provinces in China showed that the stubble height of machine-harvested crops is apparently higher than that of by manually. In Henan and Shandong provinces, there are apparent differences in the stubble height between machine-harvested and manually harvested wheat. For example, the average crop height in wheat was 85 cm but, the stubble height of manually harvested wheat was only 5-8 cm, the average being 6 cm, whereas the stubble height of machine-harvested wheat was 20-40 cm, the average being 30 cm. Therefore, the straw resources must be divided into two groups as machine-harvested and manually harvested, according to the method of harvesting while determining the collectable and usable coefficient of straw resources.

Except mountainous, uplands and underdeveloped areas, most parts of China now use machines to harvest wheat. By 2005, the machine-harvested area for wheat throughout the country was accounted for 80% of the total area under wheat cultivation. The harvesting with leaving high-stubbles is the most popular and common mechanical method of harvesting wheat in China. In most areas, stubble height is 20-40 cm, whereas in individual areas, stubble height even reaches to 40-50 cm. To prevent wheat straw from being burnt, many provinces provide that the stubble heights of machine-harvested wheat be less than 15 or 20 cm. But, without the support of state policies, it is difficult to maintain the stubble height of machine-harvested wheat throughout the country to meet that requirement. Considering that high-stubble harvesting of wheat remains an important way of directly returning straw to the field in China, when measuring and calculating the collectable and usable coefficient of the straws of machine-harvested wheat, the value of the stubble height of machine-harvested wheat is 25 cm. Moreover, when measuring and calculating the collectable and usable coefficient of the straw of machine-harvested rice and soybeans, the values are taken according to the investigation results on the stubble height of machine-harvested rice and soybeans.

By 2005, the proportions of machine-harvested areas of wheat, rice and soybean in China were 80, 33.5 and 28.5%, respectively, whereas the proportions of machine-harvested areas of other major crops were very limited. The proportions of machine-harvested areas of corn and rape seed were only 3.04 and 6.87%, respectively. Therefore, while determining the collectable and usable coefficients of various straw resources, the wheat, rice and soybean were treated differently by taking value according to a different method of harvesting, though the values of the collectable and usable coefficients of the straw for other crops were taken according to the method of manual harvesting.

The evaluation of suitability of straw

The evaluation of straw suitability is very critical fundamental issue in the comprehensive utilization studies and management of straw. The straw suitability includes suitability of raw and processed straw (after being processed, the utilization value and suitability scope of straws could be notably increased). As the straw of the most crops have multiple utilization, the evaluation of suitability of straw resources is mainly a qualitative and quantitative evaluation of raw and processed straw suitable to be used as fuel, feed, fertilizer, industrial raw material, and base material for edible mushrooms.

There are tens of kinds of straw and each kind of straw has multiple suitability, which differs greatly individually. So, it is a very complicated job to make an all-round and systematic suitability evaluation. The straw can classified into three classes *viz*., most suitable, suitable and not so suitable on the basis of the different characteristics of straw such as flammability and palatability. The quantitative assessment was made as collectable and usable volumes of different classes of straw.

RESULTS

The evaluation of the collectable and usable volume of straw resources in China

The collectable and usable coefficients of straw resources were determined to evaluate the collectable and usable volumes of straw resources. The evaluation according to field survey and relevant data information showed that the average collectable coefficient of crop straw during 2005 in China was 0.81, among which the collectable and usable coefficient of grain stalk, oil plant stalks, and cotton stalks were 0.83, 0.85, and 0.90, respectively. Furthermore, the collectable and usable coefficients of sugar plant by-product, tobacco stalk, remains of medicinal herb, vine and remains of vegetables, and other crop straw were 0.88, 0.90, 0.50, 0.80, and 0.60, respectively. The gross output of straw resources based on the amount of various straw resources during 2005 in China is shown in Table 1. The gross output of straw resources during 2005 in China was 84 183.12×10^4 t, among which grain stalk output was 59 110×10^4 t; cash crop stalk output was 21 195×10^4 t; and the stalk output of other crops was 3 879×10^4 t. The total stalk output of the five major crops, *viz*., grain crops, cotton, oil seed crops, sugar crops, and vegetable plants was 79 180×10^4 t, among which cotton stalk output was 5 257×10^4 t, oil seed crop stalk output was 4 423×10^4 t, the output of sugar crop by-product was 2 741×10^4 t, and the output of vegetable vines and remains was 7 648×10^4 t. The total straw output of the three major crops (rice, cotton and wheat) was 52 056×10^4 t, among which the straw outputs of rice, cotton, and wheat were 21 129×10^4, 20 208×10^4, and 10 719×10^4 t, respectively.

Based on the collectable and usable coefficients determined in this study, the collectable and usable volumes of various straw resources for particular year was worked out according to formula described earlier. The results showed that the gross collectable and usable volume of straw resources during 2005 in China was 68 595×10^4 t, with 19% of it left in the fields or wasted during the collection process. The collectable and usable volume of grain stalks was 49 231×10^4 t, accounting for 71.77%, cash crop straw was 16 261×

Table 1 Total yield, collectable and utilizable coefficients, and quantities of different straws during 2005 in China (×10^4 t)

Straw type	Total straw yield	Collectable coefficient	Collectable and utilizable quantity
1 Straws of food crops	59 110	0.83	49 231
1.1 Grain straw	53 714	0.83	44 627
1.2 Straws of bean crops	3 662	0.88	3 217
1.3 Potato vine	1 734	0.80	1 387
2 Straws of oil crops	4 423	0.85	3 753
3 Cotton stalk	5 257	0.90	4 731
4 Hemp stalk	125	0.87	109
5 By-products of sugar crops	2 741	0.88	2 407
6 Tobacco stalk	429	0.90	386
7 Residue of medical material crops	571	0.50	285
8 Vegetable vine and residue	7 648	0.60	4 589
9 Straws of other crops	3 879	0.80	3 103
Total	84 183	0.81	68 595

10^4 t, accounting for 23.71%, and other crop straw was 3 103×10^4 t, accounting for 4.52%.

The suitability of straw resources in China

The majority of crop straw is suitable for fuel, feedstuff, fertilizer, industrial raw material, and base material of edible mushrooms, and the quantitative or qualitative evaluation for respective collectable and utilizable quantity and suitability of straw resources was carried out.

The evaluation of combustibility of straw resources in China

The determination of combustibility is a fundamental characteristic of biomass. The vast majority of straw are burnable, with the exception of some straw, which are hard to be air or sun dried. In this point of view, the quantity of burnable straw was 63 500× 10^4 t during 2005 in China and accounted for 92.57% of total collectable and utilizable quantity of straw of the country. The mean thermal value of straw (moisture content is about 15%) is 14 226 KJ kg^{-1}, which is lower than that of core wood by 15% and is equivalent to 48.57% of that of standard coal. Simply, the 2 kg of straw is equivalent to about 1 kg standard coal. Therefore, the burnable straw which could be converted into standard coal was estimated to be 30 800 × 10^4 t during 2005 in China. The thermal value of different straw has as apparent difference of less than 17%. The straw that are not suitable for burning such as sweet potato vine straw, have high thermal value, as compared with straw such as cotton stalk that are suitable for burning, which is even higher than rape seed stalk and corn stalk that are suitable for burning. Therefore, straw could not be classified on the basis of combustibility or thermal value of straw.

The burning resistance is an important characteristic of straw. The burning resistance of straw depends mainly on degree of lignification. The higher is the degree of lignification, the stronger the burning resistance and vice versa. For instance, the xylogen content of cotton stalk>corn stalk>wheat straw. Therefore, the burning resistance of cotton stalk is more than for corn and wheat stalk. In accordance with burning resistance of straw and cooking practices of rural people, the straw is divided into three classes, *viz*., most suitable, suitable, and marginally suitable. The statistics showed that the straw that are most suitable, suitable, marginally suitable, and not suitable for burning were 15 962×10^4, 21 687×10^4, 25 889×10^4, and 5 058×10^4 t which were accounted for 23.27, 31.62, 37.74, and 7.37%, respectively of the total collectable and utilizable quantity of straw in China during 2005.

The evaluation of feedibility for straw resources in China

The evaluation base on direct feeding of straw The straw was divided according to the palatability and digestible nutrients for direct feeding into suitable, marginally suitable and unsuitable (Table 2). The quantities of straw that were suitable, marginally suitable, and unsuitable for direct feeding were 33 870×10^4, 17 719 × 10^4, and 17 006×10^4 t which were accounted for 49.38, 25.83 and 24.79%, respectively of total quantity of collectable and utilizable straws in China during 2005. The overall straw resources for direct feeding were 51 589 × 10^4 t, which were accounted for 75.21% of total quantity of collectable and utilizable straw all over the country.

The evaluation based on processable straw According to processing of straw for feeding, the straw was classified as straw suitable for processable feeding and straw not suitable for processable feeding (Table 2). The results showed that, among the total quantity of collectable and utilizable straws during 2005 in China, straw that were suitable for processable feeding and unsuitable for processable feeding were 58 764 ×10^4 and 9 831×10^4 t which were accounted for 85.67 and 14.33%, respectively of total collectable and utilizable straw. The both kinds of straw suitable for direct feeding and suitable for feeding after processing have significant impact on the development of regional livestock raising industry and fodder grass resources. The improvement in processing technique of straw for feeding would further lead to rise in the straw suitable for feeding which is a promising prospect for livestock industry.

The suitability of direct field restoration of straw resources in China

The straw could be used for field restoration through

Table 2 The evaluation of feedibility and collectable and utilizable volumes of different straws and stalks (×10^4 t)

Straw type	Direct feeding			Processing and feeding		Collectable and utilizable
	Suitable	Less suitable	Not suitable-suitable	Suitable	Not suitable-suitable	
Straw	√			√		13 490
Rice hull			√		√	4 632
Wheat straw	√			√		6 581
Corn stalk		√		√		15 051
Corn cob			√	√		33 780
Straws of other grains		√		√		1 492
Soybean straw	√			√		2 276
Straws of other beans	√			√		941
Sweet potato vine	√			√		388
Stem and leaf of other potatoes		√		√		999
Peanuts	√			√		975
Peanut shell	√			√		314
Rape straw			√	√		1 664
Rape leaf	√			√		
Sesame stem		√		√		124
Sesame leaf	√			√		
Benne stem			√	√		78
Sunflower stalk			√	√		538
Stalks of other oil crops			√	√		60
Cotton stalk			√		√	4 731
Peeled hemp stalk			√		√	109
Branch and leaf of bast fibers		√		√		
Sugarcane bagasse			√	√		1 871
Leaf tip of sugarcane	√			√		416
Beet pulp		√		√		57
Stem and leaf of beet	√			√		63
Tobacco stem			√		√	386
Residue of medical material crops	√			√		285
Vegetable vine and residue	√			√		4 589
Straws of other crops	√			√		3 103

direct field restoration which shattered directly and restored in the soil or in an original way without cultivation or through animal excreta and its byproducts. The field restoration by residual straw is one of important ways of direct field restoration by straw. The field restoration quantity of residual straw was 15 588×10^4 t, which accounted for 18.52% of total yield of straw resources in China during 2005.

Though all straw could be restored to the field, straw suitable for direct field restoration should be restored in the field on the spot during the crop harvest. The research indicates that crop by-products including corn cob, rice hull, peanut shell, sugarcane trash, sunflower disc, and beet pulp should be eliminated from straw suitable for direct field restoration. In addition, some crop straw, including potato vine, peanut vine, peanut shell, beet pulp, beet leave, vegetable vine, bean stalk, sesame straw, corn cob, and sunflower disc are high-quality fodder and should be eliminated from straw suitable for direct field restoration. Apart from the abovementioned two kinds of straws, the quantity of straw suitable for direct field restoration was 46 000×10^4 t, accounted for about two-thirds of the collectable and utilizable straw resources in China during 2005. Further, the residual straw returned to the field and collectable and utilizable straws suitable for direct field restoration was 61 600×10^4 t, accounted for three-fourths of the total straw yield in China during 2005.

The suitability of straw resources for industrial processing

The use of straw for industrial processing has great importance in making pulp for paper, preparation of packaging material, artificial boards, environmental friendly commodities, etc. The straw suitable for processing mainly include grain straw, bean straw, oil seed crop straw, cotton stalk, hemp stalk, tobacco stalk, and sugarcane trash. Their collectable and utilizable quantity was about 58 700× 10^4 t, which accounted for above 85% of total quantity of collectable and utilizable straw in China during 2005.

The suitability of straw resources for cultivation of edible mushrooms

The straw contains various nutrient sources for the cultivation of edible mushrooms including carbon sources (monosaccharide, disaccharide, hemicellulose, cellulose, and lignin), nitrogen sources (protein, amino acid, urea and ammonium sulfate), mineral substances (kalium, calcium, phosphorus, magnesium, iron, boron), and vitamin (B1), etc. Therefore, straw could be used as raw material for cultivation of edible mushrooms with combination of small quantity of fertilizers in accordance with the production formula. The straw suitable for cultivation of edible mushrooms is the same with those, suitable for industrial processing, and the total resources were about $58\,700\times10^4$ t, accounted for more than 85% of total quantity of collectable and utilizable straw in China during 2005. At present, the straw which is mostly used for the cultivation of edible mushroom includes haulms, rice hull, corn cob, cotton shell, peanut shell, rape seed shell, and wheat stalk.

DISCUSSION

The evaluation of the collectable and usable volume of straw

The evaluation of the collectable, usable coefficient, and volume of straw is only limited to major crops such as rice, wheat, corn, cotton, and rape seed, etc. Based on the results of the stubble heights of major crops in the Huang-Huai-Hai area, the preliminary evaluation of the collectable and usable coefficient and the collectable and usable volumes of the various straw resources in China were worked out.

The comprehensive evaluation of suitability of straw

The suitability of straw is divided into two groups as monographic analysis and comprehensive evaluation. Monographic analysis is realized by analyzing the utilization effects of one or several kinds of straw for a given special purpose (for instance, the suitability analysis of the use of straw as a feed for livestock). There are comparatively more studies in this aspect, but it lacks systematic summarization. The comprehensive evaluation suitability of straw mainly comprises of suitability differences and classified evaluations of different utilization of the same kind of straw. At present, the evaluations of suitability of the straw resources as a whole remain at the stage of perceptual knowledge. The uni-standard classification and quantitative comprehensive studies of straw resources base on evaluation of suitability of straw are seldom seen both at home and abroad. Moreover, most of the existing studies on straw suitability start from the different uses of straw resources (usually as fuel, fertilizer, feed, and industrial raw material), and roughly evaluate straw suitable for different uses, and make classified evaluations of suitability of straw resources for a given special purpose. In present study, the straw was divided on the basis of different uses into three classes as the most suitable, suitable, and not so suitable, and made separate quantitative evaluation over the collectable and usable volumes of straw of different classes, and therefore could be viewed as being innovative.

The present study evaluated the suitability of straw for the traditional use for directly as fuel, and does not give emphasis on its utilization as new energy source. With the continuous progress of science and technology, the awareness about the use of straw as new energy source is gradually increasing. The development and utilization of straw as new energy source which can be used for straw gasification, straw densification, straw carbonization, straw liquefaction, and straw electricity generation. The straw gasification has a wide and a narrow sense. The former includes biomass gasification and thermal gasification, whereas the latter exclusively refers to the thermal gasification of straw. The straw biomass gasification is also called straw biogas. During the development and utilization of straw as new energy source, the different ways of development and utilization with different requirements for straw need to be further supplemented and improved in future studies.

CONCLUSION

It was found that on the basis of collectable and utilizable coefficients of straw during 2005, it can be inferred that collectable and utilizable quantity of straw resources in China are abundant. The collectable and utilizable quantity of straws was 68 595×10^4 t and the mean collectable coefficient of straws was 0.81 during 2005 in China. The straw resources could be widely used as fuel, feedstuff, fertilizers, industrial raw materials, and base materials of edible mushrooms. The quantitative and qualitative evaluation of straw on the basis of suitability showed that the quantities of straw suitable for burning, direct feeding, and suitable for feeding after processing were 63 500×10^4, 51 589×10^4, and 58 764×10^4 t which were accounted for 92.63, 75.21, and 85.67%, respectively of total collectable and utilizable quantity of straw in China during 2005. The residual straw returned to the field and a collectable and utilizable straw suitable for direct field restoration was about 61 600×10^4 t, accounted for three-fourths of total straw yield in China. The quantity of straw suitable for cultivating edible mushrooms and for industrial processing was about 58 700×10^4 t accounted for more than 85% of the total quantity of collectable and utilizable straw in China.

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