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Haze Control by Industrialization: A Win-win Mode of Ecological Civilization and Economic Development

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Abstract Haze control is a difficult and arduous battle, and it is a major decision concerning the people's livelihood and national ecological civilization construction. Taking Heilongjiang Province as an example, this paper introduced a new idea for haze control. Haze in Heilongjiang Province was mainly resulted from straw burning. Market-oriented, large-scale, and industrialized haze control relying on science and technology is new opportunity and challenge for realizing ecological civilization and revitalizing the economy of Heilongjiang Province.

Key words Haze, Control, Industrialization

1 Introduction

With the frequent occurrence of haze, China firstly included the haze forecast into weather disaster forecast in January 2014. The *Action Plan on Prevention and Control of Air Pollution* issued by the State Council set forth a detailed blueprint for haze control in 2017 and put forward specific requirements of every province in reducing the concentration of PM_{2.5}^[1]. Both leaders of the state and Heilongjiang Province have always attached great importance to haze control. In February 2014, President Xi Jinping pointed out in his survey in Beijing: the primary task for haze control and air quality improvement is to control PM_{2.5}, so it is required to take great actions to strengthen supervision of environmental law enforcement, and seriously investigate responsibility^[2].

Premier of the State Council, Li Keqiang, held a standing meeting of the State Council on February 12, 2014. At the meeting, he mentioned a tough and protracted war against the haze^[3]. In view of the haze situation, Heilongjiang provincial government held a special meeting for haze control in the whole province^[4]. On October 8, 2016, Heilongjiang provincial government issued the *Implementation Program for the Ban on Straw Burning in Heilongjiang Province to Improve the Air Quality*, which specified that Harbin City, Suihua City, regions under the administration of Heilongjiang Farms & Land Reclamation Administration, and pilot counties of comprehensive utilization of crop straw are straw burning forbidden areas. Heilongjiang Province is a large agricultural province. The major reason for its haze pollution is straw burning. Fine particulate matter PM_{2.5}, PM₁₀ and other pollutants generated from straw burning will cause serious air pollution^[5,6]. Scientifically controlling the straw burning is the fundamental method for haze control. Taking the straw as an industrial raw materials to realize straw fertilizer, feed, and energy not only can effectively

control the haze pollution, but also can achieve increase in agricultural income, help farmers get rich, and promote industrialized economic development of Heilongjiang Province. Industrialized haze control is a win-win mode to achieve economic revitalization and ecological construction of Heilongjiang Province.

2 Overview of Heilongjiang Province

Heilongjiang Province is a large grain province. In 2013, the crop farmland area was 14.678 million ha, and grain crop sown area was 14.037 million ha. Grain area was 11.332 million ha, including 403.1 ha rice, 661.5 ha corn, and 2.75 million ha beans^[7]. It is estimated that 1 kg rice can produce 1.5 kg straw, 1 kg wheat can produce 1.5 kg wheat straw, 1 kg corn can produce 4 kg corn stalks^[8]. With the substantial increase in grain yield, the straw yield is also increasing sharply; with the popularization of coal saving technology and coal and liquefied petroleum gas, straw starts to become excessive; according to statistics, the annual yield of straw is more than 700 million tons^[9]. Most of the straw is treated through burning, which will pollute the atmospheric environment. Straw as a kind of biomass energy generally refers to the remainder of wheat, rice, corn, potato, oil crops, cotton, sugar cane and other crops after harvesting the seed^[10]. The straws of these crops are generally abandoned in the field, they are relatively moist, and the smoke of ignition contains large amount of dust, droplet and other contaminants^[11]. Straw burning has become an important source of air pollution in Harbin. According to the *Ambient Air Quality Standard* (GB3095–2012), in Harbin City, the effective monitoring days in 2014 were 365 days, mild pollution accounted for 52 days (about 11.5%), moderate pollution accounted for 41 days (11.2%), severe pollution accounted for 30 days (8.3%), and serious pollution accounted for 10 days (2.7%)^[12]. In 2015, Harbin experienced two times of serious haze pollution. *Several Opinions Concerning Promotion of Socialist New Countryside Construction* (No. 1 document of central govern-

ment) issued by Central Committee of the Communist Party of China and the State Council proposed popularizing straw gasification, curing molding, power generation, livestock breeding and other technologies, developing biomass energy and biomass materials, and cultivating the biomass industry^[13]. A few years ago, Heilongjiang Province has set up an integrated straw utilization association for research, development, and promotion of integrated utilization of modern new technologies^[14]. However, due to restriction of market mechanism and science and technology level, it achieved little effect. Setting up the "recycling, low-carbon, and application type" industrialized and integrated straw utilization mode is a correct choice for building a resource-saving society.

3 Main existing problems

3.1 The public have weak awareness of environmental protection and low degree of participation In the face of severe haze pollution, most of the public have weak awareness of environmental protection and the degree of environmental protection participation is not high. People are unwilling to use manpower to cut down, tie, and transport straw, leading smoke of straw burning everywhere in rural fields^[15]. This not only pollutes the atmospheric environment, endangers public safety, but also wastes valuable biomass resources. Although China has issued the *Methods for Management of Straw Burning and Integrated Utilization*, but the public are still low in participation and implementation, and the haze control effect is not significant.

3.2 The purchase of straw is scattered, and storage and transportation service system is not perfect After years of research, Wang Qingge, deputy of the People's Congress of Heilongjiang Province, concluded that one of the reasons for the straw burning is that few enterprises use straw and the purchase market is scattered. Most of the rural areas did not have straw recycling stations and the company acquisition route, the sales market space is small, storage and transportation transport service system is imperfect, farmers had to choose to burn or abandon straw, naturally leading to pollution. This is largely connected to the limited industrialization in economic development of straw and the lack of farmers' network information technology application.

3.3 Enterprise acquisition costs are high and the support is weak Generally, a kilogram of straw needs at least 1–2 cents of acquisition cost and 10 yuan for employing workers to handle one ton of straw^[16], plus the cost of transportation and equipment costs, the costs are high. The acquisition of processing sites and the purchase of equipment need a lot of money and discourage straw companies. In the face of the adjustment of rural consumption structure and the acceleration of the transformation of farmers' lifestyles, seasonal and the structural surplus problems of crop straws become more and more prominent. Thus, achieving the sustainable development of straw enterprises is the key to solve these problems.

3.4 Scientific and technological talents are few and the technological transformation degree is low Straw processing costs are high, technological transformation is insufficient, and it lacks

processing technology industry and talents, so it is difficult to realize the economic value of straw. Most rural young and middle-aged people choose to do migrant work, leaving the elderly, women and children behind, their knowledge level is limited. In the aspect of use of technology, it lacks technical advice on the use of technology and knowledge training, and the straw use technology fails to be popularized. In addition, enterprises lack straw gasification, straw crushing technology and equipment using technicians.

3.5 Regional joint prevention and control cooperation is not strong and the information disclosure is inadequate In practice, the haze control is generally independent work of the local government, lacking central coordination and the regional exchange of information. Environmental monitoring and PM_{2.5} information disclosure is a manifestation of whether the environment meets the standard. If the information is not disclosed or not real, it will not only affect the public participation in the haze control and supervision, it will also be unfavorable for targeted implementation of prevention and control measures and improvement of the national regulatory mechanisms and decisions. Therefore, the government should guide the public to set up innovative ideas and straw recycling concept, so as to increase the integrated straw utilization efficiency.

4 Industrial development ideas

Crop straw is an important material foundation for the development of circular economy in China, and its integrated utilization conforms to the new energy industry policy^[17]. It is recommended to promote the agricultural economic development through industrialization and take the road of low carbon development. Low-carbon agriculture is an essential part of low-carbon economy. Through the industrialization of straw, it is expected to achieve win-win of agricultural economy and ecological and environmental protection. Industrialized development of straw can take three optimization models, namely, industrialized operation optimization of integrated straw utilization, product production optimization of integrated straw utilization, technology optimization of integrated straw utilization.

4.1 Industrialized operation optimization of integrated straw utilization

4.1.1 SPS integration model. SPS refers to supply, production, and sales^[18]. SPS integration model is the tie and mechanism reform taking straw as biomaterial. It recombines straw production, sales, and market into an economic coalition entity to make industrialized operation.

4.1.2 BOT investment model. BOT (build-operate-transfer) is a form of project financing, wherein a private entity receives a concession from the private or public sector to finance, design, construct, and operate a facility stated in the concession contract^[19]. In the case of lack of funds, the enterprise engaged in integrated straw use may seek the subsidy from the local government. The government will provide subsidy funds and the right to use the contract. After the expiration of the contract, the owner-

ship belongs to the government, and the government only needs to recover the corresponding funds to recover the investment. Through this investment model, it is able to establish the capital chain, realize wide participation, and solve the problems of insufficient funds and operational discontinuity.

4.1.3 Contractual operation model. The integrated straw utilization industry may be operated by enterprises with goodwill through contract in specified years. Government does not participate in the structural operation. In this way, it is expected to establish excellent competitive operation mode and stimulate economic growth. The established straw industry may auction off the operation right to other enterprises to extend the vitality of industrialization.

4.2 Product production optimization of integrated straw utilization

4.2.1 Straw board application. Straw can be made into building materials and used in modern buildings, such as straw board, straw wall, straw brick, so that its insulation, light weight, and environmental protection performance can realize maximum use. After the straw is crushed and compressed, it is very practical to get a certain shape of the compressed body and apply it to the construction industry.

4.2.2 Input of power generation raw material. After centralized collection, bundling and storage, straws can be used as raw materials for power generation of power plant. The electric energy generated from straw is less than that from coal, but with reasonable use of straw, it can save a lot of coal resources.

4.2.3 Culture medium for fungus and cultivation of fermentation agent. As the straw is rich in nutrients, people can use straw to produce culture medium for fungus, such as *Pleurotus ostreatus*, *Lentinus edodes* and Enoki mushroom^[20,21]. Straw can also be fermented and used to improve the quality of meat, straw fermentation agent mainly consists of many active substances such as mold, yeast, lactobacilli and a variety of beneficial microorganisms and their products, protease, lipase, amylase, glucoamylase, cellulase and other organisms^[22]. For the fermented corn stalks, the crude protein content will increase, and amino acid content and vitamin B will also increase.

4.2.4 Biomass energy utilization. Through gasification and anaerobic fermentation, straw can be transformed into gas and used in rural energy construction. First, the crop straw is dried in the hypoxic condition. With the temperature rise, the straw contains volatile substances which are gradually precipitated and cracked, these precipitates and straw residual materials will have combustion reaction in case of air, oxygen and steam, and generate CO and methane and other gases, and obtain straw gas^[23]. Straw energy is a method of resource optimization.

4.2.5 Feed and chemical fertilizer processing. Straw can be used as feed of livestock. However, because of the low nutritional value, straw must be properly treated before it is served as livestock feed, converting its macromolecule matter into monosaccharides or oligosaccharides^[24,25] to increase the nutritional value and utilization ratio of straw. Mechanized crushing and returning to the

field is to use biochemical rapid curing technology to produce high quality organic fertilizer, which not only reduces the amount of fertilizer applied, saves agricultural investment, but also optimizes the physical and chemical properties of soil. Due to slow decomposition after returning to the field, straw also needs to sprinkle a certain amount of remover to speed up the decay of straw.

4.2.6 Straw rope processing. Straw rope is a comprehensive straw utilization model, turning waste into wealth. Rice straw can be processed into straw rope, handicrafts for ornament, wrapping trees to protect trees, packaging ceramics, building ceramics, woven into net as breeding ground of rare fishes^[26]. Straw processing into straw rope is very suitable for industrial development, rural surplus straw can be digested to protect the environment, and can develop new biological energy to achieve efficient use of straw energy conversion.

4.3 Straw recycling technology optimization model

4.3.1 Straw recycling residual film technology optimization. Straw recycling machine can save a lot of manpower and time, straw can be harvested and crushed and compressed into particles without the need of being cut down, which greatly increases the efficiency of the integrated straw utilization. It is recommended to increase film recycling technology, improve the cutting root technology, and design more reasonable hanger structure. It is recommended to improve the operation of straw recycling machine and optimize the industrialized development of straw.

4.3.2 Straw recycling packaging technology optimization. Heilongjiang Province has developed a new agricultural technology-straw recycling packaging technology, this new technology uses advanced corn straw packaging machine, rapidly collecting and packaging straws for feed, power generation, firewood, etc., to improve both the social and economic benefits. At present, pilot test has been carried out for this technology. It is recommended to optimize straw recycling and packaging technology to improve collection, packaging rate and accuracy, and reduce repetition of work.

5 Successful cases of straw utilization

5.1 Case 1: formaldehyde-free environment-friendly straw board project

5.1.1 Development background and market prospect. According to the prediction of the Ministry of Construction, in 2001 – 2012, China's annual average residential completion was 330 million m², if the decoration proportion was 80%, the project was up to 264 million m². Besides, there was another 8 million m² of public buildings and high-grade office needed decoration^[27], which brings huge room for the use of wood-based plate. Shanghai Kangbai Company, committed to the introduction of domestic technology and innovative technology, has established the straw board production liens in Heze City of Shandong Province and Harbin City of Heilongjiang Province. With the independent intellectual property rights, its system has realized the desired effect for large-scale industrialization, which lays a certain foundation for large scale

development. The company has realized an annual output of 30000 m³ of straw boards, feed base 60000 tons, straw boards are exported

ted the EU with an annual output value of 150 million yuan.

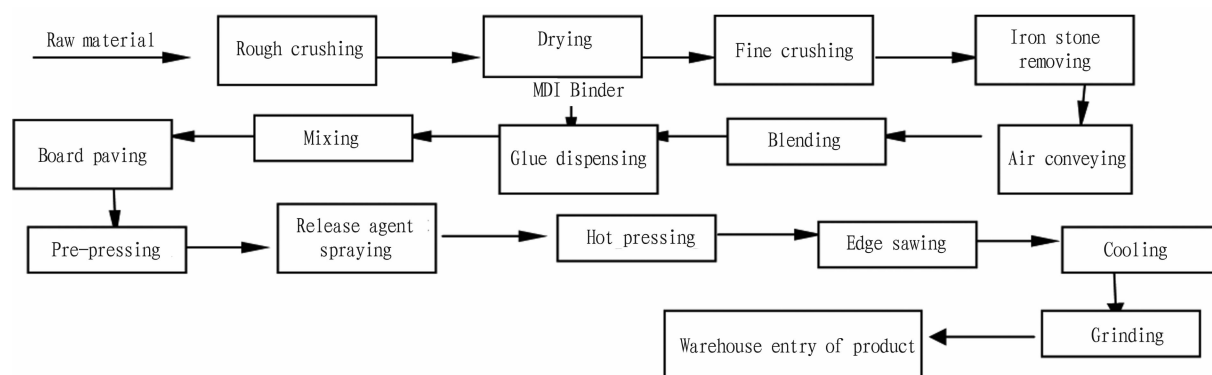


Fig. 1 Workflow of high strength environment-friendly straw board

5.1.2 Workflow. Kangbai straw board is a project of replacing wood with straw, so its market capacity is huge. The main raw material of this project is corn stalk. Its main ingredient is lignocellulose, which is formed by the combination of cellulose, hemicellulose and lignin through covalent bond or noncovalent bond. Taking corn stalks as basic material to manufacture formaldehyde-free environment-friendly board is high-tech product initially invented by Shanghai Kangbai Environmental Protection Equipment Co., Ltd. Fig. 1 illustrates the workflow of environment-friendly straw boards. The acquisition of raw materials adopts separate fixed point as per the harvesting method of corn. The packaging of raw materials will adopt two different ways based on the different ways of harvesting. Using the combined harvester, it is able to directly pack and seal the crushed straws. In case of other harvesting methods, firstly it is necessary to make bundling and then transport. This can take full use of the advantages of local raw material resources, in order to reduce the management cost of raw materials and reduce land use.

5.1.3 Economic and social benefits. With the approval Zhaodong Municipal People's Government, Shanghai Kangbai Environmental Protection Equipment Co., Ltd. invested 300 million yuan to build the integrated straw utilization project in Zhaodong Economic Development Zone, with an annual output of formaldehyde-free environment-friendly straw board up to 120000 m³ and an annual output of 240000 tons of crude fiber feed. After the project is put into use, it is estimated that the average annual sales income will be 78.11 million yuan, the average annual value-added tax will be 3.9127 million yuan, and the additional education fee of 3225 thousand yuan. The average profit of the production period will be 15.7244 million yuan and the average profit after income tax will be 11.793 million yuan. Besides, it can reach the objectives of effectively reducing the waste of natural resources, low-carbon environmental protection, and economic benefits. After the second phase of the project is formally put into operation, the annual acquisition of straw is up to 400000 tons, creating about 100 million yuan income for farmers, increasing more than 200 jobs, reducing CO₂ and other harmful gases about 1.2 million tons, showing double growth in economic benefits, employment opportu-

nities, and environmental protection. The project is an integrated straw utilization project and it is a systematic project closely related with the agriculture.

5.2 Case 2: using crop straws to cultivate edible fungi

5.2.1 Background of the project. China advocates the development of green food industry. Integrated straw utilization and deep processing of edible fungi will further promote the cultivation of edible fungi and agriculture, aquaculture industry to realize rapid pollution-free and green development. Edible fungus production can transform most discarded crop stalks into high quality protein and healthy food for human consumption. The medium waste (slag) is good agricultural organic fertilizer and is an essential part for extension of agricultural industry chain and promotion of agro-ecological environment optimization^[28]. Jiangyan City of Jiangsu Province, as a large edible fungus production city, constantly researches and develops using crop straw to cultivate edible fungi in large-scale and industrialization model. It has cultivated excellent high yield, high quality, multi-resistant fine strains using straw^[29], such as white black brown gray mushroom, high and low temperature *Pleurotus ostreatus* and mushroom, high temperature *coprinus comatus*, high temperature *hypsizygus marmoreus* and so on.

5.2.2 Integrated straw utilization and benefits. Straw can be used to make the culture medium. With sterilization treatment, straw can realize mushroom strain growth and spore germination. In Jiangyan City, there is 56000 tons of crop straws for the cultivation of edible fungi every year, it can produce various types of fresh mushrooms nearly 40000 tons, the total output value is more than 100 million yuan, it can provide 5000 jobs for the remaining labors, slag after generation of mushroom is up to 28000 tons, if all are used as harmless additives for green organic fertilizer, the fertilizer efficiency can be equivalent to 48000 tons of 100% carbon fertilizer^[30]. Through putting up simple greenhouse and cultivating 667 m² edible fungus annually, it can solve the 2–3 ha crop straw, produce 20000 kg of fresh mushrooms, 40000 yuan net income^[31], so it can transform large volume of crop straws, and also can reduce the environmental pollution resulted from straw burning, and increase farmers' income. The agricultural ecological

chain of straw-edible fungi * nutritious food – slag feed – breeding – organic fertilizer brings Jiangyan City with economic wealth and healthy ecological environment. Using straw to cultivate edible fungi will encourage surrounding farmers to produce agricultural and sideline products, so that agricultural production scale and intensification degree will be greatly improved, and it will greatly increase the farmers' income.

6 Recommendations

6.1 Raising the environmental protection awareness and establishing the accountability system Raising the environmental protection awareness and public participation is more favorable for the effective implementation of haze control. Relevant departments should strictly enforce the laws and strengthen the straw burning supervision and accountability system. It is recommended to strengthen the supervision and inspection of straw burning and monitoring of atmospheric environment in busy farming season, and promptly feedback the changes in quality of atmospheric environment and problems found in the inspection of forbidden burning to the government. Besides, it is required to establish the pollution accountability system. In the administrative punishment, it is required to largely increase the amount of punishment and intensify the punishment on the destruction of the atmospheric environment and illegal discharge of pollutants and other illegal acts.

6.2 Strengthening the propaganda of industrialization It is recommended to extensively carry out various forms of propaganda and education activities, vigorously promote the significance of integrated straw utilization and the harm of the straw burning, and elaborate the typical cases of integrated straw utilization technologies. We should give full play to the role of public opinion and create excellent propaganda effect. Besides, it is recommended to establish propaganda groups to have mutually supervision and mutual encouragement, and realize smooth implementation of integrated straw utilization. Everyone should set up the concept of protecting natural ecology and effectively controlling the haze, and take the reduction of haze and low-carbon lifestyle as his spontaneous action.

6.3 Implementing scientific and technological personnel training strategy and extending scientific research resources

Taking scientific research units, institutions, colleges and universities as the basis, it is recommended to strengthen scientific and technological research strategy, carry out integrated straw utilization technology training and research work, as well as new equipment research and development. In addition, it is recommended to fully promote the agricultural machinery technology and increase the subjective initiative of agricultural technology organizations, and monitor the effectiveness of haze control relying on integrated straw utilization demonstration bases. Through delivering technology to the countryside and farmer technical training, it is expected to speed up the promotion of integrated straw utilization technologies and new processes. Reducing the labor intensity and promoting the development of industrialization are effective approaches for increasing the agricultural production efficiency, reducing emission, and increasing income.

6.4 Strengthening the integrated straw utilization planning and formulating comprehensive supporting policies According to the distribution of agricultural resources in Heilongjiang Province, it is recommended to determine suitable integrated straw utilization methods, quantity and layout, make reasonable planning for straw utilization projects and industrial development site and scale, extend the integrated straw utilization industry chain, and gradually form an integrated, regional, professional, and industrialized straw utilization pattern. Combined with the actual situation of Heilongjiang Province, the government should formulate comprehensive supporting policies for integrated straw utilization and prevention and control of haze pollution.

6.5 Formulating support and encouragement measures and implementing the government subject responsibility Governments at all levels should strengthen the leadership of the integrated straw utilization and banning work, make clear the objectives and tasks, strengthen the subject responsibility; implement the target responsibility system for integrated straw utilization and banning work, and build the government-led, department cooperative and farmers participating work pattern. Besides, all levels of government should strengthen the supervision and guidance of the integrated straw utilization, expand the scale of utilization, enhance the technical level, promote the construction of straw storage and transportation system, and encourage the diversification of straw utilization, to improve the atmospheric environment.

6.6 Accelerating the progress of the implementation of haze control laws, to ensure the healthy development of straw industry China has formulated air pollution control laws and environmental protection laws, but it should bring the revision of environmental protection law into schedule, accelerate the implementation of the haze control laws, in response to the increasingly complex atmospheric environmental pollution and haze situation. In addition, it is required to establish an effective environmental protection assessment system, attach greater importance to the haze control, and speed up the implementation of the laws and regulations, to ensure healthy development of integrated straw utilization industry.

References

- [1] General Office of the State Council printed the action plan of atmospheric pollution prevention([2013]37). (in Chinese).
- [2] Xinhua Network. Xinjinping proposed 5 points about constructing the most philanthropic and benevolent community[Z]. 2014-02-26. (in Chinese).
- [3] China News Network. Li Keqiang: An attacking battle and protracted war governing haze, 2016-02-28. (in Chinese).
- [4] Chinese Communist News Network. Lu Hao carried on the research of governing hazy weather in Heilongjiang Province, 2013-11-3. (in Chinese).
- [5] NIL O, HAKKI B, ASLI B. Investigation of fluorine content in PM_{2.5} airborne particles of Istanbul, Turkey[J]. Environment Science Pollution Research, 2016(23):13169-13177.
- [6] MIYEON L. An analysis on the concentration characteristics of PM_{2.5} in Seoul, Korea from 2005 to 2012[J]. Atmosphere Science, 2014, 50(S): 33-42.
- [7] Heilongjiang Bureau of Statistics. Heilongjiang Statistics Yearbook 2014[R]. Harbin: Heilongjiang Science and Technique Publishing House,

- [8] YANG LS. The measuring and impacting factors analysis of rural straw yield[J]. Journal of Anhui Agricultural Sciences, 2011, 39(10) : 6243 - 6245, 6248. (in Chinese).
- [9] HUANG C, DENG LJ, GAO XS. Evaluation of ecological footprint of straw resources utilization based on energy theory; A case study of typical rice-wheat rotation region in Chengdu Plain[J]. Chinese Journal of Eco-Agriculture, 2014, 22(6) : 722-728. (in Chinese).
- [10] WANG Y, CHAI YK, TAN XY, et al. A brief analysis on the characteristics of basic weather elements of Harbin hazy weathers [J]. Heilongjiang Meteorology, 2016, 33(3) : 29-30. (in Chinese).
- [11] HENRIETTE L. Case study one: Transboundary haze pollution[J]. Regimes in Southeast Asia, 2012: 89-138.
- [12] ZHANG L, QI XY. Causes and countermeasures for hazy weathers in Harbin[J]. Environmental Science and Management, 2015, 40(12) : 93-95. (in Chinese).
- [13] Several opinions on promoting the construction of new socialist countryside by the CPC Central Committee and State Council (No. 1 document, 2006). (in Chinese).
- [14] WANG DH, LI CX. Calculating of the reserves of straw biomass energy in Heilongjiang Province[J]. Ecological Economy, 2009(11) : 127-130, 144. (in Chinese).
- [15] TANG XB, HUANG C, LOU SR, et al. Emission factors and PM chemical composition study of biomass burning in the Yangtze River Delta Region[J]. Chinese Journal of Environmental Science, 2014, 35(5) : 1623-1632. (in Chinese).
- [16] MA F, ZHANG XX, WANG L. Economic and environmental evaluation of straw transportation radius for straw-energy engineering[J]. Journal of Harbin Institute of Technology, 2015, 47(8) : 48-53. (in Chinese).
- [17] LIU Z, LIU L, ZHANG SM, et al. Comparison of energy efficiency and sustainable development capability between different agricultural circulation modes with straw utilization[J]. Acta Ecologica Sinica, 2016, 36(15) : 4739-4750. (in Chinese).
- [18] WEI MG, WANG XY, XIE GH. Field residue of field crops and its temporal distribution among thirty-one provinces of China[J]. Journal of China Agricultural University, 2012, 17(6) : 32-44. (in Chinese).
- [19] ZHENG BS, YI XM. Research on the industrialization about creative products based on Sichuan straw reuse[J]. The Science Education Art-
- (From page 43)
- tem based on wireless network[J]. Jiangsu Agricultural Sciences, 2012, 40(12) : 373-375. (in Chinese).
- [9] REN XL, YU HB. Study of realizing technology on ZigBee wireless communication protocol[J]. Computer Engineering and Applications, 2007, 43(6) : 143-145. (in Chinese).
- [10] YANG W, LV K, ZHANG D, et al. Development of wireless intelligent control terminal of greenhouse based on ZigBee[J]. Transactions of the Chinese Society of Agricultural Engineering, 2010, 26(3) : 198-202. (in Chinese).
- [11] LI WY, WANG JX, WANG W. Design of ZigBee-based environment monitoring system for vegetable greenhouse [J]. Modern Electronic
- Technique, 2015(12) : 51-54. (in Chinese).
- [12] JU CX, WU ZY. Intelligent greenhouse control system based on ZigBee technology[J]. Jiangsu Agricultural Sciences, 2013(12) : 405-407. (in Chinese).
- [13] HE CP, GONG YM, LIN W. Facility agriculture intelligent monitoring system based on wireless sensor networks[J]. Journal of Anhui Agricultural Sciences, 2010, 38(8) : 4370-4372. (in Chinese).
- [14] HAN HF, DU KM, SUN ZF, et al. Design and application of ZigBee-based telemonitoring system for greenhouse environment data acquisition [J]. Transactions of the Chinese Society of Agricultural Engineering, 2009, 25(7) : 158-163. (in Chinese).