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Analysis of Resource-based Disposal Modes and Benefit Evaluation of Crop Straw

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Abstract: Crop straw belongs to agricultural waste resources with both resource and ecological attributes. Its resource-based disposal can resolve agricultural pollution, optimize idle resources, and facilitate the green and low-carbon transformation of agriculture. At present, the annual output of crop straw remains at a high level, and its comprehensive utilization rate keeps rising. Nevertheless, problems such as single disposal patterns and low-level resource utilization still exist. This paper analyzes resource-based disposal modes of crop straw and the technical routes of each mode. It constructs an evaluation system for straw resource-based disposal from multiple dimensions. It aims to provide theoretical and practical references for scientifically promoting resource-based disposal of straw, realizing the recycling of agricultural wastes and boosting high-quality agricultural development.

Keywords: Crop straw; Resource-based disposal; Disposal modes; Benefit evaluation

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1. Introduction

Against the background of the "Dual-Carbon" strategy and policies for green agricultural development, the resource-based utilization of agricultural waste has become an important carrier for agricultural transformation. The state has issued numerous policy documents to clarify the comprehensive utilization of crop straw, prohibit open-air straw burning, and build a green agricultural development system. According to statistical data from the Ministry of Agriculture and Rural Affairs, the total annual output of various crop straws in China is approximately 900 million tons, and more than 700 million tons of straw resources are collectible and utilizable. Straw resources have a huge base and considerable potential for development and utilization. Through scientific means, resource-based disposal can realize the resource-oriented, commercialized, and industrialized transformation of straw, convert agricultural waste, and truly achieve "turning waste into treasure." Compared with traditional disposal forms, resource-based disposal modes possess values including resource conservation and ecological protection. They can connect the agricultural

circular-economy chain and promote the transformation of agricultural production. This paper systematically analyzes mainstream resource-based disposal modes of straw, explores benefit evaluation from multiple dimensions, analyzes existing problems in straw resource-based utilization, and puts forward specific optimization countermeasures, so as to provide practical references for improving the resource-based utilization level of crop straw.

2. Resource-based disposal modes of crop straw

At present, the resource-based disposal of crop straw in China has formed a diversified pattern coexisting with fertilizer-oriented utilization, feed-oriented utilization, fuel-oriented utilization, base-material-oriented utilization, and raw-material-oriented utilization (**Figure 1**). The utilization scale of each mode varies significantly, and the proportion structure of various disposal modes is shown in the pie chart.

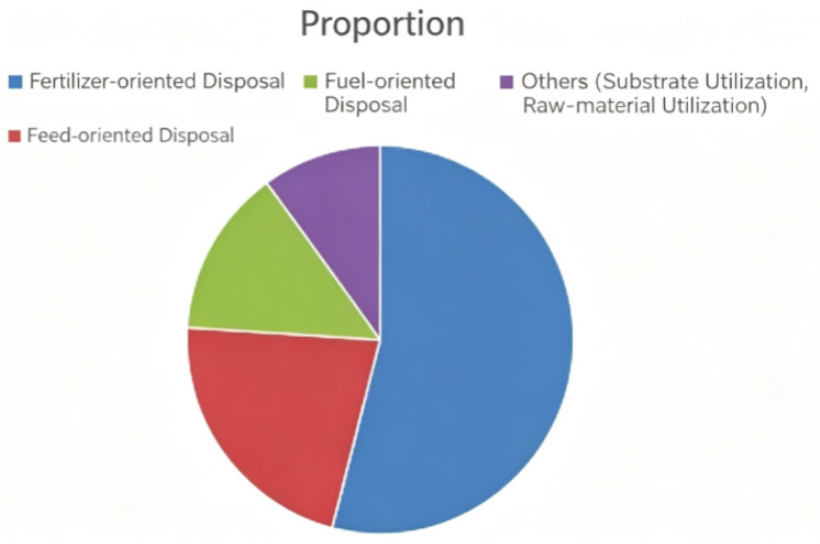

Figure 1. Resource-based disposal modes of crop straw

2.1. Straw fertilizer-oriented disposal mode

Straw fertilizer-oriented utilization is the most widely-adopted resource-based disposal method in China, accounting for more than half of total utilization with the largest scale. Its core lies in making use of organic matter, nitrogen, phosphorus, potassium, and other nutrients inside straw, and converting them into organic fertilizer through returning-to-field and processing to realize farmland recycling and achieve planting-breeding circulation (**Figure 2**) [1].



Figure 2. Site picture of direct straw crushing and returning-to-field operation

This mode includes two technical routes: direct straw returning-to-field and straw organic-fertilizer processing. Direct straw returning-to-field is convenient: straw is crushed by a crushing-returning-to-field machine and then plowed into the soil for decomposition by soil microorganisms. It requires no complex processing technology, features low cost and strong adaptability, and is applicable to most grain-planting areas. In straw organic-fertilizer processing, straw serves as the core raw material. Industrial fermentation and drying are carried out with microbial agents to produce commercial organic fertilizer, which adapts to large-scale agricultural production and the industrialized development of organic fertilizer [2]. In straw fertilizer-oriented disposal, straw can be treated and utilized locally without long-distance collection, transportation, and storage, which greatly cuts disposal costs, effectively raises soil organic-matter content, improves soil aggregate structure, and alleviates soil compaction caused by long-term chemical-fertilizer application, thus realizing the virtuous-cycle goal of "straw returning-to-field, soil improvement and yield increase." This mode features low technical thresholds and little promotion difficulty, which can effectively guarantee cultivated-land quality and facilitate green planting. Still, it has technical shortcomings such as long decomposition cycles and low decomposition efficiency under low-temperature environments [3].

2.2. Straw feed-oriented disposal mode

Straw feed-oriented utilization refers to the resource-based mode that converts straw into livestock-and-poultry breeding feed by processing to improve palatability and nutritional value, making use of crude fiber, crude protein, and other components in straw. It can effectively connect planting and breeding industries. Crop straw such as corn, wheat, and rapeseed straw can be used as high-quality feed raw materials [4]. Raw straw is hard and poorly palatable and cannot be directly fed to livestock and poultry. Processing technologies such as silage, ammoniation, and micro-storage can be adopted to destroy original straw fiber and substantially improve nutrient-utilization efficiency. In current China, straw feed-oriented utilization is mainly divided into large-scale silage processing and simple household-level processing for feeding. Silage technology is mature: it retains original straw

nutrients through anaerobic fermentation, featuring a long fresh-keeping period and good palatability, and can meet large-scale breeding demands of herbivorous livestock and poultry [5]. The advantages of this mode lie in converting agricultural resources, effectively substituting commercial feed, lowering livestock-and-poultry breeding costs, realizing circulation between planting by-products and breeding production, satisfying agricultural development of integrated planting-breeding, and suiting agro-pastoral areas with large-scale livestock-and-poultry breeding and sufficient straw resources. Nevertheless, this mode is restricted by high processing requirements, and losses are likely to occur during transportation and storage [6].

2.3. Straw fuel-oriented disposal mode

Straw fuel-oriented utilization converts straw into clean energy to replace traditional fossil energy. It belongs to high-value-added disposal with a relatively low proportion in total straw utilization. Its core technologies include straw combustion-for-power-generation, straw anaerobic-fermentation for biogas production, and so on [7]. For effective application of this mode, physical, chemical, and biotechnologies are adopted to convert biomass energy from straw into clean energy such as electric energy and heat energy, which are widely applied in scenarios including power supply and residential heating.

Nowadays, straw molded-fuel processing is the most common fuel-disposal approach. Straw is crushed, compressed, and solidified to produce pellet fuel and briquette fuel, which feature stable calorific value and environmental-friendliness, and can replace coal for industrial use and rural heating (**Figure 3**) [8]. Straw power generation and biogas fermentation represent industrialized and large-scale utilization modes. Large-scale biomass power plants can consume straw in batches to realize grid-connected power generation and satisfy centralized gas supply demands. Large-scale straw energy-oriented utilization can replace hundreds of thousands of tons of standard coal and substantially reduce fossil-energy consumption. This mode features a high level of industrialization and large resource consumption capacity. It can eliminate local straw stockpiles and is suitable for regions with abundant straw resources, convenient transportation, and established energy-industry foundations. Its disadvantages include high upfront equipment-investment costs, heavy dependence on transportation costs, and low economic benefits for small-scale utilization [9].



Figure 3. Finished-product picture of straw briquette fuel

3. Benefits of resource-based disposal for crop straw

3.1. Economic benefits

Economic benefits constitute the core driving force in straw resource-based disposal. Various disposal modes can realize commercialized and industrialized transformation of straw resources, effectively cut agricultural-production costs, create industrial returns, and form stable economic value. Different disposal modes deliver differentiated economic benefits to satisfy diverse industrial-development demands. The economic benefits of the straw fertilizer-oriented mode are reflected in cost savings and yield increases. Straw returning-to-field can improve soil fertility, reduce chemical-fertilizer consumption, and raise crop yields [10]. Compared with commercial organic-fertilizer purchase, local straw returning-to-field saves agricultural-material procurement costs per mu and brings stable and long-lasting economic returns.

The core economic value of the straw feed-oriented mode lies in substituting commercial feed and lowering breeding costs. Processed silage and micro-storage products are cost-effective, which can cut breeding investment substantially. Meanwhile, the integrated planting-breeding mode realizes straw transformation, reduces straw losses, extends the agricultural industrial chain, raises returns for planting and breeding industries, and achieves income increase and expenditure reduction in agro-pastoral regions [11].

Straw fuel-oriented and raw-material-oriented utilization bring prominent industrial economic benefits. Large-scale straw-energy projects can substitute standard coal and save fossil-energy procurement costs, bringing sound industrial profits. Products processed from straw raw-materials possess high added value. Some enterprises manufacture various products with straw to raise straw value and drive income growth in related regions [12]. In short, the continuous improvement of straw resource-based utilization ratio can boost local straw utilization and inject impetus into industrial development.

3.2. Ecological benefits

Resource-based disposal of straw delivers remarkable ecological benefits. It can fundamentally eliminate environmental pollution caused by open-air burning, realize soil improvement and carbon emission reduction, facilitate agricultural ecological restoration, support the achievement of the “Dual-Carbon” goals, and provide solid guarantees for green agricultural development [13]. First, it effectively reduces air pollution and promotes carbon-emission-reduction goals. Traditional open-air straw burning releases massive particulate matter, nitrogen oxides, and other pollutants, pollutes the rural atmospheric environment, and discharges large quantities of carbon dioxide. Resource-based disposal of straw can avoid burning-related pollution. When applied on a large scale, regional straw energy-oriented utilization can substantially cut carbon-dioxide emissions and highlight low-carbon ecological values. Second, it improves the soil ecological environment and guarantees cultivated-land quality. Fertilizer-oriented straw returning-to-field supplements soil organic matter, alleviates soil problems such as compaction and salinization, raises soil water-retention and fertilizer-retention capacity, reduces soil pollution and water eutrophication triggered by excessive chemical-fertilizer application, and builds a safety barrier for cultivated-land ecology [14]. Third, it promotes resource recycling and cuts resource waste. Resource-based disposal converts discarded agricultural by-products into usable resources to substitute chemical fertilizer, coal, wood, and other raw-materials, and reduces exploitation and consumption of virgin resources and resource losses in agricultural production. In addition, multi-level recycling improves resource-utilization efficiency. Processing by-products from straw-based material-oriented and raw-material-oriented utilization can be recycled to form a low-carbon green

agricultural-development pattern and continuously optimize the rural ecological environment.

3.3. Social benefits

Resource-based disposal of straw brings social benefits including industry empowerment, employment creation, and rural-governance improvement. It promotes the implementation of the rural-revitalization strategy, raises the level of agricultural modernization, and optimizes human-living environments. First, it drives rural employment and expands income-increase channels [15]. The straw-resource-based industrial chain covers many links such as straw collection, processing, and sales, which creates plenty of rural-job positions and absorbs surplus rural labor force. In relevant industrial projects such as straw processing and board production, stable household-income growth can be realized and rural industrial vitality can be stimulated. Second, it optimizes rural governance and improves human-living environments. Random straw stockpiling is a key difficulty in rural human-living-environment improvement. The implementation of resource-based disposal realizes standardized, harmless, and resource-oriented straw treatment, fundamentally eliminates straw-related pollution and potential fire hazards, improves rural appearance, and facilitates the construction of a beautiful countryside. Third, it promotes agricultural industrial upgrading and builds a sound agricultural-modernization system. Resource-based straw disposal builds connecting channels for planting, agricultural-product processing, and breeding industries, and drives the transformation from unitary agricultural production to diversified industries, so as to construct a favorable agricultural-industrial structure. Meanwhile, the application of straw-resource-based technologies optimizes agricultural production, raises its scientization and standardization levels, promotes the transformation of traditional agriculture toward green and high-efficiency development, and injects vitality into rural revitalization. Furthermore, the straw-recycling-utilization pattern helps foster farmers' green-production concepts, implements green-agricultural-development ideas, and builds a favorable atmosphere for agricultural development.

4. Conclusion

To sum up, resource-based disposal of crop straw is developing toward refinement, industrialization, and large-scale operation. It can unlock the value of idle agricultural resources, adjust the agricultural circular-economy system, promote the coordinated development of agricultural production and ecological protection, and provide solid guarantees for agricultural low-carbon transformation and rural-industry revitalization. It boasts favorable development prospects and practical significance.

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