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UTILIZATION OF CROP STRAW RESOURCES IN ANHUI PROVINCE, EASTERN CHINA

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Abstract

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Returning straw to fields is one of the most effective ways of maintaining and improving soil fertility. However, straw burning is a recurring phenomenon in China. To better understand the current situation facing the utilization of straw resources in Anhui Province, a total of 731 typical fields and farmers were surveyed on a provincial scale in 2011 along a national highway, provincial highway and county road. Moreover, a total of 344 fields and farmers were surveyed on a county scale in three typical counties, i.e., Mengcheng County, Dingyuan County and Xuanzhou District. The average rates of straw returning were generally low in Anhui Province, with 30.2% for single-middle-season rice, 16.1% for early rice, 14.3% for wheat, 2.9% for rape, 1.8% for late rice and 1.8% for maize, respectively. The average return rate of wheat in the three typical counties was 13.2%, lower than the rates of the entire province; however, the return rates of other crops in the counties were all higher than those of the entire province. However, straw burning was still prevalent. The average rates of burning wheat, rape and maize straw reached 65.5%, 75.8% and 57.3% on the provincial scale, respectively, and 86.0%, 64.0% and 51.3% in the three typical counties, respectively. Only a small fraction of straw was utilized in traditional ways, adhering to the following order: household fuel>fodder>industrial raw material. Therefore, it is crucial to strengthen policy regarding the prohibition of straw burning and to enhance straw returning and the comprehensive utilization of straw resources.

Key words: Anhui; stubble; straw burning; straw returning; straw resource utilization

Introduction

The residues remaining after wheat, rice, maize, yam, rape, cotton, sugarcane and other crops are harvested are generally called crop straws. Nitrogen, phosphorus, potassium, magnesium, calcium and other major nutrient elements and organic matter in crop straws can improve soil fertility and are necessary for crop growth (Wang et al., 2005). Straws are multipurpose and precious renewable biomass resources (Zhou et al., 2011). Returning straw to fields can increase the amount of soil organic matter and the carbon sequestration potential of farmland soil, which cannot only increase grain yield but also promote the sustainable utilization of cultivated land (Hendrix et al., 1998).

From 1995 to 2005, approximately 630 million tons of crop straws was produced in China per year, with 50% coming from eastern and south-central China (Liu et al., 2008). Anhui Province, a typical agricultural province, is located in eastern China. The arable area in Anhui was 4.184×10^6 ha at the end of 2011, covering 30% of the total land area. The sown area of grain crops was 6.621×10^6 ha, and the total grain output reached 31.355×10^6 tons (Statistics Bureau of Anhui Province, 2012). The province features rich straw resources, dominated by rice, wheat, maize, rape, cotton, beans, melon and yam (Ruan et al., 2002). Anhui Province can be divided into several districts according to topography: 1) a plain on the northern bank of the Huai River and an area along the Huai River in northern Anhui, which is

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mainly used for wheat-maize rotation; 2) a hilly terrain between the Yangtze and Huai Rivers in central Anhui, which is mainly used for wheat-rice rotation; 3) mountainous areas in western Anhui; 4) a plain along the Yangtze River; and 5) a low mountainous and hilly region in southern Anhui, which is mainly used for early rice/rape – late rice rotation. Thus, rice and rape straws are mainly distributed in the hilly terrain between the Yangtze and Huai Rivers and the plain along the Yangtze River, whereas wheat and maize straws are mainly distributed over the plain on the northern bank of the Huai River (Xu and Wu, 2009). Along with the accelerating progress of agricultural modernization, rural labor transfer, structural changes in energy consumption and outdated comprehensive utilization techniques have caused straws to become relatively overproduced and burnt out in the open (Zárate et al., 2000) or discarded. Survey data collected in 2008 regarding agricultural pollutant sources in Anhui Province indicate that of the 40 million tons of straw resources, approximately 50% was returned to fields, 40% was burned at random, 29% was used for fuel, 10% was used for fodder, compost or industrial raw materials and approximately 45% was not used effectively (Tao and Wei, 2010). In recent years, governments at all levels have frequently issued many mandates to prohibit straw burning at random, advocating straw returning and comprehensive utilization (Standing Committee of the National People's Congress, 2005). Straw burning and discarding at random may be controlled to some extent in some areas. However, the rate at which straw decomposes is slower, which affects the planting and management of the next crop. Due to the unsatisfactory feasibility and operability of the current techniques and supporting policies for the comprehensive utilization of straws, straw burning at random is still prevalent in some regions.

However, in China, information provided in reports regarding straw utilization currently entails only rough estimates. Thus, to more accurately evaluate the utilization of straw resources in eastern China, in 2011, we selected Anhui Province as a representative of the agricultural regions of eastern China and surveyed the current utilization of main crop straw resources in the area.

Materials and Methods

Method of field survey

Information regarding straw utilization was obtained on two scales, a provincial scale and a county scale. In the first case, data regarding crop stubble height, straw burning, straw returning and the comprehensive utilization of straw throughout Anhui Province were obtained along a national highway, provincial highway and county road by conducting an on-site survey and consulting with local farmers; a total of 731 farmers and their farmlands were investigated. In the second case, three typical regions, Mengcheng County in the plain on the northern bank of the Huai River in northern Anhui, Dingyuan County in the hilly terrain between the Yangtze and Huai Rivers in central Anhui and Xuanzhou District in the low mountainous and hilly region in southern Anhui, were chosen for a more detailed survey on straw utilization, and a total of 344 farmers and their farmlands were investigated. The spatial distribution of the investigated fields in the province and three typical counties is shown in Figure 1.

Time of the investigation

Wheat straw throughout the entire province and rape straw in the plain along the Yangtze River, in the hilly terrain between the Yangtze and Huai Rivers in central Anhui and in the low mountainous and hilly region in southern Anhui were investigated in early June 2011. Early rice straw in these areas was investigated in late July. Single-middle-season rice straw throughout the entire province and maize and soybean straw in the plain on the northern bank of the Huai River in northern Anhui were investigated in late September. The late rice straw in the plain along the Yangtze River, in the hilly terrain between the Yangtze and Huai Rivers in central Anhui and in the low mountainous and hilly region in southern Anhui were investigated in late October 2011.

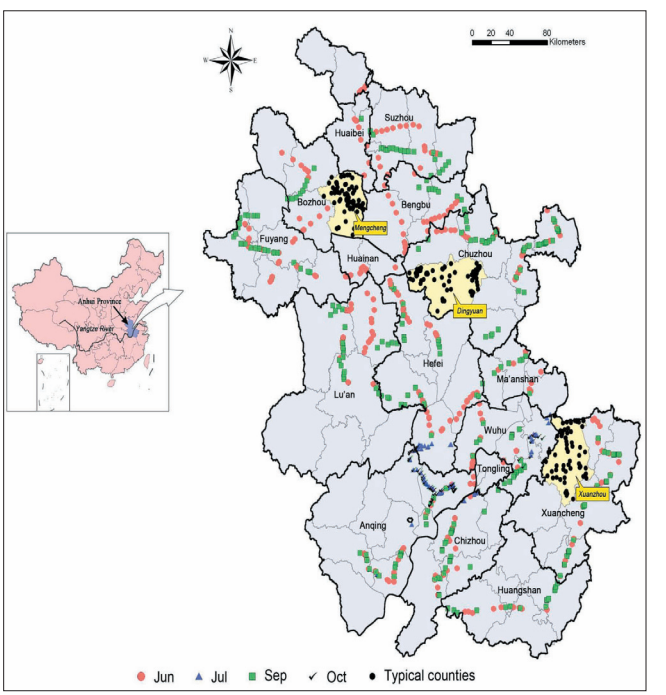

Fig. 1. Spatial distribution of the investigated fields

Method of the investigation

Straw refers to what remains, except for roots and stubble, after crops are harvested. The utilization of straws is classified into the following activities: 1) straw burning, 2) straw returning and 3) the removal of straw outside of a field for other uses, for example, as fuel or fodder. Straw returning refers to the act of returning straw directly to the original field, including straw mulching and turning over. Straw and stubble burning in fields are excluded from straw returning and are classified as straw burning. The stubble height is the average height of 10-15 stubbles chosen at random in a field; it is measured on site with a ruler. In this study, straw burning, returning and other uses were investigated by conducting an on-site survey in the fields of Anhui Province and consulting with local farmers.

Statistical analysis

The data obtained were analyzed using Office Excel 2007 (Microsoft, USA, 2006) for Windows XP. Figures were drawn using ArcGIS 9.3 Desktop (ESRI, USA, 2008). The proportions of straw burning, straw returning and other uses of various crops in different regions were calculated from the weighted averages of all sampling fields or farmers in the region.

Results

Stubble height

The average stubble heights of maize and soybean were 7.8 cm and 11.3 cm, respectively, on the provincial scale (Tables 1 and 2), whereas the average stubble heights of maize and soybean were 12.6 cm and 4.8 cm, respectively, in the three typical regions, all of which were within the quality standard (15 cm) for agricultural machinery. The average stubble heights of wheat, single-middle-season rice and rape were 20.2 cm, 23.1 cm and 20.1 cm, respectively, on the provincial scale, higher than the quality standard for agricultural machinery. It should be noted that the stubble height may be related to the quality of mechanized processing. The harvesting of wheat and

Table 1
Average crop stubble height and crop harvest method on the provincial scale

Crops	Household	Average stubble height of harvesting by hand, cm	Average stubble height of harvesting by machine, cm	Average stubble height of harvesting, cm	Proportion of harvesting by hand, %	Proportion of harvesting by machine, %
Wheat	244	19	21.4	20.2	4.8	95.2
Rape	75	21.8	18.3	20.1	78.7	21.3
Early rice	90	18	18.4	18.2	54.7	45.3
Single-middle-season rice	197	19.6	26.6	23.1	21.9	78.1
Late rice	51	18.3	18.7	18.5	47.6	52.4
Maize	55	7.2	8.5	7.8	95.1	4.9
Soybean	19	10.5	12.2	11.3	14.7	85.3

Table 2
Average crop stubble height and crop harvest method on the county scale

Crops	Household	Average stubble height of harvesting by hand, cm	Average stubble height of harvesting by machine, cm	Average stubble height of harvesting, cm	Proportion of harvesting by hand, %	Proportion of harvesting by machine, %
Wheat	167	24.6	21.3	23	6	94
Rape	14	15.2	19.2	17.2	85.7	14.3
Early rice	28	19.2	21.9	20.5	35.7	64.3
Single-middle-season rice	21	—	16.4	16.4	0	100
Late rice	42	22.2	22.4	22.3	38.1	61.9
Maize	48	15.5	9.7	12.6	4.2	95.8
Soybean	24	—	4.8	4.8	0	100

single-middle-season rice by machine was rapidly performed and extended, and the proportions of crop harvested by machine were 95.2% and 78.1%, respectively, on the provincial scale. The proportion of rape harvested by machine was 21.3%, whose mechanized operation was in its initial stages in Anhui Province. However, the harvesting of single-middle-season rice and soybean by machine was performed and extended over the three typical regions. The proportion of maize harvested by machine on the provincial scale was only 4.9%, whereas the proportion in the three typical regions reached approximately 95.8%, which indicates great spatial heterogeneity in the stubble height in Anhui Province. Increased stubble height reduces the costs of fuel-oil consumption and protects harvesting machines. However, increased stubble height not only reduces the collection of straw resources but also likely affects the sowing of the next crop. Thus, it was determined that much of the stubble was burned alone on site or burned together with the straw in the field.

Straw burning

From the survey conducted on the provincial scale (Table 3), four major types of crop straw were determined to have been burned: wheat, rape, maize and rice. The straw burning proportions of wheat, rape and maize reached 65.5%, 75.8% and 57.3%, respectively, whereas the straw burning proportions of early rice, single-middle-season rice and late rice were only 28.9%, 38.2% and 41.4%, respectively. There were higher proportions of wheat straw burning (86.0%) than maize (51.3%) and rape straw burning (64.0%) in the three typical regions. Moreover, the straw burning proportions of early rice, single-middle-season rice and late rice were lower, only 13.9%, 3.8% and 13.5%, respectively (Table 4).

Table 3
Statistics on crop straw burning, returning, and removal on the provincial scale

Crops	Household	Proportion of straw burning, %	Proportion of straw returning, %	Situation of mechanical crushing to straw		Proportion of straw removal, %
				Proportion of mechanical crushing, %	Proportion of not mechanical crushing, %	
Wheat	244	65.5	14.3	76.3	23.7	20.2
Rape	75	75.8	2.9	25	75	21.3
Early rice	90	28.9	16.1	93.3	6.7	55
Single-middle-season rice	197	38.2	30.2	65.3	34.7	31.6
Late rice	51	41.4	1.8	0	100	56.8
Maize	55	57.3	1.8	66.7	33.3	40.9
Soybean	19	16.8	3.7	100	0	79.5

Table 4
Statistics on crop straw burning, returning, and removal on the county scale

Crops	Household	Proportion of straw burning, %	Proportion of straw returning, %	Situation of mechanical crushing to straw		Proportion of straw removal, %
				Proportion of mechanical crushing, %	Proportion of not mechanical crushing, %	
Wheat	167	86	13.2	100	0	0.8
Rape	14	64	27.1	100	0	8.9
Early rice	28	13.9	86.1	100	0	0
Single-middle-season rice	21	3.8	96.2	100	0	0
Late rice	42	13.5	86.5	100	0	0
Maize	48	51.3	48.3	91.7	8.3	0.4
Soybean	24	71.7	25	100	0	3.3

The period spanning from the end of May to the middle of June is the wheat harvesting and rice planting season in the province. There are only a few days for tilling and sowing or transplanting the next crop; in addition, the straw of the summer harvest crop, such as wheat or rape, is comparatively dry and can be easily burned during the summer harvest period, which results in a higher proportion of straw burning. However, there is plenty of time for tilling and sowing or transplanting the next crop from the middle of September to late October, and the straw of the autumn harvest crop, such as rice, usually has a high water content and is difficult to burn during the fall harvest period. We believe that these factors are the main reasons for the difference in the proportions of straw burning or returning between the two types of crops.

There may be several reasons why straw burning is performed: First, with the rapid development of rural economies and improved living conditions, farmers now use electricity or gas for cooking and seldom raise livestock such as pigs and cattle. Thus, the phenomenon of using straw as fuel or fodder has clearly decreased in extent; moreover, farmers also believe that the collection and transportation of straw resources are too costly. It is also generally believed that returning straw directly to fields may cause serious plant diseases and insect pests to arise in the next crop (Chen et al., 2005) and reduce the nitrogen uptake and yield of the next crop (Sidhu and Beri, 1989). Finally, straw burning can, to a certain extent, release nutrients (e.g., potassium) to the next crop cycle after harvest. Therefore, a large quantity of straw is still burned *in situ* in the survey area (Picture 1), which not only wastes useful resources but also causes serious air pollution, although governments at all levels have frequently issued many mandates to prohibit straw burning at random and advocate straw returning and comprehensive utilization.

Picture 1. Open field burning of wheat straw in a wheat field near Dadian Village (32°22′36″N, 116°29′30″E), Yinghe Town, Shou County, Lu'an City, China (picture was taken on 7th June 2011)

Straw returning

The proportions of crop straw returning on the provincial scale were low (Table 3). The proportion of single-middle-season rice straw returning reached 30.2%, which was higher than the proportions of other crops. The proportions of soybean, rape and maize straw returning were relatively lower, only 3.7%, 2.9% and 1.8%, respectively. In the three typical regions, 80-90% of the rice straw was returned, whereas the proportions of soybean, rape and maize straw returning were 25.0%, 27.1% and 48.3%, respectively (Table 4). The proportions of straw returning in various regions were different (Table 5 and Figure 2); there was only one city (Hefei) whose proportion of straw returning was higher than 30% among 16 cities. The proportion of straw returning in different regions is related to the level of economic development and local lifestyle. Hefei, as the provincial capital of Anhui Province, is the most developed city in the province. Its GDP in 2011 was 363.7×10^9 *yuan* RMB (Table 6), the highest among the cities considered, and its proportion of straws used for fuel and fodder was the lowest, which is due to the great effort of the Hefei government to prohibit straw burning and to the farmers' increased awareness of environmental protection. In the typical regions, the net income per capita in Xuanzhou District reached 8938.1 *yuan* RMB, higher than the incomes of the other two regions. The proportion of straw returning in Xuanzhou District was also higher than the proportions in the other regions. This investigation showed that the dominant method of straw returning was direct returning to fields after the straws were broken into pieces by a straw pulverizer or combine harvester in fields, and some farmers directly mulched straws on the soil surface without cutting them to save money, which amounted to approximately 300 *yuan* RMB /ha in savings.

Other utilization

According to the statistics regarding crop straw resource utilization throughout the province, only approximately one-third of crop straw was used as fuel, fodder, industrial raw material, etc. The modes of utilization of various crop straws are different. The rates of utilization of wheat straw for fuel, fodder and industrial raw material were 4.7%, 0.8% and 1.2%, respectively, and the rates of utilization of rape straw were 10.9% for fuel and 0.4% for fodder. The proportions of straw used as fuel for early rice, single-middle-season rice and late rice reached 39.4%, 12.8% and 36.0%, respectively.

Table 5
Statistics on crop straw returning and straw resource utilization in each region in the whole province and in three typical counties

Region	Household	Proportion of straw returning, %	Proportion of straw removal, %	Proportion of straw as fuel, %	Proportion of straw as fodder, %	Proportion of straw as industrial raw material, %	Proportion of straw as other uses, %	Proportion of straw discarded, %
Anqing	132	3.3	66.6	50.6	7.3	0.7	4.3	3.7
Bengbu	32	4.1	30.3	8.3	0.9	3.1	0	18
Bozhou	15	16	42	40	0	1.3	0	0.7
Chizhou	55	22.7	20.9	0	1.8	0	0	19.1
Chuzhou	75	18.7	7.7	5.1	0	0	0	2.6
Fuyang	58	9.1	52.6	23.8	0.9	0.5	0	27.4
Hefei	81	36.3	28.4	17.9	5.2	0	1.5	3.8
Huaibei	8	0	15	12.5	0	2.5	0	0
Huainan	17	23.5	11.8	0	0	0	0	11.8
Huangshan	29	13.8	34.5	0	0	0	0	34.5
Lu'an	54	26.5	34.3	9.4	3.5	4.8	0	16.6
Ma'anshan	17	10.6	41.8	26.5	15.3	0	0	0
Suzhou	48	5.8	29.7	18	0.6	0.5	0	10.6
Tongling	6	8.3	0	0	0	0	0	0
Wuhu	59	20	9.2	1.7	0	0	0	7.5
Xuancheng	45	11.6	23.1	0	0.7	0	0	22.4
Dingyuan	114	33.9	0	0	0	0	0	0
Mengcheng	117	16.8	1.8	0.3	1.5	0	0	0
Xuanzhou	66	68.5	1.3	1.3	0	0	0	0

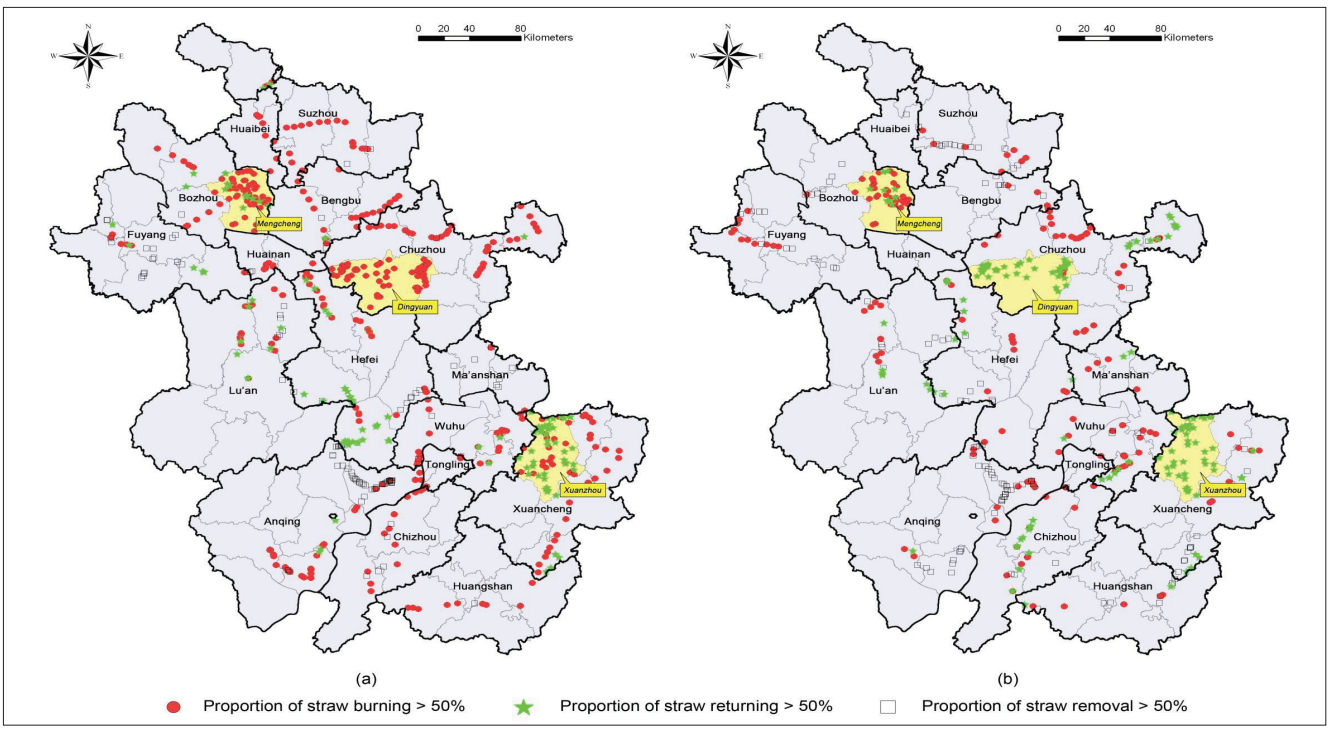

Fig. 2. Overview of straw burning, returning and removal of summer harvesting crop (a) and autumn harvesting crop (b) in the survey

The rate of utilization of rice straw used as fodder was higher than the rates of other crops. The proportions of straw used as fodder for early rice, single-middle-season rice and late rice were 5.6%, 3.8%, and 9.6%, respectively. Rice straw was seldom used as an industrial raw material. The rates of utilization of maize straw for fuel, fodder and industrial raw material were 27.1%, 2.0% and 2.4%, respectively. The rates of utilization of soybean straw for fuel and fodder were 73.8% and 1.9%, respectively. Compared with the average proportion of the entire province, the proportions of comprehensive utilization of different kinds of straw in the three typical regions were much lower, all lower than 10% (Table 7). In sum, regarding the three main modes of utilization, fuel occupied a large proportion, mainly in underdeveloped regions

Table 6
Sown area of grain crops, GDP and per capita net income in each region in the whole province and in three typical counties [a]

Region	Total sown area, 10^3 ha	Sown area of grain crops, 10^3 ha	GDP, 10^9 *yuan* RMB	GDP per capita, *yuan* RMB	Per capita net income, *yuan* RMB
Anqing	772.8	450.7	121.6	22893	5899.6
Bengbu	650.6	478.8	78	24594	6615.3
Bozhou	1050.5	863.1	62.7	12866	5638.4
Chizhou	200	114.1	37.2	26446	6908.5
Chuzhou	866.7	700.3	85	21608	7017
Fuyang	1234.6	1017.4	85.3	11202	5100.5
Hefei	751.2	475.2	363.7	48540	7861.6
Huaibei	286.4	266.5	55.5	26225	6313.3
Huainan	249.7	212.4	71	30400	6795
Huangshan	130.5	65	37.9	27967	7952.4
Lu'an	889.2	702.3	82.1	14592	5643.5
Ma'anshan	238.1	146.1	114.4	52108	9504.8
Suzhou	991.9	794.2	80.2	14959	5720.1
Tongling	47.5	27	57.9	79644	8562.3
Wuhu	387.1	198.8	165.8	46626	8413.3
Xuancheng	357	230.2	67.1	26428	7844.4
Dingyuan	217	—	10.3	10578	6358.2
Mengcheng	257.7	—	14	10576	6159
Xuanzhou	133.4	—	—	—	8938.1

[a] Data from "Anhui Statistical Yearbook 2012". (Statistics Bureau of Anhui Province, 2012)

Table 7
Statistics on crop straw resource utilization in three typical counties

Crops	Household	Proportion of straw removal, %	Proportion of straw as fuel, %	Proportion of straw as fodder, %	Proportion of straw as industrial raw material, %	Proportion of straw as other uses, %	Proportion of straw discarded, %
Wheat	167	0.8	0.1	0.7	0	0	0
Rape	14	8.9	8.9	0	0	0	0
Early rice	28	0	0	0	0	0	0
Single-middle-season rice	21	0	0	0	0	0	0
Late rice	42	0	0	0	0	0	0
Maize	48	0.4	0.4	0	0	0	0
Soybean	24	3.3	0.7	2.6	0	0	0

with energy scarcity. On the provincial scale (Table 5), the proportion of straw used as fuel reached 50.6% in Anqing City. In Zongyang County in particular, most of the straws were used as fuel; in that county, farmers still maintain the traditional custom of burning straws and grasses, and their net income per capita is only 5219.0 *yuan* RMB. The main industrial use of straw is for papermaking, electric power generation and weaving, with an average rate of less than 5% in Anhui Province. Only a few straw-based power plants are profitable. It was observed that straw is used to cultivate edible mushrooms in Tongcheng County, Anqing City and Lujiang County, Hefei City. After fermentation, the culture medium could be returned to the field as high-quality fertilizer. In general, plenty of straw was burned or discarded and was not yet effectively utilized; only a small proportion of straw was still utilized in traditional ways, adhering to the following order of extent: household fuel>fodder> industrial raw material.

Discussions

The proportions of burning wheat, rice and maize straw ranged from 28.9% to 75.8%, which are much higher than government figures indicate. The proportions of crop straw returning were far below 20%, except for the proportion of returning single-middle-season rice (30.2%), which was lower than that indicated by government data. The general plan for the comprehensive utilization of straw in Anhui established by the Anhui Development and Reform Commission showed that straw returning accounted for approximately 25% of total straw resources and that the rates of straw utilization were 25% for fodder and 20% for fuel and industrial raw material. Burned and discarded straw accounted for approximately 25% and 5%, respectively. The reasons for this difference are as follows: Governments at some levels usually obtain data by rough and optimistic estimation. Therefore, it is highly important and necessary to conduct such a survey to more accurately evaluate the utilization of straw resources in eastern China.

There were obvious differences in the survey results between those obtained on the provincial scale and those obtained on the county scale. The most likely cause is that farmers living adjacent to the roads have rather high external incomes; thus, their enthusiasm for planting crops is lower, and they usually burn straws to save both time and labor. On the other hand, the typical counties feature extensive farmlands, and most farmers have low earnings and a high interest in farming; therefore, the proportion of straw returning is much higher. Moreover, it is relatively easy to manage straw burning. These findings also indicate that choosing farmlands close to roads may reduce the representativeness of the survey results; thus, farmlands located farther from roads should also be considered.

Many studies have demonstrated the various disadvantages of straw burning (Dormaar et al., 1979; Korenaga et al., 2001; Gullett and Touati, 2003; Torigoe et al., 2000; Andreae and Merlet, 2001). Although governments at all levels in China have frequently reproduced documents that prohibit straw burning and some techniques have been established for straw returning and comprehensive utilization (Li et al., 2009; Wang et al., 2010), a large quantity of straw is burned *in situ*. Thus, determining how to improve the actual enforcement of these documents and techniques is vital to changing the current critical situation of straw utilization. The government should guide and encourage local farmers to return straw to protect the environment and set up a straw briquetting station and vaporizing station for batch treatment. The companies and farmers who return straw to fields at harvest time by machine or treat straws comprehensively could receive subsidies from the government. Straw returning should be promoted with matching implements and biotechnology supporting rapid straw decomposition to boost crop yields and carbon sequestration in soil, to increase the comprehensive productivity of land, and to protect the environment.

Conclusions

In this study, it was discovered that crop straws of wheat, rape and maize under dry farming were mainly burned at random in the open in the following proportions 65.5%, 75.8% and 57.3%, respectively. In addition, the proportions of straw returning of early rice and single-middle-season rice were relatively high compared with those of the other crops, approximately 16.1% and 30.2%, respectively. Most late rice and soybean straws were removed from fields for other uses. Crop straws are mainly used for fuel, fodder and industrial raw materials, although the proportions of straws that are used in these ways are very limited.

Various regions showed some differences in their rates and modes of straw utilization. In the relatively developed economical regions, farmers seldom used straw as fuel or fodder, and the government placed a ban on straw burning. Relatively more straws were returned to the field or used as industrial raw materials. On the other hand, in the economically underdeveloped regions, farmers cooked and raised livestock with straws. They burned superfluous amounts of straw randomly on site because of their limited awareness of environmental protection, and they almost never utilized straws as an industrial raw material due to the poor economic conditions of the regions.

Overall, the survey conducted in this study covered a considerable sample size, even if the selection of farmlands near roads may still present some limitations. The survey should be improved to more accurately evaluate the utilization of straw resources in eastern China.

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