ASSESSMENT AND UTILIZATION OF AGRICULTURAL RESIDUE RESOURCES IN HENAN PROVINCE, CHINA

Zhi-Wei Wang,[a,b,c] Ting-Zhou Lei,[a,c,]* Xiao-Yu Yan,[d] Ying-Li Li,[a,e] Xiao-Feng He,[b,c] and Jin-ling Zhu [b,c]

Henan is the main agricultural province in China and is the top producer of wheat, representing 25% of the national wheat output. Henan has been the top province in terms of total food crop production since 2000. So, agricultural residue resources, which could provide material for future social and economic development, are abundant in Henan. But the province is facing critical problems from burning agricultural residues. Both efficient use and environmental protection of the resources are beginning to receive more attention. This study assessed the agricultural residue resources available for utilization and examined recent development targets in Henan. Agricultural residues were estimated for the base year 2009. Approximately 59.12 million tonnes of agricultural residues were consumed in various ways, and the average percentage of agricultural residue utilization was 70.07%. Agricultural residue is mainly used as a fertilizer, an energy source, industrial material, forage, and as feedstock for edible fungi. Short-term targets were provided for the development of suitable uses for agricultural residues through several demonstration projects, which will help to increase the efficient use of agricultural residue in Henan, China.

Keywords: Agricultural residues; Comprehensive utilization; Development target; Henan Province, China

*Contact information: a: College of Mechanical and Electrical Engineering, Henan Agricultural University, Nongye Road 63, Zhengzhou, Henan 450002, China; b: Energy Research Institute Co., Ltd, Henan Academy of Sciences, Huayuan Road 29, Zhengzhou, Henan 450008, China; c: Henan Key Lab of biomass Energy, Huayuan Road 29, Zhengzhou, Henan 450008, China; d: Department of Engineering, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, UK; e: Zhengzhou Technical College, Zhengshang Road 81, Zhengzhou, Henan 450121, China; *Corresponding author: bioenergy@163.com*

INTRODUCTION

China has abundant biomass from agricultural residues (Cui *et al.* 2008; Han *et al.* 2002; Zhang 2009a). Henan is one of the main agricultural provinces and food-producing regions in China, where agricultural residue resources are available in large quantities (NBSC 2010; HPBS *et al*. 2010). However, in recent years, a large portion of these resources have been discarded or burnt directly in the field, resulting in adverse environmental impacts and a significant waste of potential energy resources. This has occurred mainly because of changes in the industrial and agricultural production practices and the lifestyle of rural residents, as well as a lack of methods and techniques to efficiently utilize these residues (Wu *et al.* 2010).

Along with China's social and economic development and the transition from traditional to modern agriculture, there have been profound changes in the utilization patterns of rural energy and forage, and consequently the use of agricultural residues.

Although technological development has provided new methods and options for utilizing agricultural residues, the oversupply of residues in major agricultural regions results in a huge waste of valuable biomass resources and adverse environmental impacts, mainly from field burning (Li *et al.* 2009). These issues have become serious problems and are attracting greater public attention (Tan and Liu 2011). Optimal utilization of agricultural residues is essential for sustaining an agricultural system, as this utilization can have significant impacts on soil fertility as well as soil and water conservation. Agricultural residues are also very important for rural households, as they can provide renewable energy for heating and cooking and also affect the local environment and, hence, human health (Wang *et al.* 2010). Therefore, efficient utilization of agricultural residues is important for sustainable development of agriculture and the rural economy in Henan as well as in China (Bi *et al.* 2009; Bi *et al.* 2010). To facilitate better use of agricultural residue resources, the present study offers a comprehensive analysis of the composition, distribution, and utilization methods of agricultural residues in Henan province based on statistical data and surveys collected in 2009. The problems in current practices are identified, and development targets for future improvements are discussed.

AGRICULTURAL RESIDUE RESOURCES

Food Production

Henan province is located in central China (Fig. 1). It has an area of 16.70 million ha (Mha), which accounts for 1.73% of the total national area. Henan has 7.87 Mha in cultivated land, representing 6.51% of the national total (NBSC 2010; HPBS *et al.* 2010). Henan has been the top province for total food crop production since 2000 (NBSC 2012). Henan is the top producer of wheat and accounts for about 25% of the national wheat output. It is also among the top three producers of corn, soybean, cotton, rapeseed, and vegetables. Table 1 shows the total food crop production in China and Henan Province (NBSC 2012).

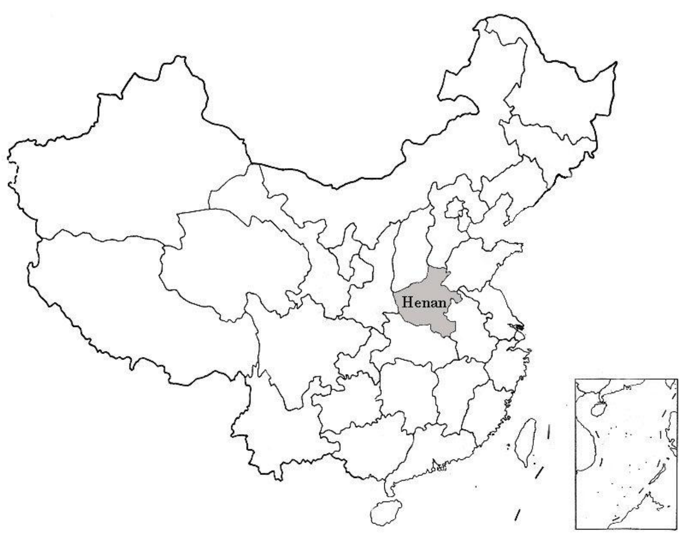

Fig. 1. Henan Province in mid-China

Table 1. Food Crop Yield in China and Henan Province from 2000 to 2010 (Unit: 10^6 tonnes) (NBSC 2012)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
China	462.18	452.64	457.06	430.70	469.48	484.02	498.04	501.60	528.71	530.82	546.41
Henan Province	41.02	41.20	42.10	35.70	42.60	45.82	50.10	52.45	53.66	53.89	54.37
Share of total/%	8.88	9.10	9.21	8.29	9.07	9.47	10.06	10.46	10.15	10.15	9.95

Henan proposed a plan to establish the 'Henan Core Producing Area' of the National Food Strategy Project in 2008 (HPGO 2010b). This plan targets 5 Mha of the existing 7.87 Mha of cultivated land as a core producing area and aims to increase the total cultivated area to 10 Mha, the average food yield to 1 tonne per mu (1 ha = 15 mu), and the 'tonne food' farmland to 1.67 Mha (Henan is double-cropping area). Annual total food crop production is expected to increase from 54.37 million tonnes (Mt) in 2010 to 62.5 Mt by 2015 and to 65 Mt by 2020 (HPGO 2010a-c). According to the crop distribution in Henan, the main increase yield of crop are wheat, corn and rice, the increase yield target of that are 3.95 Mt, 8.5 Mt, and 0.55 Mt by 2020, respectively.

Agricultural Residue Resources

Henan produces a variety of food crops, including wheat, corn, rice, peanuts, beans, cotton, tubers, vegetables, rapeseed, and sesame. After these crops have been harvested and processed, various residues and by-products such as stalks, straw, husks, and shells remain. Based on crop-production statistics and appropriate residue-to-crop ratios (Table 2), the amount of agricultural residues can be calculated by the following formula (Bi *et al.* 2009; Tan, *et al.* 2010),

$$S_n = \sum_{i=1}^{n} S_i d_i \qquad (1)$$

where S_n is the total amount of crop residues in tonnes, S_i is the production of the ith crop in tonnes, and d_i is the residue to crop ratio for the ith crop.

Table 2. Measured Residue-to-crop Ratios in Henan Province, China

	Residue to crop ratios	Remarks
Wheat	1.24	Wheat is dry, residue is about 15%wt moisture, 10 cm stubble.
Corn	1.48	Corn is dry, residue is about 15%wt moisture, 5 cm stubble.
Rice	1.10	Rice is dry, residue is about 15%wt moisture, 10 cm stubble.
Peanuts	0.89	Peanuts is dry, residue is about 15%wt moisture, no stubble.
Soybeans	2.38	Soybeans is dry, residue is about 15%wt moisture, 5 cm stubble.
Cotton	2.26	Cotton is dry, residue is about 15%wt moisture, 5 cm stubble.
Tubers	1.70	Tubers is fresh, residue is about 15%wt moisture, no stubble.
Vegetables	0.07	Vegetables is fresh, residue is about 15%wt moisture, no stubble.
Rapeseeds	1.01	Rapeseeds is dry, residue is about 15%wt moisture, 5 cm stubble.
Sesame	2.00	Sesame is dry, residue is about 15%wt moisture, 5 cm stubble.

Based on the output of major agricultural products (HPBS *et al.* 2010), it is estimated that 84.38 Mt of agricultural residues were produced in Henan in 2009. The spatial distribution of these crop residues among the 18 cities in Henan is shown in Fig. 2. It can be seen that Nanyang and Zhoukou have the highest production, both exceeding 10 Mt and accounting for more than 12% of total production. They are followed by Zhumadian, Shangqiu, Xinyang, Xinxiang, and Anyang where production is 5 to 10 Mt, and the share of the total is 6.12 to 11.18%. Production in Kaifeng, Xuchang, Puyang, Jiaozuo, Luoyang, Zhengzhou, Luohe, Pingdingshan, and Hebi is 1 to 5 Mt, with shares in the total range of 1.73 to 5.52%. Sanmenxia and Jiyuan have relatively low production of agricultural residues, both <1 Mt (HPDRC 2011a; HPDRC 2011b).

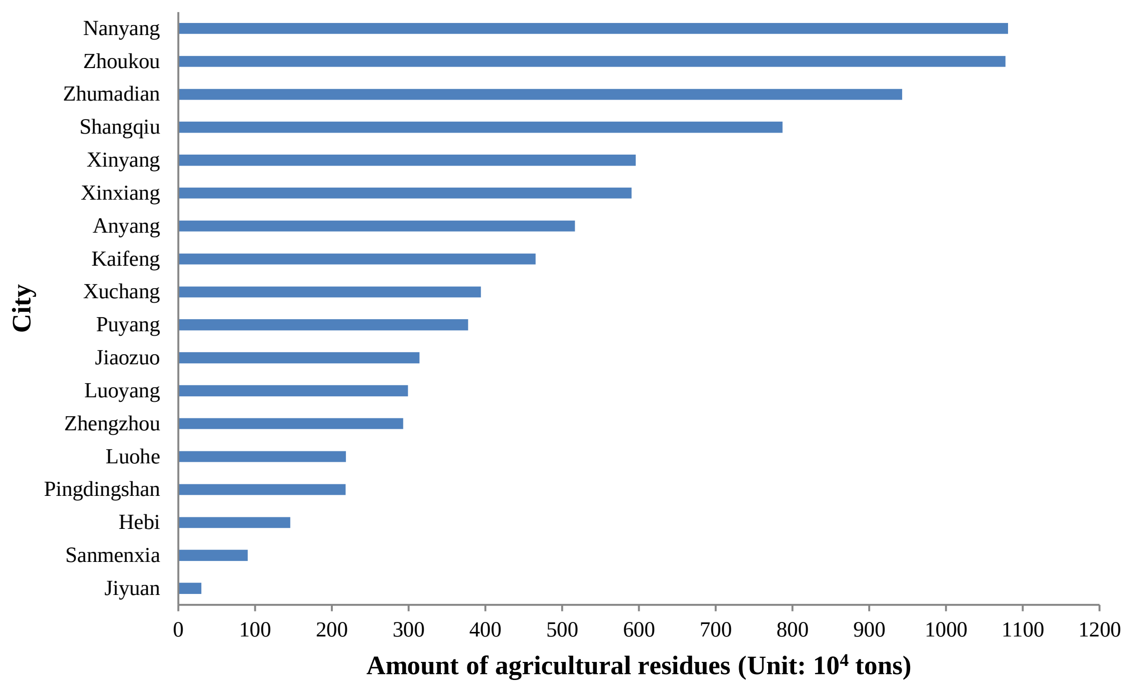

Fig. 2. Spatial distribution of agricultural residues in Henan Province in 2009

Figure 3 illustrates the shares of different sources of agricultural residues in Henan. Wheat straw and corn stalks are the main types of residues, accounting for 44.84% and 28.33% of the total, respectively. These are followed by residues from vegetables, rice, peanuts, tubers, soybean, cotton, and others. In terms of regional differences, Kaifeng produces mainly wheat straw and vegetable residues, and Xinyang produces mainly wheat and rice straw, whereas all the other 16 cities produce mainly wheat straw and corn stalks (HPDRC 2011a,b).

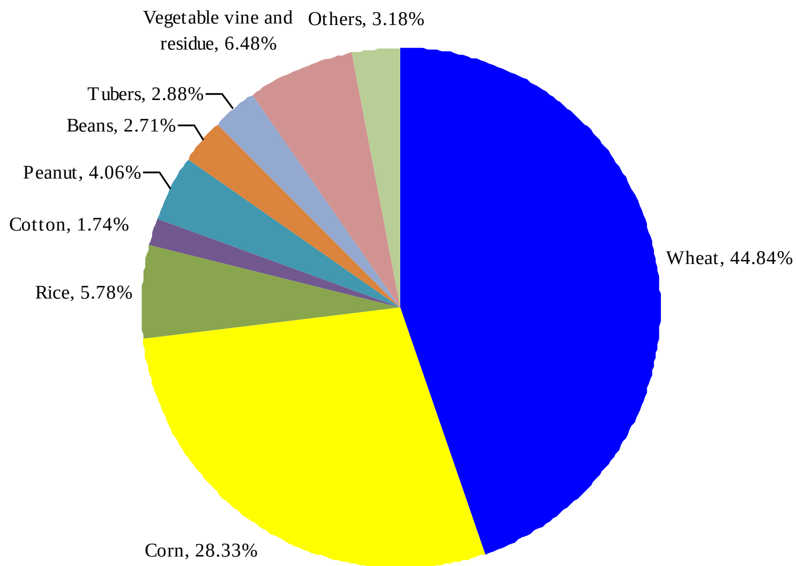

Fig. 3. Shares of different sources of agricultural residues in Henan Province in 2009

STATUS OF AGRICULTURAL RESIDUE UTILIZATION

According to our investigation, an estimated 59.12 Mt of agricultural residues were utilized in Henan in 2009 through various techniques, implying an aggregated utilization level of 70%. Figure 4 shows the regional differences in the level of utiliza-

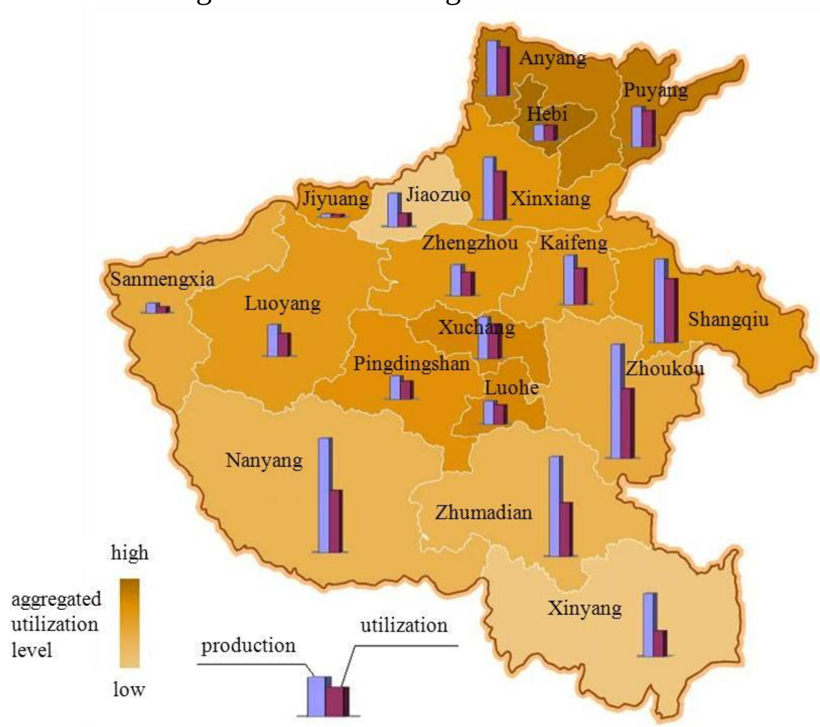

Fig. 4. Production and utilization of agricultural residues in 2009 in different regions of Henan Province (HPDRC 2011a; HPDRC 2011b)

ation. The aggregated utilization levels in Hebi and Puyang are the highest (>90%), followed by Anyang, Xuchang, Luohe, Jiyuan, Pingdingshan, Xinxiang, Shangqiu, Zhengzhou, Kaifeng, and Luoyang (>70%). The aggregated utilization levels in the remaining cities fall below the provincial average (<70%) (HPDRC 2011a,b).

Agricultural residues in Henan are mainly used for fertilizers, forage, energy, and industrial raw material. Table 3 presents the amount of each residue type utilized for different purposes. Peanut shells and leaves, tubers, wheat straw, and corn stalks are among the highest in terms of utilization levels (>70%), whereas use of other types of residues is relatively low. Wheat straw and corn stalks are mainly used for fertilizer and forage, rice straw for forage and industrial material, cotton stalks for energy, peanut shells and leaves and tubers for forage, bean stems and leaves for forage and fuel, and vegetable residues for fertilizer and forage (HPDRC 2011a,b).

Table 3. Utilization of Different Types of Agricultural Residues in Henan Province in 2009 through Various Techniques (Unit: 10^4 tonnes) (HPDRC 2011a; HPDRC 2011b)

	Wheat	Corn	Rice	Cotton	Peanuts	Beans	Tubers	Vs and Ms	others	Total
Residue amount	3783.24	2390.20	487.43	147.08	342.29	228.96	243.10	546.69	268.63	8437.62
Utilization amount	2721.50	1762.19	313.67	88.72	286.35	121.77	192.2	315.69	110.19	5912.28
Level of utilization / %	71.94	73.73	64.35	60.32	83.66	53.18	79.06	57.75	41.02	70.07
For fertilizers	1539.09	967.95	56.49	3.63	26.73	21.58	22.29	165.45	23.57	2826.78
For forage	690.68	602.55	114.73	-	222.28	60.37	134.73	92.30	27.96	1945.60
For energy	94.44	120.08	1.94	69.83	26.18	28.62	2.09	9.11	38.01	390.30
For industrial material	328.91	42.90	86.87	10.33	8.01	2.76	12.78	10.38	2.40	505.34
For edible fungi feedstock	68.38	28.71	53.64	4.93	3.15	8.44	20.31	38.45	18.25	244.26

Fertilizers

The use of agricultural residues as fertilizers in Henan is mainly through direct return to the field. Methods used include straw being returned to the field, straw chopping and mulching in the field, straw quick composting in the field, straw pile fermentation returned to the field, straw-produced organic fertilizers, straw-produced ammoniation, and straw-produced silage. In 2009, the amount of wheat straw and corn stalks used for fertilizers was 15.4 and 9.7 Mt (Table 3), accounting for 54% and 34% of the total residues used for fertilizers, respectively (HPDRC 2011a,b).

As organic fertilizers, agricultural residues represent 12 to 19% of the total organic resources in China (NATESC 1999; Bao 2002; Huang *et al.* 2006), and their N, P, and K nutrients account for 25 to 35% of organic nutrients in China (Bao *et al.* 2003). The use of agricultural residues as fertilizers reduces the use of synthetic fertilizers while also improving the efficiency of nutrient recycling in the field. In recent years, the application of various techniques for returning crop residues to the field, and a ban on field burning have been promoted by government policies and some agricultural subsidies. Henan has made noticeable achievements in promoting the deployment of special machinery for returning direct residue to the field. By 2009, the number of special machines in use reached 79,700, and the area in which residue was mechanically returned to the field reached 3.2 Mha. Henan has also been promoting trials and demonstrations of conservation tillage since 2002. Forty-three demonstration regions have been established, with a total area of 0.2 Mha. Furthermore, Henan encourages mechanical handling of residues in the field, with 758 straw-collecting and -bundling machines currently in use over an area of 50 thousand ha (HPDRC 2011a,b).

Forage

Using agricultural residues as forage is currently a very promising option (Schmidt and Thomsen 1998; Lv 2010; Li *et al.* 2000; Xi *et al.* 2003). The most common utilization methods are direct feeding, ammoniation, and ensilage. In 2009, the amount of wheat straw, corn stalks, and peanut shells and leaves used as forage was 6.9, 6.0, and 2.2 Mt (Table 3), representing 36%, 31%, and 11% of the total residues used for forage, respectively(HPDRC 2011a,b).

In recent years, Henan has encouraged forage utilization from agricultural residues through large-scale livestock production. In particular, a high-quality beef and lamb production zone and a green diary production zone have emerged near the Yellow River area. A number of mechanised ammoniation and ensilage storage silos with sound design, drainage facilities, and large storage volumes have been built. In 2009, 2250 new silos with a total storage volume of 5.3 million m^3 were built in Henan, and 39.3 Mt of agricultural residues were processed through ammoniation and ensilage (HPDRC 2011a,b).

Energy

Using agricultural residues for energy is another important method for comprehensive utilization (Nilsson *et al*. 2011; Hu *et al.* 2010; Allica *et al.* 2001; Gomez-Barea and Leckner 2010; Zhu *et al.* 2010; Li *et al.* 2011). Currently the main ways to use residues for energy in Henan include the following: direct combustion for power generation, direct combustion for rural household fuel use, gasification for central gas supply, briquettes, carbonisation, ethanol fermentation, and biogas digestion. In 2009, the amount of agricultural residues used for energy was 3.9 Mt, accounting for 6.6% of the total residue utilization and 4.6% of the total residue production, respectively. The amount of corn stalks and wheat straw used for energy was 1.20 and 0.94 Mt (Table 3), accounting for 31% and 24% of the total residues used for energy, respectively (HPDRC 2011a,b).

In terms of power generation, there are currently nine straw-fired power plants operating in Zhoukou, Xuchang, and Xinyang, with a total installed capacity of 152 MW and an annual residue consumption of 1.5 Mt. The technologies for gasification, briquettes, and carbonization are being commercialized. Many briquette plants have been established in Kaifeng, Jiaozuo, Xinxiang, Pingdingshan, and Shangqiu, producing solid fuels for industry and households as an alternative to coal. Demonstrations and development of gasification for central gas supply have been successful. Seventy-four large- and medium-scale gasification projects have been completed, supplying gas to 15.5 thousand households. Five trial biogas digestion projects are underway in Anyang. Liquid fuels produced from cellulosic feedstocks such as agricultural residues could potentially contribute to China's low-carbon transport energy supply (Yan *et al.* 2010). The Tianguan Group in Henan, one of five licensed fuel ethanol plants in China, has a demonstration project for cellulosic ethanol production in operation in Nanyang, with an annual ethanol output of 10 thousand tonnes and residue consumption of 70 thousand tonnes (HPDRC 2011a,b).

Industrial Raw Material

Agricultural residues can also be used as raw material for the chemical (Chang *et al.* 2007), pulp and paper, building decoration, biodegradable packaging, and textile industries (Pan 2008; Rodriguez *et al.* 2008; Zhou *et al.* 2004, 2007). The pulp and paper industry has become a major consumer of agricultural residues. Additionally, local governments encourage and support enterprises and farmers to diversify the residue-processing industry. For example, some emerging enterprises in Xinyang and Kaifeng produce environmentally friendly and fire-proof doors and boards from residues. In 2009, the amount of agricultural residues used as industrial raw material was 5.1 Mt, accounting for 8.5% of the total residue utilization and 6% of the total residue production, respectively. The amount of wheat straw and rice straw used for industrial material was 3.29 and 0.87 Mt (Table 3), accounting for 69% and 17% of the total residue used for industrial material, respectively (HPDRC 2011a,b).

Feedstock for Edible Fungi Cultivation

Using agricultural residues as feedstock for edible fungi cultivation can increase the residues value (Bian 2006; Sánchez 2009; Wan *et al.* 2011). After fungi cultivation, the feedstock can still be used as an organic fertilizer and forage to make full use of the biomass resource. In Henan, large-scale utilization of agricultural residues as feedstock for cultivation of edible fungi has been commercialized. For example, edible fungi cultivation using residues as feedstock reached 52 ha in Luoyang alone, consuming 20 thousand tonnes of residues annually. Edible fungi cultivation is also developing rapidly in other cities such as Anyang and Puyang. In 2009, the amount of agricultural residues used for fungi cultivation was 2.44 Mt, accounting for 4% of the total residues utilization and 3% of the total residues production, respectively. The amount of wheat straw and rice straw used for fungi cultivation was 0.68 and 0.53 Mt (Table 3), accounting for 28% and 22% of the total residue used for feedstock, respectively (HPDRC 2011a,b).

After being used as forage, energy, and feedstock, the residues can still be used as fertilizers or in biogas digesters to achieve full utilization. Finally, the fertilizers can be used in crop cultivation to enhance yield (Weng *et al.* 2010; Meng 2007; Li *et al.* 1993; Sun *et al.* 2008; Weng *et al.* 2009). Agricultural residues material cycle is illustrated in Fig. 5.

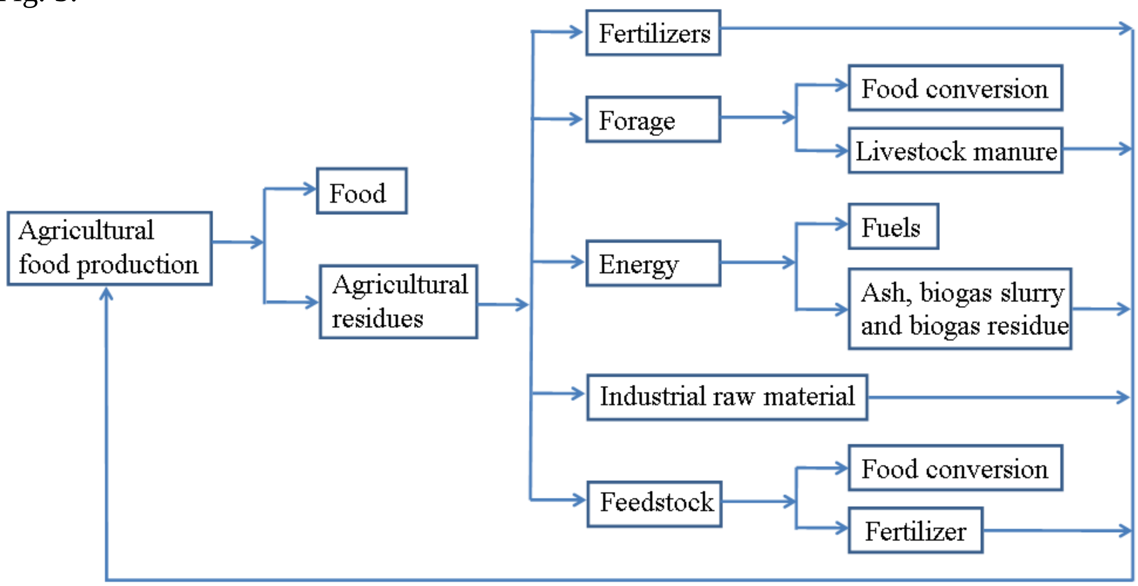

Fig. 5. Agricultural residue material cycle

A PROPOSAL FOR AGRICULTURAL RESIDUE UTILIZATION

Henan is a major producer of food and livestock in China (Zhang 2009b; Zhou *et al.* 2011). The foci of agricultural residue utilization are to enhance soil fertility, supply forage, and ensure the security of the food supply and the sustainable development of livestock production. Henan should make good use of wheat straw and corn stalks based on the shares of different agricultural residue sources, and different sources should be used in different fertilizers, forage, energy, industrial materials, and feedstock for edible fungi.

Targets for Forage Utilization

As a major livestock producing province, it is very important for Henan to make efficient use of its agricultural residues for forage to support the development of the livestock industry. By 2016, the amount of agricultural residues used for forage is expected to be more than 30% of total residue utilization (HPDRC 2011a). Given the double- and multiple-cropping systems used in Henan, techniques for straw rubbing, ammoniation, and ensilage should be promoted. Sources for forage should be expanded by introducing, researching, and demonstrating relevant forage techniques, such as straw briquetting and pellet forage. In the near future, a number of forage-production demonstration projects will be built from agricultural residues (Table 4) (HPDRC 2011a). The production of forage from agricultural residues is expected to reach 4 Mt by 2016.

Table 4. Key Future Demonstration Projects for Forage using Agricultural Residue in Henan Province

Demonstration Projects	Construction Contents	Project Output
Residue ammoniation and silage by 2016	Twenty ammoniation and 40 silage projects, with an annual output of 0.1 Mt each, will be built.	Projects will be established in high-quality beef and lamb production zones, including Shangqiu, Zhoukou, Nanyang, Zhumadian, Zhengzhou, Xinxiang, and Luoyang, and a green diary production zone will be established near the Yellow River.
Residue processing for forage	Twenty briquetting and 20 pellet projects, with an annual output of 0.1 Mt, will be built.	By 2016, projects will be established in high-quality beef and lamb production zones, including Shangqiu, Zhoukou, Nanyang, Zhumadian, and Pingdingshan.

Targets for Fertilizer Utilization

Using agricultural residues as fertilizers is the most economic and practical technique. By 2016, the amount of agricultural residue used for fertilizers will account for 37% of total residue utilization. The amount of pile fermentation returned to the field and livestock consumption in the field will account for more than 40% of the total residue used for fertilizer. In the future, techniques for straw chopping and mulching in the field will be steadily developed, techniques for pile fermentation and returning to the field and for livestock consumption in the field will be developed, and a straw-pile fermentation technique will be explored (Table 5) (HPDRC 2011a).

Table 5. Key Future Demonstration Projects for Fertilizers using Agricultural Residues in Henan Province

Demonstration projects	Construction contents	Projects output
Straw chopping and mulching in the field	Ten, ten, and three projects for wheat straw, corn stalk, and rice straw,	The demonstration area will reach 0.33 Mha by 2016, in the surrounding areas of major cities, airport, railways, and highways and areas with abundant straw resources.
Straw quick composting in the field	Ten, six, three, and three projects for wheat straw, corn stalk, rice straw, and vegetable residues.	The demonstration area will reach 0.03 Mha by 2016 and will be located in Zhengzhou, Kaifeng, Nanyang, Pingdingshan, Xinxiang, and Puyang.
Straw pile fermentation returned to the field	Ten projects for straw-pile fermentation returned to the field.	By 2016, the demonstration area will be more than 0.03 Mha and will be located in the suburbs of Kaifeng, Zhoukou, and Shangqiu.

Targets for Energy Utilization

Using agricultural residue for energy is a good approach to improve the rural energy structure (Zeng *et al.* 2007). By 2016, the amount of agricultural residue used for energy will account for about 15% of total residue utilization. In the future, techniques for gasification, biogas digestion, ethanol fermentation, solid biofuel, and carbonization will be developed and commercialized. Combined ethanol and power generation projects will be developed in places with the proper conditions (Table 6) (HPDRC 2011a).

Table 6. Key Future Demonstration Projects for Energy using Agricultural Residues in Henan

Demonstration projects	Construction contents	Projects output
Power generation	Fifteen to 20 residue-fired power plants will be built.	By 2016, the installed capacity of residue-fired power plants will increase 500 MW and reach 800 MW. These will be built in places where there are abundant residue resources while also ensuring enough residues for forage and fertilizers.
Biogas	A total of 190,000 household biogas projects and 2,000 village large- and medium-scale biogas plants will be built	By 2016, large- and medium-scale biogas plants will be established in city suburbs and in economically developed villages and towns.
Solid biofuel	Four solid biofuel plants with annual output of 0.1 Mt each will be built.	By 2016, projects will be distributed first in western Henan.
Ethanol	A demonstration plant with an annual ethanol output of 0.7 Mt will be built.	By 2016, a plant will be operating in Nanyang based on technology from the Tianguan group.

Targets for Industrial Raw Material Utilization

Agricultural residues as industrial material can be used for various types of production (Zhou *et al.* 2007). By 2016, the amount of agricultural residues used for industrial material will account for about 15% of total residue utilization. In the future, techniques for papermaking, building decorations, and texture materials will be developed according to local conditions (Table 7) (HPDRC 2011a).

Table 7. Key Future Demonstration Projects for Industrial Material using Agricultural Residues in Henan Province

Demonstration projects	Construction contents	Projects distribution
Fire-proof boards	Ten fire-proof board plants with an annual output of 0.1 million m3 each will be built.	By 2016, projects will be established in major producing areas for wheat straw, rice straw, and cotton stalk.

Targets for Edible Fungi Feedstock Utilization

Edible fungi cultivation is the main technique for using agricultural residue as feedstock. Henan has a long history of cultivating edible fungi and is currently the top province in terms of edible fungi production in China. At present, the use of agricultural residue for feedstock utilization is usually a supplement for other utilization methods, particularly in hilly areas where mechanised agriculture is difficult. In the future, this method will focus on cultivating high yield, high quality strains of edible fungi using different types of residue.

CONCLUSIONS

1. A variety of agricultural residues are produced in large quantities in Henan, China, and there are promising opportunities for further exploitation. The amount of agricultural residue produced in Henan was 84.4 million tonnes in 2009. Wheat straw and corn stalks are the main types of residues, accounting for 44.84% and 28.33% of the total, respectively.
2. Agricultural residues are mainly used for fertilizers, forage, energy, and industrial raw material (Table 3). Wheat straw and corn stalks are mainly used for fertilizer and forage, rice straw for forage and industrial material, cotton stalks for energy, peanut shells and leaves and tubers for forage, bean stems and leaves for forage and fuel, and vegetable residues for fertilizer and forage. Peanut shells and leaves, tubers, wheat straw, and corn stalks are among the highest in terms of utilization levels (>70%). The aggregated comprehensive utilization levels in Hebi and Puyang are the highest (>90%).
3. There is a huge amount of agricultural residue that has not been rationally and effectively used. Therefore, it is an inevitable trend for Henan to continue to improve its agricultural residue utilization. With the development of agricultural residue utilization techniques and demonstration projects (Tables 4 to 7), the sustainability of the province will be promoted. Taking these steps will definitely reduce waste and burning of agricultural residues and the associated environmental impacts.

ACKNOWLEDGMENTS

The authors are grateful for the Hi-tech Research and Development Program of China (2012AA051802), the Innovation Fund for Small Technology-based Firms of China (10C26214102171) and the National Science and Technology Support Program (2012BAD30B03) for their support.

REFERENCES CITED

Allica, J. H., Mitre, A. J., and González Bustamante, J. A. (2001). "Straw quality for its combustion in a straw-fired power plant," *Biomass Bioenergy* 21, 249-258.

Bao, X. M. (2002). "Resource characteristic of organic fertilisers and nutrients recycling in China," *Ph.D. Diss, China Agricultural University.*

Bao, X. M., Zhang, F. S., and Ma, W. Q. (2003). "The resources of crop straw and their recycling nutrients in China," *J. Agric. Sci. Technol. (Nongye Kexue Jishu)* 5, 14-17.

Bi, Y. Y., Gao, C. Y., and Wang, Y. J. (2009). "Estimation of straw resources in China," *Trans. Chin. Soc. Agric. Eng. (Nongye Gongcheng Xuebao)* 25(12), 211-217.

Bi, Y. Y., Wang, Y. J., and Gao, C. Y. (2010). "System constitution and general trend of straw resource comprehensive utilization in China," *Chin. J. Agric. Resour. Regional Planning (Zhongguo Nongye Ziyuan Yu Quhua)*31(4), 35-38.

Bian, Y. B. (2006). "Effect of straw resource status on the development of edible fungi industry in China," *Edible Fungi China (Zhongguo Shiyongjun)* 25, 5-7.

Chang, C., Cen, P. L., and Ma, X. J. (2007). "Levulinic acid production from wheat straw," *Bioresour. Technol.* 98, 1448-1453.

Cui, M., Zhao, L. X., and Tian, Y. S. (2008). "Analysis and evaluation on energy utilization of main crop straw resources in China," *Trans. Chin. Soc. Agric. Eng. (Nongye Gongcheng Xuebao)* 24(12), 291-296.

Gomez-Barea, A., and Leckner, B. (2010). "Modeling of biomass gasification in fluidized bed," *Prog. Energy Combust. Sci.* 36, 444-509.

Han, L. J., Yan, Q. J., and Liu, X. Y. (2002). "Straw resources and their utilization in China," *Trans. Chin. Soc. Agric. Eng. (Nongye Gongcheng Xuebao)* 18(3), 87-91.

NBSC. (2010). *Statistics Yearbook of China in 2010*, Beijing, China, China Statistics Press.

NBSC. (2012).*Statistics Yearbook of China.(*http://www.stats.gov.cn/tjsj/ndsj/).

HPBS. (SSBHIU). (2010). *Henan Statistics Yearbook in 2010*, Beijing, China, China Statistics Press.

HPDRC. (2011a) . *Comprehensive Utilization for Agricultural Residues in Henan Province*, Zhengzhou, China, Henan Province Development and Reform Commission.

HPDRC. (2011b) .*Development Plan for Biomass in Henan Province*, Zhengzhou, China, Henan Province Development and Reform Commission.

HPGO. (2010a). *Statistical Communique of the People's Republic of China on National Grain Yield in 2008*, (http//www.stats.gov.cn/tjdt/zygg/gjtjjgg/t20101203_402687721.htm).

HPGO. (2010b). "Henan makes a new record on food production with exceeding 50 million tonnes for five consecutive years," (http://www.china.com.cn/city/2010-12/08/content_21502731.htm).

HPGO. (2010c). "Henan People's Government Office calls for implementation advice about construction planning of Henan core grain-producing area of national grain strategy engineering," (http//www.henan.gov.cn/zwgk/system/2010/10/12/010215492.shtml).

Hu, J. J., Lei, T. Z., and Xu, G. Y. (2009). "Experimental study of stress relaxation in the process of cold molding with straw," *BioResources* 4(3), 1158-1167.

Huang, H. X., Li, S. T., and Li, X. L.(2006). "Analysis on the status of organic fertiliser and its development strategies in China," *Soil Fertiliser (Turang Feiliao)* (1), 3-8.

Li, Qi., Zang, L. J., and Wu, C. Q. (2009). "Satellite-remote-sensing-based monitoring of straw burning and analysis of its impact on air quality," *Journal of Ecology and Rural Environment (Shengtai yu nongcun huanjing xuebao)* 25(1), 32-37.

Li, W. M., He, S. Q., and Xu, Q. M. (1993). "Report of test of flocculated fermentation residue and fermentation effluent of pig farm on cucumber," *Acta Energiae Solar Sinica (Taiyangneng xuebao)*14(4), 295-299.
Li, W., Lin, S. S., and Tan, Y. Z. (2000). "Innovated techniques on comprehensive utilization of crop straw," *Trans. Chin. Soc. Agric. Eng.(Nongye Gongcheng Xuebao)* 16(1), 291-296.
Li, Z. M., Liu, Y., and Liao, W. (2011). "Bioethanol production using genetically modified and mutant wheat and barley straws,"*Biomass Bioenergy* 35, 542-548.
Lv, W. L. (2010). "The Effects of silage additives on the ensiling fermentation of green corn stalk silage," *Ph.D. Diss, Chinese Academy of Agricultural Sciences.*
Meng, L. J. (2007). "The project study on the applying of agricultural wastes*," Ph.D. Diss, Tianjin University*.
NATESC. (1999). "Organic fertilisers resources in China," Beijing, China, China Agriculture Press.
Nilsson, D., Bernesson, S., and Hansson, P. A. (2011). "Pellet production from agricultural raw materials - A systems study," *Biomass Bioenergy* 35, 679-689.
Pan, M. Z. (2008). "Preparation and properties of wheat straw fibre/polypropylene composites," *Ph.D. Diss, Nanjing Forestry University*.
Rodriguez, A., Moral, A., and Serrano, L. (2008). "Rice straw pulp obtained by using various methods," *Bioresour. Technol.* 99, 2881-2886.
Sánchez, C. (2009). "Lignocellulosic residues. Biodegradation and bioconversion by fungi," *Biotechnol. Adv.* 27, 185-194.
Schmidt, A. S., and Thomsen, A. B. (1998). "Optimization of wet oxidation pretreatment of wheat straw," *Bioresour. Technol.* 64, 139-151.
Sun, J. H., Yuan, L., and Zhang, Y. (2008). "Research on compost manufacture by use of edible fungus dregs," *Soil Fertiliser Sci. Chin.(Zhongguo Turang yu Feiliao)* (1), 52-55.
Tan, T. W., Shang, F., and Zhang, X. (2010). "Current development of biorefinery in China," *Biotechnol. Adv.* 28, 543-555.
Tan, Z.Y., and Liu, X.R. (2011). "Burning straw creates heavy fog," (http://hj.ce.cn/news/2011-10-27/4008_2.html)
Wan, C. X., and Li, Y. B. (2011). "Effectiveness of microbial pretreatment by *Ceriporiopsis subvermispora* on different biomass feedstocks," *Bioresour. Technol.* 102, 7507-7512.
Wang, Y. J., Bi, Y. Y., and Gao, C. Y. (2010). "Collectable amounts and suitability evaluation of straw resource in China," *Sci. Agric. Sinica (Zhongguo Nongye Kexue)* 43(9), 1852-1859.
Weng, B. Q., Lei, J. G., and Wang, Y. X. (2010). "Strategy of the low-carbon agricultural development based on the circulating utilization model of straw-edible fungi industry," *J. Fujian Agric. For. Univ. (Fujian Nonglin Daxue Xuebao)* 13, 1-6.
Weng, B. Q., Liao, J. H., and Luo, T.(2009). "Integrative technology of straw-edible fungi industry and management countermeasure for resource recycling utilization," *Chin. J. Eco-Agric. (Zhongguo Shengtai Xuebao)*17(5), 1007-1011.

Wu, Y. P., Zhang, L. W., and Cui, G. Q. (2010). "Investigation and thoughts on the comprehensive utilization of crop stalk resources in Henan Province," *J. Agric. Univ. Henan (Henan Nongye Daxue Xuebao)* 44(3), 352-359.
Xi, X. J., Han, L. J., and Hara, S. I. (2003). "Effects of lactobacillus and cellulase on the quality of corn stover silage," *J. China Agric. Univ. (Zhongguo Nongye Daxue Xuebao)* 17(2), 21-24.
Yan, X. Y., and Crookes, R. J. (2010). "Energy demand and emissions from road transportation vehicles in China," *Prog. Energy Combust. Sci.* 36, 651-676.
Zeng, X. Y., Ma, Y. T., and Ma, L. R. (2007). "Utilization of straw in biomass energy in China," *Renew. Sustain Energy Rev.* 11, 976-987.
Zhang, Y. (2009a). "The analysis contrastively on "5F" utilization of straw resource in China," *Chin. Agric. Sci. Bull. (Zhong guo Nongxue Tongbao)* 25(23), 45-51.
Zhang, Z. J. (2009b). "A study on the modern agricultural construction in big agricultural provinces-taking Henan province as an example," *Econ. Surv. (Jingji Guancha)* (4), 14-117.
Zhou, D. G., and Mei, C. T. (2004). "Development of agricultural straw material industry in the 21st century," *J. Nanjing For. Univ. (Nanjing Linye Daxue Xuebao)* 24, 1-4.
Zhou, D. G., and Zhang, Y. (2007). "The development of straw–based composites industry in China," *China Wood Ind. (Mucai Gongye)* 21, 5-8.
Zhou, K., Zhang, W. J., and Lei, Z. Y. (2011). "Advantage, several key issues and policy support in developing a livestock husbandry province from large to strong in Henan province," *Res. Agric. Mod. (Xiandai Nongye Yanjiu)* (1), 23-27.
Zhu, J. L., He, X. F., and Wang, Z. W. (2010). "Experimental study on pyrolysising and producing charcoal with corn straw pellet," *Acta Energiae Solar Sinica (Taiyangneng Xuebao)* 31(7), 789-793.

Article submitted: May 7, 2012; Peer review completed: June 10, 2012; Revised version received and accepted: June 29, 2012; Published: July 5, 2012.