

**Review Article**

Review on the Crop Straw Utilization Technology of China

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Abstract: China is an large agricultural country, which grain output has been among the highest in the world. In recent years, agricultural waste caused by high grain yield has attracted more and more attention. As one of the main agricultural waste, the total straw amount of China has reached 870 million tons by year of 2019, and the straw utilization amount has reached 730 million tons, which indicates enormous strains on the environment. In China, straw burning is strictly forbidden by local governments, so it is mostly utilized by returning the field, making manure, fodder, fuel, base stock or raw material. The five utilization ways separately make up 61.3%, 5.3%, 14.9%, 10.3%, 0.8%, 1.0% of the total share. To promote better utilization of straw, this paper made a comprehensive review of the main utilization technologies in China by the method of literature research. According to the research, the utilization technologies of straw mainly include corn straw deep tillage technology, cotton straw deep-turning technology, wheat straw mulching-corn straw rotating tillage technology, less no-tillage straw mulching technology, rice-wheat (or rape) straw crushing returning rotary tillage technology, straw rapid maturing, straw-forage-fertilizer planting and raising combination technology, straw-biogas-fertilizer energy ecological technology, straw-bacteria-fertilizer substrate utilization technology, straw-carbon-fertilizer returning and soil improvement technology. All these utilization have promoted the rapid development of the comprehensive utilization of straw in China, and enlightened further development of straw utilization.

Keywords: Crop Straw Yield, Utilization Status, Utilization Technology, Direction of Development

1. Introduction

China is a large agricultural country with a wide variety, huge quantities and wide distribution of crop straw. With agricultural production and farmers' lifestyle transformation, rural labor transfer, energy consumption structure improvement and application of all kinds of alternative materials, straw utilization ways have change dramatically [1-2]. Regional, seasonal, structural surplus were continuously emerging, and open burning persisted despite repeated prohibition, which brought severe challenges to straw resource utilization. In this paper, the distribution of straw resources and the main technical modes of straw utilization in China are analyzed comprehensively, and the corresponding development countermeasures are put forward in order to provide theoretical support for the burning prohibition and comprehensive utilization of straw in China.

2. Characteristics and Utilization of Crop Straw Resources in China

According to the statistics, the total output of China's main crops was about 870 million tons. Corn, rice, wheat, cotton, rapeseed, peanut, soybean, potato, sweet potato and other crops respectively account for 46.2%, 21.4%, 15.5%, 3.5%, 2.1%, 2.1%, 2.4%, 1.5% and 3.4% of the total output. China's straw was mainly composed of corn, rice and wheat, with a total yield of 7.2×10^8 t, accounting for 83.2% of the total straw.

The effective use of straw in China was about 730 million tons, of which 450 million tons are directly returned to the fields, accounting for 61.3%. Off-field use of straw was about 280 million tons, accounting for 38.7% of the total. Off-field straw is mainly used for producing organic fertilizer, livestock

feed, rural fuel, edible fungus base and industrial raw materials, accounting for 5.3%, 14.9%, 10.3%, 0.8% and 1.0% respectively.

3. Main Technologies of Crop Utilization in China

In general, the comprehensive straw utilization technology in China can be divided into two categories: returning utilization technology and off-field recycling.

3.1. Straw Returning Technology

According to the planting system, China's straw mulching technology can be divided into six categories: corn straw deep tillage technology, cotton straw deep tillage technology, wheat straw mulching corn straw rotary tillage technology, rice and wheat straw crushing rotary tillage technology, less no-tillage straw mulching technology, straw rapid maturing technology.

- 1) The technical operation steps of corn straw deep tillage are as follows: corn straw crushing and sprinkling straw secondary crushing mechanical deep turning harrowing and rotary tilling (ridge raising) mechanical sowing. The main points of this technology system is the maize straw crushing length should be less than 10 cm, and when subsoiling with hydraulic reversible plough, the depth should be between 25~35 cm, and the bury rate of straw and stubble should be more than 90%. The corn straw should be distributed by paralleled clusters with the same line space (65 cm), the water layer and water seepage field should be arranged in interval, with both consideration of longitudinal loose and tightness [3].
- 2) The operation process of cotton straw deep-turning technology mode is as follows: cotton harvesting mechanical crushing stubble breaking deep-turning harrowing winter irrigation. The technical system requires that the straw be returned to the field immediately after the cotton is harvested. After crushing, the length of cotton stalk is less than 5 cm, and root missing rate is less than 0.5%. After crushing, the straw should be turned over and ploughed into the soil as soon as possible. The depth of ploughing should be more than 25 cm, and the straw should be watered in time to accelerate the decomposition rate [4].
- 3) The operation process of wheat straw mulching-corn straw rotating tillage technology are as follows: mechanical harvesting of wheat straw crushing and throwing into the field spraying straw decaying agent no-tillage seeding of corn mechanical harvesting of corn straw crushing and returning to the field mechanical rotary tillage sowing of wheat. This technology requires that wheat and corn stalks should be crushed to a length of 5-10 cm, stubble height less than 15 cm, and the high-horsepower rotary tiller should be used for rotary tillage at a depth of about 15 cm. At the same time, the land was ploughed or loosened once in a 3-year cycle, with a depth of about 30 cm [5].

- 4) The operation process of less no-tillage straw mulching technology are as follows: crop harvest straw mulching with high stubble subsoiling weeding in fallow period shallow turning and rake before sowing fertilizing and sowing. This technology requires that the height of stubble should be controlled at about 20 cm during harvest, and the length of crushed straw should be less than 10 cm and evenly covered on the ground, so as to reduce mechanical blockage during sowing. For areas where the soil is relatively viscous (bulk density is over $1.3 \text{ g}\cdot\text{cm}^{-3}$) or where straw mulching has just been returned to the field with less no-till tillage, and where plots with ploughing bottom exist in the soil, subsoiling should be carried out. Shallow loose operation before sowing should be carried out 10-15 days before sowing, and the depth of operation should be controlled within 10 cm. No-till planter is used for sowing, and the sowing depth is generally about 3 cm.
- 5) The operation process of rice-wheat (or rape) straw crushing returning rotary tillage technology are as follows: wheat (or rape) straw harvesters straw crushing and evenly sprinkling water soaking for 24h nitrogen phosphorus basal dressing rotary plowing rice planting mechanical harvesting of rice straw crushing and evenly sprinkling nitrogen phosphorus basal fertilizer buried inversion of stubble spin straw wheat seeding machine machinery repression machinery trenching [6-8]. The technical system requires the use of high performance full feeding combined with cutting, grinding and even-throwing device, to ensure that 90% of wheat straw is chopped to a length of less than 10 cm and evenly distributed in the field. Rotary tillage depth should be more than 12 cm, and the soil moisture content of straw decomposition should be controlled at 60% of the field water capacity. In general, 67.5 kg pure nitrogen and 22.5 kg pure phosphorus should be applied to the return of 7500 kg straw per ha to promote the decomposition of straw. After wheat sowing, it is appropriate to suppress the soil in time to ensure sowing quality, and the optimum moisture content of suppressed soil was 18~22% [9].
- 6) The operation process of straw rapid maturing and returning to the field are as follows: crop harvest straw crushing and evenly sprinkling application of decaying agent and base fertilizer mechanical rotation or tilling crop planting. The technical system requires that the straw should be chopped into length of 10 cm and the height of crop stubble should be controlled below 10 cm at harvest time. After the straw is crushed, spread the biochemical decaying agent (about 3% of the stalk capacity) evenly in the field. After 7~10 days, rotate or turn the straw by mechanic operation with a depth of 15~20cm. For the full amount return of straw to the field, an additional 45-75kg/ha nitrogen fertilizer should be added on the basis of the original fertilizer amount, the potassium fertilizer could be reduced by 10~20%, and the sowing amount should increase by about 10% compared with the conventional cultivation method.

3.2. Straw Off-field Recycling Technology

According to the circulation chain, the off-field straw recycling mode in China can be divided into four categories: equal length straw-forage-fertilizer planting and raising combination technology, straw-biogas-fertilizer energy ecological technology, straw-bacteria-fertilizer substrate utilization technology, straw-carbon-fertilizer return to the field and soil improvement technology.

- 1) Straw-forage-fertilizer planting and raising combination technology is to return the crop straw to the field, through silage (yellow) storage, microbial storage, briquetting, granulation, extrusion processing and after high-temperature aerobic compost of animal manure, fermentation and other processing methods aiming to produce organic fertilizer, so as to realize the organic combination of planting and breeding. This technology model can fully convert matter and energy between plants and animals and accelerate a good circulation [10].
- 2) Straw-biogas-fertilizer energy ecological technology is to make biogas out of crop straw for rural residents, or supply biogas for vehicles and industrial use after purification. Through deep processing, the biogas residue or slurry can be made into water-dissolved humic acid fertilizer, foliar fertilizer, or substrate, etc. The application of it can significantly improve the quality and yield of agricultural products as well as reduce the fertilizer quantity. Developing the technology model of "stubble-marsh-fertilizer" is conducive to providing high-quality clean energy and improving the living environment for China's new rural construction on one hand. It can effectively alleviate the pressure of energy shortage in rural areas [11] on the other hand.
- 3) Straw-bacteria-fertilizer substrate utilization technology is a recycling technology that uses crop straw as the main raw material, mixes with other raw materials or ferments at high temperature to prepare edible fungus cultivation matrix, and after the end of edible fungus cultivation and collection, fungus chaff is returned to farmland after composting at high temperature [12]. The utilization mode of "strain-bacteria-fertilizer" includes three important technical links: preparation of substrate, cultivation of edible fungi and compost of fungus chaff. Previous studies have shown that the potential demand for straw cultivated by edible fungi in China is 150 million tons [13]. At present, the utilization of base materials is only 18.37 million tons, indicating great development potential.
- 4) Straw-carbon-fertilizer returning and soil improvement technology refers to the conversion of crop straw into carbonaceous mixture rich in stable organic matter through low-temperature thermal cracking process, and then production of carbon-based fertilizer particles with carbonaceous mixture as medium and application in farmland, so as to improve the soil structure, physical

and chemical properties. The pyrolysis and gasification of straw can produce not only biochar, but also bio-oil, straw vinegar and combustible gas. Bio-oil can be upgraded to biodiesel or chemicals to help reduce dependence on fossil fuels, combustible gas can be used for heating or providing domestic energy for rural residents [14]. Straw vinegar is an ideal substitute for agricultural chemicals, and can be used for pest control of vegetables, fruits and other crops [15-16] aiming to produce pollution-free products.

4. The Technology Direction of Comprehensive Utilization of Straw in China

At present, the comprehensive utilization rate of straw in China has reached around 84%, but nearly 150 million tons of straw are still burned or discarded, with carbon emission of about 30 million tons [17]. In order to further promote the comprehensive utilization of straw in China, the following technical difficulties need to be overcome.

- 1) Research and development of straw returning technology system. The technical modes of straw returning for different agricultural areas and different crops should be determined according to local conditions, the appropriate amount of straw returning for different areas should be determined, the screening and research and development of straw rapidly decaying bacteria should be accelerated, the supporting integration of agricultural machinery and technology should be strengthened, the problem of straw returning to the field should be solved, and the negative impact of straw returning to the field should be reduced.
- 2) Research and development of large and medium-sized straw collection equipment. At present, China's small straw baling machinery is generally mature, but the large machinery heavily depends on import. It is necessary to intensify the research and development of agricultural machinery, promote the research and development process of large and medium-sized straw collection equipment, and further mature the integrated equipment for grain harvesting and straw baling of major crops such as wheat, corn and rice, so as to overcome the bottleneck of straw separation technology and equipment.
- 3) Research and develop straw pretreatment technology. In view of the straw's dense and solid structure, which is difficult to be directly degraded by microorganisms and enzymes, the properties of straw lignocellulose components and their action mechanism, regulatory factors and synergistic effects with cellulase hydrolysis should be studied, and efficient and low-cost pretreatment technology should be developed to improve straw conversion efficiency.
- 4) Research and development of straw thermochemical transformation and pollutant control technology and equipment. Aiming at the problems of high ash content

of straw, high content of alkali metal, low fuel quality, easy slagging and high NO_x emission, the technologies of low-temperature baking, washing and adding additives in the process of thermochemical transformation of straw should be studied to remove harmful impurities and improve the fuel quality of straw. At the same time, in view of the problems such as non-persistent production of straw charcoal and variety instability, research should be made to put forward the best carbonization process parameters. New efficient continuous carbonization equipment should be investigated to achieve continuous production and energy utilization.

- 5) Accelerate the construction of a standard system for straw comprehensive utilization. From the perspective of the whole industrial chain, technical standards covering products, equipment, quality testing and other aspects of the system should be established to standardize the production process of straw comprehensive utilization to continuously improve the industrialization and standardization level of straw comprehensive utilization in China.

5. Conclusion

Straw utilization is related to the green development of agriculture and the protection of cultivated and resources, and it is a new requirement and task to promote the straw utilization in a more reasonable, scientific and efficient way at the present stage. Aiming at the problems existing in the application technology, all counterpart need to work together to improve the practicability and efficiency of technologies.

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