How to Support Environmental Protection Policy in Agriculture: A Case Study in Henan and Hebei Provinces, China

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HOW TO SUPPORT ENVIRONMENTAL PROTECTION POLICY IN AGRICULTURE: A CASE STUDY IN HENAN AND HEBEI PROVINCES, CHINA

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Abstract

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Abstract

Crop straw (agricultural residue) is one of the most important biomass resources in China. Crop straw is either burned in the field or collected for recycling. Open burning of crop straw releases particulate matter and gaseous pollutants, which play a key role in poor air quality, prompting heavy haze episodes during the harvest season. Such episodes threaten human health and interfere with social and economic activities. In contrast, recycling of crop straw reduces open burning and avoids its negative environmental impacts. In fact, improving the efficiency of straw use contributes to a circular economy, dedicated to reducing waste, while also making the best use of any 'waste' in economically viable processes that increase its value. Returning straw to agricultural fields in China is the easiest solution and the most important measure promoted by governments promising clean technologies to replace open burning. Recently, China's municipalities have issued regulations forbidding outdoor burning of straw to reduce air pollution and have passed regulations to encourage farmers to use straw shredders during harvesting, and return crop straw as a bio-fertilizer. However, these regulations have not achieved the desired results, with ongoing open burning and reluctant use of straw on fields.

In the first part of this research, urban residents' willingness of to pay (WTP) for a corn straw ban in Henan (China) was assessed using contingent valuation in a face-to-face survey. Such assessments are important for policy makers to determine the investment and policy instruments for regulating the environmental impacts of straw open burning. The expected WTP analyzed using the Tobit model was about 77 RMB per person per year for the total respondents and 143 RMB per person per year for respondents with positive WTP bids. Aggregate values were between 3.4 and 3.9 billion RMB, suggesting that the corn straw burning ban is of considerable economic value in Henan.

In the second part of this research, the factors affecting farmers' willingness to participate in corn straw return and their willingness to accept compensation (WTA) were explored using a questionnaire survey and face-to-face interviews. A logistic regression model was used to assess adoption success, and the Tobit model was used for WTA analysis. High machinery costs, amount of straw returned, and slow decomposition rates of straw were the most significant factors negatively influencing adoption of this practice. They had a positive influence on the WTA. Poor quality of the straw was another significant factor reducing the probability of using straw return technology. Sown areas and soil improvements associated with adding straw were both positive factors determining adoption of the practice and negative determinants affecting WTA compensation. The mean WTA for the total respondent sample was 47 RMB per mu.

In the third part of this research, a field experiment was carried out to compare the effects of tillage (minimum/full tillage) combined with corn straw return (mulching, incorporation, and removal) and irrigation (reduced/normal irrigation) methods on wheat productivity and water conservation. In 2013-2014, the yield for minimum tillage with residue mulch (MT_m) was slightly but not significantly higher than the yield under full tillage with residue incorporation (FT_i). Yields for MT_m with reduced irrigation were 10.2% higher than FT_i and reduced irrigation. The positive crop response to MT_m may reflect higher topsoil moisture and soil temperature under MT_m compared with FT_i during winter.

In conclusion, this study showed there is huge value to prohibiting open burning of corn straw to improve air quality. Despite machinery and operational problems that negatively influence farmers' enthusiasm for straw return, minimum tillage coupled with corn straw return does benefit subsequent wheat yields.

Keywords: corn straw, open burning, straw return, willingness to pay, wheat yield

Résumé

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Résumé

Les pailles de céréales (un résidu agricole) constituent l'une des plus importantes ressources de biomasse en Chine. Les pailles de céréales sont soit brûlées dans le champ, soit collectées pour être recyclées. La combustion à l'air libre des pailles de céréales libère des particules fines et des polluants gazeux qui jouent un rôle clé dans la mauvaise qualité de l'air, provoquant des épisodes de brume épaisse pendant la saison des récoltes. De tels épisodes menacent la santé humaine et entravent les activités sociales et économiques. En revanche, le recyclage des pailles de céréales réduit la combustion à l'air libre et évite ses impacts négatifs sur l'environnement. En fait, améliorer l'efficacité de l'utilisation de la paille contribue à une économie circulaire centrée sur la réduction des déchets, tout en utilisant au mieux tout déchet dans des processus économiquement viables afin d'en accroître la valeur. Le retour de la paille de culture sur les terres agricoles est la solution la plus simple et la mesure la plus importante préconisée par les gouvernements qui promettent des technologies propres pour remplacer la combustion à l'air libre. Récemment, les autorités municipales chinoises ont publié des règlements interdisant la combustion de paille à l'air libre afin de réduire la pollution atmosphérique et ont adopté des réglementations dans le but d'encourager les agriculteurs à utiliser des broyeurs de pailles lors de la récolte et se servir des pailles de céréales comme engrais biologiques. Cependant, ces réglementations n'ont pas donné les résultats escomptés car les paysans continuent de brûler les pailles de céréales dans les champs au lieu de les utiliser comme biofertilisant.

Dans la première partie de la présente étude, la méthode de l'évaluation contingente à l'aide d'enquêtes en face-à-face a été appliquée afin d'évaluer la volonté des résidents des villes de payer (WTP-Willingness of To Pay) pour une interdiction de la paille de maïs dans le Henan (Chine). De telles évaluations sont importantes pour les décideurs pour qu'ils puissent déterminer les investissements et les instruments politiques permettant de réguler les impacts environnementaux de la combustion des pailles de céréales à l'air libre. Le WTP attendu, analysé à l'aide du modèle Tobit, a fourni comme résultat environ 77 RMB par personne et par an pour l'ensemble des personnes interrogées, et 143 RMB par personne et par an pour les répondants aux offres positives. Les valeurs totales se situaient entre 3,4 et 3,9 milliards de RMB, ce qui suggère que l'interdiction de brûler de la paille de maïs a une valeur économique considérable dans le Henan.

Dans la deuxième partie de cette recherche, les facteurs qui ont influencé la volonté des agriculteurs de participer au retour de la paille et leur volonté d'accepter une compensation (WTA) ont été examinés à l’aide de questionnaires et d’entretiens en face-à-face. Un modèle de régression logistique a été utilisé pour évaluer le taux de réussite de l’adoption de la pratique et le modèle Tobit a été appliqué pour l'analyse WTA. Les coûts élevés des machines, la quantité de paille retournée et les faibles taux de décomposition des pailles ont été les facteurs les plus significatifs influençant négativement l’adoption de cette pratique. Ils ont eu une influence positive sur la WTA. La mauvaise qualité des pailles est un autre facteur important réduisant la probabilité d’utiliser la pratique de retour de la paille. Les superficies ensemencées et les améliorations du sol associées à l’ajout de paille ont été à la fois des facteurs positifs décisifs pour l’adoption de la pratique et des déterminants négatifs ayant une incidence sur la compensation WTA. La compensation moyenne de WTA pour l’ensemble de l’échantillon des répondants s’élevait à 47 RMB par personne.

Dans la troisième partie de l’étude, une expérience sur le terrain a été menée afin de comparer les effets du travail du sol (travail du sol minimum/ complet) associé avec le retour de la paille de maïs (paillage, incorporation et élimination) et les méthodes d’irrigation (irrigation réduite/normale) sur la productivité du blé et la conservation de l'eau. Entre 2013 et 2014, le rendement du travail minimum du sol avec résidus de culture (MT_m) était légèrement mais pas significativement supérieur au rendement du travail du sol complet avec incorporation de résidus (FT_i). Les rendements de MT_m avec irrigation réduite étaient supérieurs de 10,2% à ceux d'irrigation réduite de pleine culture avec les résidus. Par rapport à FT_i, la réponse positive des cultures au MT_m peut refléter une humidité de surface et une température de sol plus élevées.

En conclusion, cette étude a démontré qu'il était très utile d'interdire la combustion à l'air libre des pailles afin d’améliorer la qualité de l'air. Malgré les problèmes de machines et de fonctionnement qui affectent négativement sur l'enthousiasme des agriculteurs pour le retour de la paille, le travail minimum du sol associé au retour de la paille est effectivement bénéfique pour les rendements ultérieurs en blé.

Mots-clés : pailles de céréales, combustion à l'air libre, retour de la paille, volonté de payer, rendement du blé

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Xiaomei Yang
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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
CAAC	Civil aviation administration of China
CAP	Common Agriculture Policy
CO_2	Carbon dioxide
CT	Conservation tillage
CVM	Contingent valuation method
EU	European Union
FT	Full tillage
FT_i	Full tillage with residue incorporation
FT_r	Full tillage with residue removal
GAEC	Good agricultural and environmental conditions
kg/ha	Kilogram per hectare
km/h	Kilometers per hour
MOA	Ministry of Agriculture
MOF	Ministry of Finance
MOR	Ministry of Railways
MOT	Ministry of Transport
MT_m	Minimum tillage with residue mulch
MT_r	Minimum tillage with residue removal
NDRC	National Development and Reform Commission
NO_2	Nitrogen dioxide
NT	No tillage
O_3	Ozone
PC	Payment card
PJ	Picojoules
PM	Particulate matter
PM_{10}	Fine particles with an aerodynamic diameter of less than 10 μm
$PM_{2.5}$	Fine particles with an aerodynamic diameter of less than 2.5 μm
RMB	Chinese Yuan Renminbi
SEPA	State Environmental Protection Administration
t	Ton
WTA	Willingness to accept
WTP	Willingness to pay

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CHAPTER 1. INTRODUCTION

1. Context: The ban on open burning and encouragement of crop straw recycling to control air pollution

Rapid increases in volume and types of agricultural residue, because of intensive agriculture in the wake of population growth and improved living standards, are becoming a burgeoning problem. Open burning by the farmers to clear residues from farmland generates CO_2, CH_4, NO_2, SO_2 and particulate matter, as well as hydrocarbons. Hence, improper management of agricultural residue is contributing towards climate change, water and soil contamination, and local air pollution. One important issue is the extent to which air pollution affects life expectancy, and over the last few decades, the relationship between air pollution and human health has been researched worldwide. Open burning of crop straw is seen as a main source of air pollution during the harvest period. Developing countries face particularly difficult choices in balancing efforts to protect the environment with efforts to spur economic growth. A key element, generally neglected in making such decisions by government, is an estimate of the social benefits that an improved environment will bring. Furthermore, its inherent properties ensure that crop residue waste has a high value with respect to material and energy recovery. Many surveys highlight the importance of both costs and benefits to decisions, when adopting a new technology for recycling. In this context, it is important to have a better understanding of the status of open burning and recycling of crop straw in China.

1.1. Air pollution control

1.1.1. Need to control of air pollution

Deaths related to London fog in the 1950s were a landmark in air pollution mitigation, as they heralded the wake-up call to humanity that air pollution can cause public health problems and even mortality. Therefore, air pollution problems have since received considerable attention from the public, the scientific community, and governments. Pollutants and diseases caused by air pollution have been intensely studied over the past 60 years. Results of many epidemiological studies have suggested that there are five major outdoor air pollutants affecting human health: particulate matter (PM), ozone (O_3), nitrogen oxides, carbon monoxide, and sulfur dioxide (Cohen et al., 2005; Pope III and Dockery, 2006; Jerrett et al., 2009; Beelen et al., 2014; Burnett et al., 2014). The impacts of outdoor air pollution are severe and negative over the short-term and long-term. These pollutants can cause acute diseases, especially chronic respiratory diseases, such as asthma, chronic bronchitis, and decreasing lung function. The World Health Organization also reported that an estimated 3.7 million premature deaths were caused by air pollution worldwide in 2012. In many countries, air pollution accounts for roughly ten-times more deaths than road accidents (Lelieveld et al., 2015). Furthermore, great improvements in air quality following control of air pollution led to an immediate reduction in cardiovascular and respiratory deaths (Clancy et al., 2002). In Europe, the most troublesome pollutants in terms of harm to human health are PM, Nitrogen dioxide (NO_2) and ground-level O_3. Estimates of the health impacts attributable to exposure to air pollution indicate that $PM_{2.5}$ concentrations in 2013 were responsible for about 436000 premature deaths originating from long-term exposure in the European Union (EU)-28, and around 68 000 premature deaths due to exposure to NO_2 and 16000 premature deaths due to exposure to O_3 concentrations per year. Many parts of the United States and Europe have seen substantial improvements in air quality over recent decades, related to regulatory interventions. There is growing evidence that suggests that these improvements benefit public health (Pope III et al., 2009; Gauderman et al., 2015). In other regions, particularly heavily populated countries in Asia, residents continue to experience poor air quality. In addition, approximately 65% of the deaths and lost life-years occur in developing countries of Asia (World Health Organization, 2002). The emissions of several key air pollutants are expected to increase in the future. Thus, the need to control air pollution has become an urgent and worldwide environmental concern. As health risks linked to air pollution are discovered, control regulations, legislation and many programs to reduce pollutant emissions have been promoted.

1.1.2. Air pollution sources

To control air pollution and pollutant emissions, governments need to determine their sources of pollution. The atmosphere is susceptible to pollution from natural processes as well as from human activities. The seven main sources of air pollutants contributing to mortality are: residential-use of energy (for example, heating, cooking), agriculture, natural, power generation, industry, biomass burning and land traffic sources. Table 1-1 shows the contributions of these seven main sources of air pollution to the combined global mortality (3.3 million people) attributable to air pollution (PM- and O_3- related) in 2010; they accounted for about 31%, 20%, 18%, 14%, 7%, 5% and 5% of these deaths, respectively. Pollution caused by human activities can be reduced and controlled; it mostly originates from combustion processes. Beginning in the 19th century, in the wake of the industrial revolution, increasing use of fossil fuels intensified the severity and frequency of air pollution episodes. During the 1950s, the burning of coal for fuel caused recurrent air pollution problems in London and other large European cities. The advent of mobile sources of air pollution - i.e., gasoline-powered vehicles - had a tremendous impact on air quality problems in cities. Many efforts to engineer improvements in urban air quality have logically focused on reducing emissions from industry, transportation, and power generation. Hence, well-planned measures to combat air pollution have led to considerable reductions in the emissions from these three sectors over the past few decades. Instead, the emissions from residential energy and agricultural sources continue to grow and are becoming more important, as pollution from industry and transport as well as power generation is subject to tighter controls. Biomass burning (burning of crop residues, forest residues, and vegetation during land clearing) is also a significant contributor to poor air quality in many rural regions. Moreover, the areal extent of these sources is large.

Table 1-1: Top 15 ranked countries with premature mortality linked to seven main sources of air pollution in 2010 (Deaths)

Country	Deaths	Residential energy	Agriculture	Natural	Power generation	Industry	Biomass burning	Land traffic
China	1357351	435763	395390	118954	237324	106754	18414	44751
India	644993	325604	41541	74145	89130	42336	42163	30070
Pakistan	110571	34707	1977	63147	2761	2478	2108	3389
Bangladesh	91923	50382	9652	0	13697	6117	6418	5656
Nigeria	89022	12006	462	68479	258	176	7554	85
Russia	67152	4885	28628	630	14606	5193	5477	7731
USA	54905	3192	16221	1290	16929	3297	2537	11435
Indonesia	52417	31498	1070	71	2379	1814	14338	1244
Ukraine	51238	3011	26563	55	9459	4632	2326	5188
Vietnam	44097	22575	5343	0	5486	3627	5378	1686
Egypt	35322	190	941	32651	816	210	61	450
Germany	34422	2684	15675	0	4402	4452	279	6928
Turkey	31943	2812	9269	4912	6194	3414	1851	3487
Iran	26108	311	1656	21175	1101	662	230	969
Japan	25516	3046	9763	0	4458	4567	1154	2526
World	3297370	1002370	664100	596895	464748	226137	179268	163852

Source: Lelieveld et al., (2015); NB: USA, United States of America.

1.2. Open burning and recycling of crop straw

1.2.1. Open burning of crop straw

Activities involving production and consumption generate pollution and waste. Agriculture is one of the most important of our production activities. Open burning of agricultural straw in the field generally involves incomplete combustion; it is usually carried out intensively after crop harvesting, initially to purge croplands for subsequent crops, remove crop residues, eliminate weeds, kill worms, and release nutrients back into the soil. However, crop residue burning generates a significant amount of air pollution. On an average annual basis, 730 million tonnes of biomass are burned in Asia, of which 250 million tonnes reflect burning of crop residues in the field (Table 1-2).

Biomass burning contributes large quantities of gases and PM to the atmosphere (Andreae and Merlet, 2001), both of which have a significant impact on air quality, human health, and climate (Keywood et al., 2013). Both gas and particulate components contribute indirectly to increased O_3 pollution and to tropospheric radiation budgets on local, regional, and even global scales (Li et al., 2007). Moreover, most of the PM released when agricultural crop residues are burned is smaller than 10 microns in diameter (PM_{10}). These pollutants can be conveyed downwind to cities with large populations, worsening local and regional air quality, and causing human respiratory, pulmonary, eye, and heart problems (Kim et al., 2005; Lee et al., 2007). If emissions from biomass burning were to decline in the coming decades, then fine-particle pollution would also decrease (Bauer et al., 2016).

In addition to air pollution, burning of farm waste causes severe pollution of land and water environments at local, as well as regional and global scales. It is estimated that burning of paddy straw results in annual nutrient losses of up to 3.85 million tonnes of organic carbon, 59,000 t of nitrogen, 20,000 t of phosphorus and 34,000 t of potassium. This also adversely affects the nutrient composition of the soil. When crop residue is burned, existing minerals present in the soil are destroyed, which adversely hampers cultivation of subsequent crops. Straw carbon, nitrogen, and sulfur are completely burned and lost to the atmosphere in the process of biomass burning.

Table 1-2: Typical annual amounts of biomass burned in Asian (million tonnes)

Country	Grassland	Forest	Crop Residue	Total
Bangladesh	0	8.5	11	20
Bhutan	0	0.7	0	0.7
Brunei	0	0	0	0
Cambodia	7.6	5.4	0.9	14
China	52	25	110	180
India	8.6	37	84	130
Indonesia	21	68	5.8	95
Japan	0	0.6	1.9	2.4
Korea, North	0	1	0.9	1.8
Korea, South	0	0.1	1.7	1.8
Laos	4.9	19	0.5	25
Malaysia	0	22	0.8	23
Mongolia	23	9.2	0	33
Myanmar	1.9	56	4	61
Nepal	0	5	2	7
Pakistan	2.9	0.9	10	14
Philippines	0.2	17	7.1	24
Singapore	0	0	0	0
Sri Lanka	0	3.9	0.2	4.1
Taiwan, China	0	0.11	0.4	0.6
Thailand	12	36	7.7	56
Vietnam	12	15	6.1	33
Asia Total	150	330	250	730

Source: Streets et al., (2003)

1.2.2. Recycling of crop straw

The recycling and utilization of crop straw is important in the process of eliminating environmental pollution caused by crop straw burning. Crop residue is increasingly being viewed as a valuable resource, owing to its rich nutrients. The goal of residue management must be to maximize the value of this resource and minimize the potential for environmental degradation. Hence, many economically viable and environmentally-friendly uses of straw have been studied, developed, and promoted across the world, ranging from traditional biomass energy, animal feed, compost, and crop fertilizer.

Agricultural residue as a biomass energy is usually burned for heating, cooking, charcoal production, and for the generation of steam in mechanical and electric power applications. Of all the processes that can be used to convert agricultural waste to energy or fuels, combustion is still the dominant technology, accounting for more than 95% of all biomass energy used today (Klass, 2004). In addition, agricultural straw is of value to livestock farmers. Crop residues are used to feed ruminants, which are in turn high-quality food for human populations (Oltjen and Beckett, 1996). Agricultural straw can also be composted with manure in aerobic composting systems. Such composts are advantageous to crop growth and soil fertility, because they are rich in organic matter and mineral nutrients, have a high level of chemical stability, and no phytotoxicity (Abdelhamid et al., 2004). Of course, the use of cellulose to produce ethanol is still being investigated and developed, as it has high processing costs and production issues. These uses of agricultural residues are generally encumbered by costs related to residue collection, storage, and transport. Alternatively, straw can be chopped and incorporated into the soil in situ, prior to establishing the next crop, without needing a collection system. Recycling of agricultural straw presents a range of exciting opportunities for sustaining farming economies, which would also mitigate climate change (Field et al., 2008).

1.3. Open burning of crop straw in China

1.3.1. Production of crop straw in China

Grain self-sufficiency is one of the most important agricultural policy goals in China. This sets the challenge to provide enough food for its population of 1.3 billion. China has made commendable progress in the production of food grains, following implementation of “reform and opening-up” policies. Reflecting intense physical input, innovation, and changes in technology, food grain production (agricultural, root and tuber, and legume crops) underwent a marked increase from 304.8 million tonnes in 1977-78 to 616.3 million tonnes in 2015-16. Rice, wheat, and corn are the main crops, accounting for 34%, 21% and 36% of the total food grain production, respectively. In 1977-1978, the sown areas under rice and wheat were 34.4 and 29.2 million hectares (ha); this decreased to 30.2 and 24.2 million ha by 2015-2016, reflecting changes in market demands, land use, planting structure, and loss of arable land. The sown area of corn increased from 20 million ha in 1977-1978 to 36.8 million ha by 2015-2016 (Figure 1-1) (National Bureau of Statistics of China, 2017).

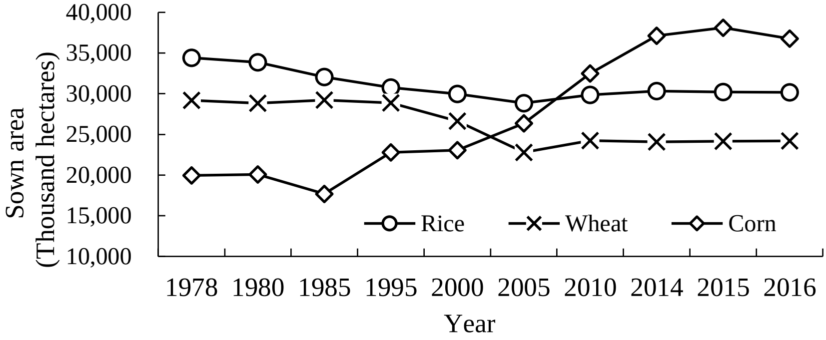

Figure 1-1: Sown area of rice, wheat, and corn in China (1978-2016)

Even though the sown area of rice and wheat has decreased over the last 40 years, improved agricultural productivity has assured high yields of food production, meeting the needs of China's growing population. The average agricultural production of rice, wheat, and corn has increased substantially over the period 1977-2016, increasing from 3978, 1845, 2803 kg/ha in 1977-1978 to 6862, 5327, 5971 kg/ha in 2015-2016, respectively (Figure 1-2) (National Bureau of Statistics of China, 2017). The agricultural growth of China has been tremendous over this period, and continues to grow substantially.

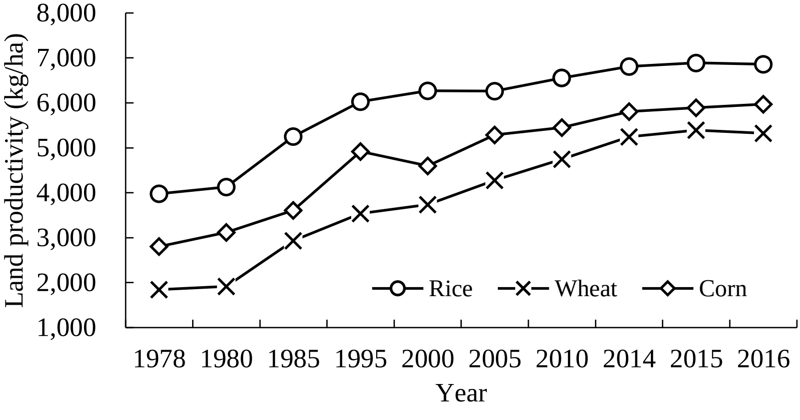

Figure 1-2: Land productivity of rice, wheat, and corn in China (1978-2016)

The growth of China's agriculture was inevitably accompanied by production of huge amounts of crop straw. The main crops in China include rice, wheat, corn, beans, tubers, oil-bearing crops, cotton, fiber crops, and sugar crops (sugar cane, sugar-beet). Taking the residue to product ratio (the ratio of the dry weight of residues produced to the total weight of crops produced) into account, the total amount of crop residue generated in China in 2016 was about 952.5 million tonnes, of which the combined rice, wheat, and corn crop residues accounted for 83% (Table 1-3).

Table 1-3: Main crop straw sources in China in 2016

Crop	Crop yield[a] (million tonnes)	Residue/crop product coefficients[b]	Residue yield (million tonnes)	Proportion (%)
Rice	207.1	1	207.1	22
Wheat	128.9	1.1	141.8	15
Corn	220	2	440.0	46
Beans	17.3	1.7	29.4	3
Tubers	33.6	1	33.6	4
Cotton	5.3	3	15.9	2
Fiber crops	0.3	1.7	0.5	0
Oil crops	36.3	2.0	71.9	8
Sugar crops	123.3	0.1	12.3	1
Total	772.1		952.5	

[a]*Source: National Bureau of Statistics of China, 2017*

[b]*Source: MOA/DOE Project Expert Team, 1998; Yuan, 2002*

Clearly, the residues of rice, wheat, and corn crops are major contributors to the total crop residues in China. Moreover, annual crop residues in China were estimated based on total crop weights for the period from 2005 to 2016 (Figure 1-3) (National Bureau of Statistics of China, 2017); they show that the annual total yield of crop residue increased from about 730 million tonnes in 2005 to 950 million tonnes in 2016, at an average rate of 2.6% per year.

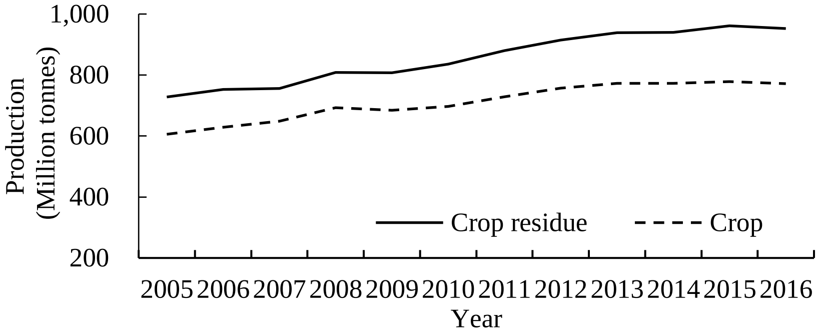

Figure 1-3: Production of crop and crop residue in China (2005-2016)

1.3.2. Open burning of crop straw in China

1.3.2.1. Possible reasons for open burning

Reasons for farmers’ open burning of crop straw vary countries, but are often due to some common reasons.

The easiest and cheapest way

Open burning is not the only solution to get rid of crop straw. There are also other alternatives such as collecting crop straw as animal feed, as cooking material, as feedstock for industry or crop straw as fertilizer returned to the field. However, compared to these disposal methods, open burning is the easiest and cheapest way available to famers.

Kill weeds

Open burning is an old technique to kill weeds. It is applied quite commonly in agriculture and even can kill weeds resistant to herbicide. The most important is open burning can kill weed seeds which will not be removed by other alternative methods. This leads the less weeds in the next crop field.

Kill pests and control of disease

Without burning, pests are hiding under the crop stubble and eat crop seedling. Disease can occur more readily in the subsequent crop, if straw is left on the field. However, pesticide is not easy to kill the pests because they hide under stubble. Open burning is an effective method if the crop residue remains are highly infested with pests. It also kills the eggs of pests, accordingly, reduces the amount of pesticide sprayed for the next crop.

Why is the question of open burning so serious in China? The reasons for open burning of crop straw are more complicated.

Cropping system

Rotation cropping system is most prevalent in China. This because China faces a major challenge of food security: large populations and limited available land resources. Crops rotations can achieve more crop yields. Short time is the main feature of rotation. Generally, the major constraint is the short time between harvesting and sowing of the next crop; any delay in sowing adversely affects grain yields of the subsequent crop. Preparation of the field also involves removal or use of straw left in the field. Given this short period, farmers must rapidly get rid of the crop residue and prepare the land for sowing the next crop; this rapid turnover of crops leads to burning of the residue in open fields.

No collection systems

There are currently no collection systems in China to help farmers to collect huge amounts of crop straw. Similarly, the high costs of straw recycling and mechanical harvesting have become a main driver of residue burning. The Chinese government strives to establish a more complete socialized service system for straw return, collecting, storing and transporting by 2020.

Not satisfied with straw return

Combined harvester can pursue more customers by leaving high stubble to save time. For wheat, the high stubble (about 30 cm or higher) remaining after harvesting inevitably increases the difficulty of sowing the next crop, making it necessary to burn this residue. At the same time, the poor quality of crushed corn residues and the total amount of residue to be returned to the field have only increased difficulties related to crop sowing subsequent crops.

1.3.2.2. Quantity of open burning

Various studies have brought to the forefront the quantity of crop straw generated in China and the proportion of crop straw burned in the field (Table 1-4). The survey data of Gao et al. (2002) shows that 6.6% of crop residue, around 39 million tonnes, was burned in the field in 2000. Yan et al. (2006) estimated the total amount of crop straw generated in China to be about 640 million tonnes in 2000, 19% of which (122 million tonnes) was burned in the field. Streets et al. (2003) also estimated that 110 million tonnes of crop residue were openly burned in China in 2000, which is even higher than Gao et al.'s estimate of 39 million tonnes. This suggests that the estimate in Gao et al. (2002) is an underestimate (Yan et al., 2006).

According to Cao et al. (2008), between 2001 and 2003, the total crop residue produced in China was 600 million tonnes, with about 23% of this crop residue (140 million tonnes) being burned in the field per year. According to Wang and Zhang (2008), total production of crop straw in China reached 720 million tonnes in 2006, of which 140 million tonnes (19%) were burned in open fields. Based on a national questionnaire, Peng et al. (2016) estimated that around 21% of crop residues were openly burned in 2010. Moreover, these residues comprised 21% wheat straw, 20% corn straw and 19% rice straw. In 2012, about 710 million tonnes of straw were produced in China, according to Li et al. (2016), of which about 160 million tonnes (23%) of crop residue were burned in open fields, comprising 42% wheat straw, 15% corn straw and 23% rice straw.

Table 1-4: Various studies reporting estimates of straw open burning in China

Year	Total amount of crop straw (million tonnes)	Ratios of crop residues burned				Data sources	Reference
		Main crop	Wheat	Corn	Rice		
2012	710	23%	42%	15%	23%	Surveys	Li et al. (2016)
2010	/	21%	21%	20%	19%	Surveys	Peng et al., (2016)
2006	720	19%	/	/	/	Surveys	Wang and Zhang, (2008)
2001 to 2003	600	23%	/	/	/	Surveys	Cao et al., (2008)
2000	640	19%	/	/	/	Surveys	Yan et al., (2006)
2000	550	7%	9%	5%	8%	Surveys	Gao et al., (2002)

1.3.2.3. The contribution of open burning to air pollution in China

China's economic growth has been accompanied by tremendous increases in energy consumption, emissions of air pollutants, and the number of poor air quality days in mega cities and their immediate vicinities. Air pollution has become one of the top environmental concerns in China; air pollution may even become the greatest threat to human health in China. In 2010, China had one of the highest premature mortality rates attributable to air pollution in the world. Approximately 1.4 million people in China die every year because of air pollution, representing nearly 40% of the global total (Lelieveld et al., 2015). Regional haze and smog events have dramatically increased in recent years. The average PM_{10} concentration during burning from 1999to 2007 was 215 $\mu g/m^3$, about 40% higher than the June average of 153 $\mu g/m^3$ (Li et al., 2008).

Around 15 June 2005 (during the summer harvest period), open burning of straw occurred in both Henan and Hebei. Two or three days later, dense smoke was detected throughout these two provinces, and even encompassed Beijing. Southwestern and western suburbs of Beijing (near Henan and Shandong) experienced extremely high hourly PM_{10} concentrations of 864 $\mu g/m^3$ and 528 $\mu g/m^3$ during these burning days (Li et al., 2008).

Around the end of October 2008 (during the autumn harvest period), straw was burned in Jiangsu and its neighboring provinces, producing PM_{10} and CO peak concentrations that were 42% and 28% higher than average (Su et al., 2012).

During October 2011, thick smog covered large parts of the densely populated North China Plain, mainly related to burning of straw (Tan and Liu, 2011). Heavy smog was sustained during October-November and January, blanketing over 70 major cities in North China, covering an area of 1430000 km^2 area or 15% of the national territory (Xinhua News, 2013). O_3 and $PM_{2.5}$ (airborne particles less than 2.5 μm in diameter) are the major pollutants in such smog. Straw burning is one of the primary contributors to haze and smog formation during harvest periods in China (Zha et al., 2013).

China is facing serious air pollution problems. The major contributors to air pollution need to be identified and controlled. Several previous studies have shown that open fires in and around the cities of China are affecting air quality (Zha et al., 2013; Chen and Xie, 2014; Liu et al., 2015; Zhang et al., 2016). This is not surprising, as biomass burning is a significant contributor to poor air quality in many regions of the world. However, China is now one of the greatest sources of biomass burning emissions in the world (Streets et al., 2003). Annual biomass burning contributes about 26% to the total PM emissions of China, half of which are derived from straw open burning (Lu et al., 2011; Guan et al., 2014). This shows that crop straw burning accounts for a major part of total biomass burning (Streets et al., 2003; Yan et al., 2006). The annual $PM_{2.5}$ emissions from straw open burning in China were about 1 million tonnes (Zhang et al., 2016) and about 20000 Chinese people have died, because of $PM_{2.5}$ and O_3 levels related to biomass burning pollution (Lelieveld et al., 2015).

1.4. Efficient recycling: The best way to control air pollution related to straw burning in China

1.4.1. Disposal of crop straw in China

Pollution related to burning of crop straws can be avoided or minimized through straw recycling, which is a sustainable strategy and, as such, should be widely prompted and developed. Moreover, the national government recently announced their goal to recycle 85% of crop straw by 2020 (China National Development and Reform Commission, 2016).

In China, crop straw is either removed from the field, burned in situ, discarded (piled or spread) along the borders of the field or returned to the field (incorporated in the soil under full tillage or mulched on the soil surface under minimum tillage). Straw burning in situ or in piles along the borders of the field is an infamous source of air pollution and waste of resources; it is now banned by the Chinese government. Straw removed from the field can be recycled as feed for animals, biomass fuel for household cooking and heating, growth media for mushrooms, or raw material in various industries. In addition, straw can be directly left in the field as an organic fertilizer for crops (Figure 1-4).

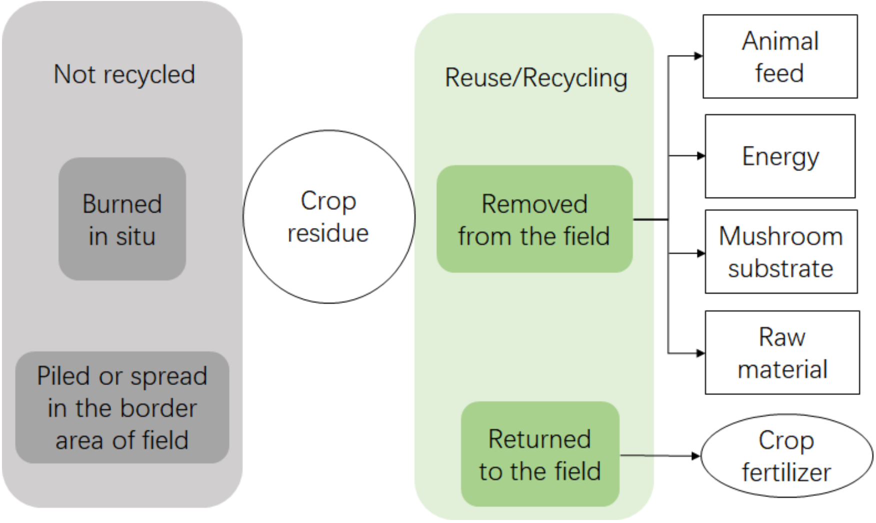

Figure 1-4: Disposal mode of crop residue in China

From 1995 to 2005, China produced about 630 million tonnes of crop residue per year. Typically, 65% (406 million tonnes) of the total crop residue was reused, while the rest was lost during collection, discarded or burned in the field. The largest part (236 million tonnes) of this reused crop residue is combusted by farmers for cooking and heating. The second largest part (145 million tonnes) was used for animal feed.

Just 25 million tonnes of this crop residue was used in industries as a raw material.

In 2015, the theoretical amount of crop residue was 1040 million tonnes. Around 69% (720 million tonnes) of the total crop residue was reused as fertilizer, feed, energy, substrate, and raw materials, accounting for 54%, 24%, 14%, 5% and 3% of these 720 million tonnes (Table 1-5). China has prioritized the development of straw-reuse technologies since the 1980s and several of these straw-reuse projects have been successful in China. Moreover, the Chinese government has implemented a variety of policies to improve technologies related to biomass energy, such as biogas, involving direct combustion of raw materials, straw briquetting, bioethanol production, and biomass gasification. However, biomass energy occupies only a small proportion of the energy sector, which is still dominated by traditional fuels in rural areas. The future of these projects is currently not viewed with much optimism. The percentage of crop residue used as fuel in 2015 was much less than that of 2005, because straw has been replaced by natural gas as a fuel source in most rural areas. Currently, production of crop fertilizers is the main method of straw recycling, followed by its use as animal feed; these uses accounted for 78% of straw recycling in 2015. Only a small amount of crop straw was used as industrial raw materials. These shifts reflect the current environmental policies, economic strengths, technology, and other factors.

Table 1-5: Amount and utilization of crop straw resources (million tonnes)

Year	Theoretical amount	Collectable amounts	Reused amount	Five methods of reusing straw				
				Crop fertilizer	Animal feed	Fuel	Mushroom substrate	Raw material
2015[a]	1040	900	720	389	169	103	36	24
2005[b]	630	536	406	/	145	236	/	25

[a] *Source: National Development and Reform Commission (2015)*

[b] *Source: Liu et al., (2008)*

Recycling of agricultural straw clearly benefits human society, although its economic value may be less than the cost of collection, transportation, and reuse. Table1-6 displays a list of advantages and disadvantages of reusing crop straw. A ‘yes’ (Y) recorded under the advantage column indicates that this option will be beneficial to society and is given a value of 1. If a ‘no’ (N) is recorded under a disadvantage column, then it also receives a value of 1. In this way, the utilization mode cannot be limited by various costs, immature technology, or markets that consume or require crop straw. The higher the total value of credits, the better or more convenient the method of straw disposal in China.

As shown in the Table1-6, open burning or discarding of straw has no benefits for the environment or for straw recycling. However, it also has no cost constraints for collection, storage, or transport, which are involved in straw removal for its use as animal feed, fuel, mushroom substrate, or industrial materials. Moreover, it also is not constrained by costs of crushing straw for its use as a crop fertilizer. There is also no need for advanced technology, a consumer market, machinery for crushing or baler machinery, and it can burned or discarded at any time. Hence, this option receives the highest score of 8, showing that open burning or discarding straw would be the easiest way to get rid of straw, if there was no ban to limit environmental pollution.

The second highest score was obtained for crop fertilizers, with a value of 7. As a crop fertilizer, straw is returned to the field, and has no costs of collection, storage, or transport associated with it. The technology involved in returning straw to the field, even though it has some shortcomings, has been practiced and applied across China in recent decades, with increasing recognition of its benefits. In this case, improving the soil is a huge advantage. However, the availability of crushing machines is limited. Moreover, the costs of returning straw to the field, including rotation and crushing, are very high.

Straw used for animal feed, mushroom substrate, energy and industrial materials needs to be collected and transport to a place where can be bought or used. In China, there is no collection system for removing straw from the field, no fair market, not enough baler machines for collecting straw, and the time for collecting it is also limited. Straw as animal feed and mushroom substrate has been universally used without technology constraints, giving them the same credit value of 4. Meanwhile, there are still some technical problems involved in reusing straw as biomass, energy and industrial materials, resulting in their limited use in China. This gives these options the lowest credit value of 3. In China, the practice of returning crop straw to the field as a crop fertilizer has been most widely supported and popularized by the government.

Table 1-6: Advantage and disadvantage of utilization of crop straw in China

Type	Advantage (Benefits)		Disadvantage (Constraints)									
	Environment protection	Recycle	Collection	Storage	Transport	Rotation	Crushing	Technology	Market	Machinery	Time	Total credits
Crop fertilizer	Y	Y	N	N	N	Y	Y	N	N	Y	Y	7
Animal feed	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	4
Energy	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	3
Mushroom substrate	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	4
Raw material	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	3
Open burning	N	N	N	N	N	Y	N	N	N	N	N	8
Discarded	N	N	N	N	N	Y	N	N	N	N	N	8

Under advantages (Benefits): Y = 1, N = 0.

Under disadvantages (Constraints): N = 1, Y = 0.

1.4.2. Straw returned to the field

When straw is returned to the field, it sustains soil organic matter, increases crop yields, and improves soil structures. The common practices of returning straw to the field involve incorporating crop straw evenly into the topsoil or surface mulching of the soil with crushed straw (Khurshid et al., 2006; Sharma et al., 2011; Yang et al., 2016). Returning crop straw to the field has been highly recommended in China as a measure to replace open burning to meet more stringent environmental conditions, and to benefit soils. Moreover, the returning of straw to the field can involve different tillage treatments.

Incorporating straw into the soil may be followed by conventional tillage (full tillage), where straw residues are ploughed directly into the soil at a depth of around 20 cm. In contrast, mulching straw on the soil surface involves conservation tillage (CT), where crop straw remains on the soil surface without being ploughed under. CT saves fuel and labor, and conserves soil and water by improving soil water retention and reducing surface runoff and erosion. No tillage, zero tillage, minimum tillage, and reduced tillage are all forms of CT. Furthermore, government documents clearly state that they will "Continue to popularize CT techniques and focus on the implementation of crop (corn, rice, wheat) straw returned directly to the field."

1.5. Policies dealing with the straw burning ban and straw utilization in China

Policy from the Chinese Central Government

The central government of China has attached great importance to reducing environmental pollution and the waste of resources caused by open burning of straw. The first burning ban administration measures was issued (No. 98 [1999]) together with the State Environmental Protection Administration (SEPA), Ministry of Agriculture (MOA), Ministry of Finance (MOF), Ministry of Railways (MOR), Ministry of Transport (MOT), and Civil Aviation Administration of China (CAAC) in 1999. The administration measures stated the definition of agricultural straw. It required that straw burning shall be supervised and managed by administrative departments of environmental protection and agriculture, at the same time, agricultural sectors should be responsible for guiding the implementation of comprehensive utilization of straw. It also stated that straw burning should be prohibited within the prescribed range. It asked local governments should actively promote straw utilization such as using straw as fertilizer to be returned to the field, as animal feed, as gasification materials, and as industrial raw materials and so on. People who burn straw will be imposed a fine of 20 RMB or less. However, people will be held criminally responsible if sever air pollution accidents happened (State Environmental Protection Administration of China, 1999).Yet there were no suggestions and measures on the utilization of crop straw.

From 1999 until 2015, there were official notices banning open burning of straw. In 2004, the Ministry of Environmental Protection (MOEP) started to monitor crop fires via remote sensing data. The crop fire occurrences were used by the central government as an important indicator of conformance to this prohibition. These data were used to evaluate the efforts of local governments to implement this environmental regulation.

In 2008, the General Office of the State Council put forward their “Suggestions on accelerating the comprehensive utilization of crop straw” (issue No.105 [2008]) to promote the comprehensive utilization of straw nationwide. It stated the local governments need to consider comprehensive utilization projects and industrial layout according to the distribution of resources by 2015 with the comprehensive utilization rate reaching over 80%. It claimed straw collection system need to be constructed which need enterprises leading, farmers’ participation, and government’s supervision. It suggested strengthen the research and development, promotion and application of technologies. It asked the local governments to take responsibility for strict enforcement, policy recommendations to promote utilization of straw and raising public awareness and participation of the comprehensive utilization. It also required the governments to increase policy support includes financial investment and tax incentives. It required the governments (1) should give appropriate subsidies to the key technologies’ research such as power generation, gasification and ethanol production as well as the system construction of collection, storage and transport; (2) should give appropriate subsidies to machinery related to straw return and straw silage; (3) offer appreciate financial support for the application process of some technologies such as returning straw to the field, gasification and solid fuel; (4) offer credit support for some companies related straw utilization to apply for a loan (General Office of the State Council of China, 2008). However, no specific measures were noted to promote such as constructing collection system and how much subsidies should be compensated to various straw utilization technology.

In 2015, the National Development and Reform Commission (NDRC), MOF, MOA and MOEP put forward their “Notice on further accelerating the comprehensive utilization and ban on open burning of straw” to emphasize the importance and urgency of the comprehensive utilization and burning-ban of crop straw (National Development and Reform of China, 2015). The content of the notice is similar with suggestions issued by General Office of the State Council in 2008.

Reasons for the burning ban policy’ poor performance

Chinese government has prohibited open burning of crop straw since 1999. Then, notices and regulations are issued to strengthen the burning ban every year. Regrettably, burning is still on going so far. The major reason for the burning ban policy’ poor performance is that these laws, regulations and notices with no specific measures. Take an example of subsidy for farmers returning crop straw to the field, the central government just asks local government to give appropriate money to farmers. The question is what is the appropriate amount? In reality, only some areas of China give subsidy to farmers with straw return and the amount of subsidy is based on local economic conditions. What is even more ridiculous is that some local governments have issued subsidy policies, but farmers have not received funds in practice.

The lack of specific measures and corresponding management regulations is the reason why the burning ban policy cannot be implemented well, which indirectly proves the necessity of this study.

Table 1-7: List of regulations implemented to control open burning of crop straw from 1999 to 2015

Document number [year]	Regulation title	Issuer
98 [1999]	Administration Measures of Prohibition Straw Burning and Comprehensive Utilization Management	State Environmental Protection Administration (SEPA); Ministry of Agriculture (MOA); Ministry of Finance (MOF); Ministry of Railways (MOR); Ministry of Transport (MOT); Civil Aviation Administration of China (CAAC)
136 [2000]	Notice on issuing the leaders' speeches of the national conference on straw burning ban and comprehensive utilization	SEPA
155 [2001]	Urgent notice on preventing straw burning in the fall of 2001	SEPA
78 [2003]	Notice on strengthening work of straw burning ban and comprehensive utilization	SEPA
105 [2008]	Suggestions on accelerating the comprehensive utilization of straw	General Office of the State Council
378 [2009]	Guidelines for the planning of comprehensive utilization of straw	National Development and Reform Commission (NDRC); MOA
2615 [2011]	Notice on printing and distributing the implementation plan of comprehensive utilization of straw in the 12th five-year plan	NDRC; MOA; MOF
930[2013]	Notice on strengthening the comprehensive utilization and prohibiting open burning of straw	NDRC; MOA; Ministry of Environmental protection (MOEP)

2231[2014]	Work plan on straw comprehensive utilization and prohibition of open burning in Beijing, Tianjin and surrounding areas	NDRC; MOA; MOEP;
2802[2014]	Catalog of straw comprehensive utilization technology (2014)	NDRC; MOA
2651 [2015]	Notice on further accelerating the comprehensive utilization and ban on open burning of straw	NDRC; MOF; MOA; MOEP

2. Objective of the thesis and research questions

2.1. Statement of the problem

2.1.1. Control of straw open burning has limited appreciation of the benefits

To manage open burning and to recycle straw as a material resource, considerable efforts are being made by various levels of governments and other entities in China. Increasingly strict executive orders are being issued to control straw burning, without the desired results. Although the ban on open burning has improved air quality, its economic and social consequences cannot be underestimated. The question is whether the benefits related to improved air quality resulting from banning straw open burning are feasible in China. There are still major financial gaps to be filled to ensure there are funds to enforce these laws and regulations.

Developing countries, like China, face particularly difficult choices in allocating funds to protect the environment, with gaps in many aspects of this funding. Since the evolution of the contingent valuation method (CVM) and other questionnaire-based valuation techniques, there are methods of evaluating a willingness to pay (WTP), which generally reflects people’s preferences for funding allocations. The purpose of stated preference techniques is generally to assign a monetary value to non-market environmental goods and services by assessing public demand for these goods in a hypothetical market. Respondents in most valuation exercises must construct their preferences for these unfamiliar, often abstract and complex environmental goods ‘on the spot,’ employing the message provided by the interviewer and any pre-existing knowledge they consider relevant (Sauer and Fischer, 2010). A WTP is used as an appropriate benefits metric for evaluating government expenditure and regulatory policies that reduce risks to human life. Hence, the public’s WTP for air quality improvement by banning straw open burning would strengthen the government’s policy response and help governments to decide how or how much to invest on the open burning ban and straw recycling incentives.

2.1.2. Practice of straw return in a limited satisfaction

Any successful plan to inhibit emissions from crop straw burning must embody backup economic solutions to the problem of overstocking of crop waste. Despite the wide range of potential uses, a substantial proportion of straw in China, particularly in areas that are distant from livestock production, is currently chopped and incorporated back into the soil, providing additional soil organic matter and some nutrients for subsequent crops (Powlson et al., 2011). To date, directly returning straw to the field is the most promising practice for using this biomass; it is also the cheapest and most convenient one at present. Despite the known benefits of return, farmers are unwilling or unlikely to return straw and continue to burn a significant portion of the crop residue in the field. Hence, more attention must be paid to enhance return of disposable straws to the soil as a fertilizer. It is crucial to better understand the issues making farmers unsatisfied with straw recycling. We need to determine whether this dissatisfaction lies with unsatisfactory technologies for chopping straw and ploughing it into soil or with financial incentives for returning it to the soil.

In China, the operations involved in straw collecting and recycling often lose money without government support, resulting in poor economic efficiency and unsustainable performance. Similarly, the recycling of straw currently relies on active participation of farmers, despite increasing costs of labor, transport, and recycling in rural areas. This clearly dampens the enthusiasm of farmers for straw recycling and drives them to burn straw instead. The government needs to compensate farmers for the economic outlays involved in using alternative methods to replace traditional practices of straw burning. Accordingly, farmers and recycling enterprises should be subsidized to offset the negative environmental externalities caused by straw burning. In China, a national compensation scheme has not yet been established.

2.1.3. Doubts about wheat yields following corn straw return and conservation tillage

Returning straw to the field conserves soil and soil water, improves soil condition and crop yields through fertilization. However, there are previous studies that reported that straw return can negatively affect the growth of subsequent crops (Kaspar et al., 1990; Unger, 1978). In particular, there are doubts about the effect of corn straw mulching combined with CT on the yields of subsequent wheat crops (Xie et al., 2007). These contradictory results further inhibit implementation of corn straw return in China.

2.2. Objectives

2.2.1. General objective

This research study aims to strengthen policy responses to the ban on straw open burning and to promote better implementation and sustainable development of technologies used to return crop straw to the field, given the current unsatisfactory performance of such technologies.

2.2.2. Specific objectives

i. To study the economic value gained from prohibiting the burning of corn straw to improve air quality. Such assessments are important for policy makers to determine the investment and policy instruments for regulating environmental impacts related to open burning of straw.

ii. To explore factors influencing farmers' adoption of the practice of returning corn straw to the field. There are some problems we need to understand more accurately. A better understanding of the reasons of farmers' unwillingness to return straw to the field provides suggestions on how to improve the technology and is important for policy makers to formulate straw return technical standards.

iii. To test and verify the effects of minimum tillage coupled with returning corn straw to the field on the growth of subsequent crops. This experiment highlights the benefits of this practice and will support further development of straw return technologies.

2.3. Research questions

China is experiencing a demand for environmental regulation, which includes the control of air pollution caused by open burning of agricultural straw. This has resulted in new environmental institutions and practices. State authorities generally determine these laws and regulations. To ensure nationwide control of open burning, several underlying issues must be identified to ensure policy makers prohibit open burning. For this to occur, state governments need to fully understanding the urgency of a ban on open burning, and to decide on standards for sustained development of crop straw utilization. Accordingly, this thesis considers the following research questions:

i. *Straw burning ban and willingness to pay*: How do urban residents value environmental benefits through a willingness to pay for the "corn straw burning ban"? What are the factors influencing urban residents' willingness to pay? These questions are answered in Chapter 2.

ii. *Straw return practices and a willingness to participate/willingness to accept*: What are the critical factors affecting farmers' willingness to participate in straw return practices? What are the determinants affecting farmers' willingness to accept financial compensation for straw return? How much are farmers' willing to accept as compensation for implementing straw return? These questions are addressed in Chapter 3.

iii. *Corn straw return, minimum tillage, and winter wheat yields*: What is the effect of minimum tillage with corn straw return on winter wheat yields? What are the differences in soil water contents under various tillage practices? If CT can conserve soil water, what are the effects of straw return with minimum tillage on yields, while reducing irrigation in North China? These questions are answered in Chapter 4.

3. Analytical framework

Environmental protection

Environmental protection is a global issue that affects all socio-economic groups, all regions and all cultural groups. Waste is a devastating environmental and health issue worldwide. Crop straw as waste by farmer burning in the field releases a lot of toxic pollutants, including greenhouse gases and particulate matter, into the atmosphere, which are commonly associated with environmental pollution and contribute to regional and global climate change. Excessive greenhouse gases cause a greenhouse effect and the consequent global warming of the Earth, which has a devastating impact on the environment and health. Although open burning is not the main anthropogenic source of global greenhouse gases, greenhouse gas emissions from open burning of waste are significant. Meanwhile, agricultural open burning has a negative impact on soil quality by destroying humus and organic matter of soil. This will greatly reduce more nutrient loss from burning soil and a greater dependence on fertilizers. How to support environmental protection to reduce environmental pollution in agricultural sector is important.

Population

Policies planned to protect environment are hard to succeed unless they hold wide public support. In the past, significant changes in environmental policies of many developed countries are due in large part to public support (Stern et al., 1985). Public support for environmental protection is their general environmental responsibility as a member of society. Population can be grouped into two categories: (1) urban residents, which aim to produce the economic value assessment of straw burning ban policy and understand that how much is the public support for ban policy; (2) farmers, which aim to find factors influencing farmers' participation in environmental protection (straw return, an effective alternative to open burning) and how much should government compensate farmers to encourage them to participate in straw return.

Agricultural production

Crop straw reused in the agricultural production is an effective method to eliminate open burning in order to protect environment. Policies designed to address environmental problems caused by open burning of crop straw are still hard to succeed without effective alternatives to open burning. Some good alternatives exist to open burning, especially like incorporating straw to the field or conservation tillage methods. Although straw return technology is recognized through the world, the effects of straw return on the subsequent crop growth are questioned which increase the difficulties of ban policy.

Analytical framework

To support environmental protection policy in agriculture, the economic value of burning ban policy, the factors affecting farmers' adoption of straw return technology, and the yield effects after straw return was analyzed. The analytical framework is designed as shown in figure 1-5.

(1) Economic value analysis: Economic value of open burning ban policy is assessed base on urban residents' WTP.

(2) Analysis factors affecting farmers' adoption of straw return technology: Factors that influence farmers' participation and willingness to accept compensation (WTA) of straw return technology will include actual problem factors (i.e., cost of straw return, quality of machinery crushing) and internal factors (i.e., household characteristics).

(3) Analysis the effects of corn straw return on the subsequent wheat growth: The results are assessed based on the soil water content effect, soil temperature effect and yield effect.

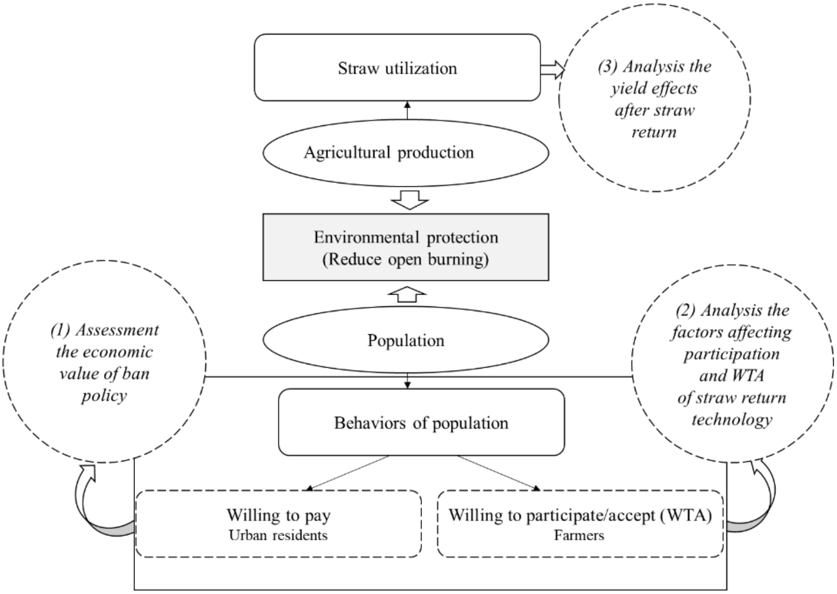

Figure 1-5: Analytical framework

4. Structure of the thesis

This thesis comprises **5 chapters,** as outlined below.

The **General Introduction (Chapter 1)** defines the scope of the thesis, outlining its scientific and empirical framework.

Chapter 2, entitled “Urban residents' willingness to pay for corn straw burning ban in Henan, China: Application of payment card”, reviews the economic benefits of a corn straw burning ban. An empirical model is used, based on questionnaire data, to quantify the various costs and benefits of the burning ban.

Chapter 3, entitled “Determinants of farmers’ willingness to participate in corn straw returned to field and willingness to accept compensation: Evidence from a questionnaire carried out in Henan, China”, explores the factors influencing farmers’ adoption of empirical research in China. This chapter examines how much of a subsidy for straw return farmers want.

Chapter 4, entitled “An evaluation of minimum tillage in the corn-wheat cropping system in Hebei province, china: wheat productivity and water conservation”, uses field experiments to compare the effects of straw mulching under various tillage practices on the yield, soil moisture, and soil temperature of a double cropping system.

The final chapter (**Chapter 5)** summarizes the main results and outlines directions for future research.

2

CHAPTER 2. URBAN RESIDENTS' WILLINGNESS TO PAY FOR CORN STRAW BURNING BAN IN HENAN, CHINA: APPLICATION OF PAYMENT CARD

How to support environmental protection policy in agriculture: A case study in Henan and Hebei Provinces, China

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(The objective of this thesis is to support environmental protection policy in agriculture. An economic valuation on such policy can be essential for sound policy. Chapter 2 is one part of research to assess the environmental protection value from willingness to pay for burning ban policy of urban residents. By understanding how the population outside of the farm think about open burning of crop straw, we hope this will give help to the Chinese policy makers to create better policy related to open burning in future.)

There is an urgent need to manage air pollution associated with the open burning of agricultural straw to protect local and regional air quality and human health. Moreover, air pollution has significant economic impacts, cutting lives short, increasing medical costs, and reducing productivity through the loss of working days across all economic sectors. Price markets established for agricultural straw in China have proved to be inadequate for addressing air pollution caused by open burning of straw. Consequently, it is essential for the Chinese government to take decisive and comprehensive action to promote environmental sustainability and a reduction in open burning. Evidently, effective policies to improve air quality require action and cooperation at global, European, national, and local levels, extending across most economic sectors and engaging the public.

Although air quality in Europe is projected to improve in the future, with the full implementation of existing legislation, air pollution has been found to be the single largest environmental health risk on this continent. The disease burden resulting from air pollution is estimated to be substantial (Lim et al., 2012). Air pollution continues to have significant impacts on the health of Europeans, particularly in urban areas. Numerous European Union (EU) member states have reported substantial emissions from open burning, which are expected to increase in the future in the absence of further policy interventions. For example, in Spain, which is the second largest rice producer (after Italy) in the EU, open burning is a significant problem. Spain generates 90,000 tonnes of rice straw annually, a large proportion of which is burned over a three-week period, in situ, around the month of October. About 50,000 tonnes of rice straw are produced in the vicinity of Albufera Nature Reserve, the burning of which has considerable impacts on nearby urban areas. In their study on biomass burning across northern Europe, Saarikoski et al. (2007) found that long-range transmission of smoke emitted from burning biomass had a strong impact on $PM_{2.5}$ mass concentrations in Helsinki over the 12-day period of burning conducted in April and May 2006.

EU legislation banning open burning of agricultural residues has been formulated as Regulation No. 1306/2013 (EU) under the framework of the European Parliament and Council (The European Parliament and the Council of the European Union, 2013). Specifically, Annex II of this regulation defines standards of good agricultural and environmental conditions (GAEC) that take into account the specific characteristics of the target areas, including soil and climatic conditions, existing farming systems, land use, crop rotation, farming practices, and farm structures. GAEC 6 refers to

"Maintenance of soil organic matter level through appropriate practices including ban on burning arable stubble, except for plant health reasons."

Effective enforcement of the above regulation is critical. For instance, in France, the ban on burning is encompassed in the obligation of farmers to maintain GAEC standards. Noncompliance results in reductions of direct payments made to farmers under the Common Agricultural Policy (Desjeux et al., 2007). The ban in France reportedly led to a reduction in emissions from open burning by 25% between 2000 and 2005. Referring to the stakeholder process of the Grenelle Environment Forum, an inter-ministerial letter, nevertheless, strongly advocated improved enforcement of the existing ban, which could reduce $PM_{2.5}$ emissions from this source by another 30% (République Française, 2011). Because biomass burning is one of the sources of CO_2 emissions, its cessation or reduction is mandated not only under Regulation No. 1306/2013 (EU) but also under the EU's green policies.

A viable strategy that combines market-based instruments and direct public interventions is required for effectively managing the environment. Compared with the past, current expectations of a majority of citizens that their governments will not only to warn them of major environmental or climate problems but will also prepare them by enacting timely policy responses are higher. Existing policy instruments for addressing climate change comprise regulations, tax instruments, trading systems, negotiations, R&D and technological development, and public investments. In general, the development of appropriate policies for promoting environmental investments entails an analysis of the benefits of investing in environmental regulation measures. Economic valuations of environmental changes are based on people's preferences relating to changes in the state of their environments. Such valuations enable economic actors to consider the environmental impacts of their activities. A few studies that were directly commissioned to provide policy inputs in the United Kingdom, or that have informed decision making, as cited by government sources, are included. An example is a study on particulate matter and health benefits conducted by Pearce and Crowards (1996) to support the development of an appropriate policy on air quality in the United Kingdom. Studies to estimate monetary benefits in other areas, such as agriculture, energy pricing, and the management of chemicals and water have played an extremely influential role in policy formulation. Whereas an increasing number of studies have focused on economic valuations, the extent of their influence on EU policies remains unclear (Bennett, 1997; Turner et al., 2000; Birol et al., 2006).

In the field of economics, evaluations of environmental improvements or governmental interventions should, as a first step, query the effects of such changes. WTP questions can be applied in analyses of private or public decision-making processes. Moreover, the CVM approach is the most frequently used method for eliciting individuals' WTP in relation to environmental goods. The latter approach entails direct questioning of subjects regarding the amount they are willing to pay for improving the environment.

The policy issued by the Chinese government prohibiting the burning of agricultural straw in fields is aimed at reducing the extent of air pollution during the harvesting period. In some areas, local governments compensate farmers for the economic burdens of using alternatives to burning. Developing countries, like China, face particularly difficult choices in allocating funds for protecting the environment, with gaps in funding being evident in many areas. Consequently, economic studies that quantify open burning of agricultural straw in China would provide valuable insights for the public and for policy makers for developing approaches that can facilitate and improve future management and funding priorities. Furthermore, for farmers, straw burning on the spot may be the most economical and simplest way to deal with straw. However, local citizens as stakeholder may suffer from poor air quality due to open burning of straw. Then, what could be done by local citizens to require agricultural producers stop straw burning?

The primary focus of this chapter is on the application of the WTP method to estimate annual benefits resulting from the ban on open burning of corn straw. Henan Province, where open burning of agricultural straw occurs frequently, was selected as the study area. Urban citizens, who are more susceptible to environmental pollution, were selected as respondents to obtain a WTP value for supporting a ban on the burning of corn straw. The chapter is aimed at answering the following two questions: (1) How do urban residents value environment benefits, reflected in their WTP for a “straw burning ban?” (2) What are the factors influencing urban residents’ WTP?

Abstract

Urban air pollution generated from straw open burning after the harvest seasons in China has been one of the significant problems interfering with the city’s proper functioning. This paper applied contingent valuation in a face to face survey to assess the individual willingness of urban residents in Henan, China to pay for corn straw burning ban to policy makers. Such assessments are important for policy makers to determine the investment and policy instruments for regulating environmental impacts of straw open burning. To investigate the determinants of the stated willingness to pay (WTP) a sample of 1890 urban residents in Henan, China was selected. The study uses Tobit model. The expected WTP was about 77 Chinese Yuan (RMB) per person per year for the total respondents and 147 RMB per person per year for observations with positive WTP bids. Aggregate value was between 3.4 and 3.9 billion RMB indicating that corn straw burning ban is of considerable economic value to Henan. Results from the study show that experience of environmental protection, expenditure on protecting health from air pollution, influence of straw burning on respondent’s health, life, work, household income, education, job place, and family size were significant variables explaining WTP. The results of the study will be useful for policy makers when making up their mind how much funds should be invested and what kinds of policy instruments could be suitable for banning straw burning.

1. Introduction

Urban heavy air pollution occurs during autumn harvest (corn harvest) every year in northern China. Around harvest time, straw open burning produces air pollutants which is the main contributor to air pollution (Zha et al., 2013) and urban residents have much complaint about the incident. Furthermore, air pollution is particularly serious when the pollutants cannot spread quickly because of atmospheric stability and other extreme weather's blocking (Houshyar et al., 2017). Straw open burning produces air pollutants including particulate matter (PM) and gaseous species (Crutzen and Andreae, 1990) and accelerates the heavy haze formation in the urban and regional atmosphere (Nie et al., 2015). Urban residents worry about their health and the relationship between health and air pollution has drawn a lot of attention (Shabanzadeh-Khoshrody et al., 2016).

Using questionnaires requesting from 591 children in Utah Valley, Pope and Dockery (1992) found that children may suffer acute health effects of respirable particulate pollution. Stieb et al. (2002) studied the health effects of air pollution and found that PM_{10}, CO, NO_2, O_3, and SO_2 are all positively and significantly associated with all-cause mortality and that acute exposure to air pollution is a significant contributor to mortality. If people are long exposed to the open field burning, the pollutants will impact human health adversely (Ryu et al., 2007). Mounting evidence suggests that air pollution contributes to the large global burden of respiratory and allergic diseases, including asthma, chronic obstructive pulmonary disease, pneumonia, and possibly tuberculosis. A study by Laumbach and Kipen (2012) indicates that air pollution from domestic fires burning biomass fuels is a major preventable cause of the increased incidence and exacerbation of respiratory disease. Another study by Ekici et al. (2005) shows that the majority of women living in rural areas in Turkey use biomass fuels for domestic energy and are exposed to high levels of indoor air pollution every day. Moreover, the sever air pollution caused by farmers' open burning of crop straw can also influence the urban residents' normal life and work and disrupt children's attending school and traffic. Therefore, urban residents hope that farmers stop open burning and recycle crop straw, and the governments are strongly urged to forbid farmers' open burning.

The reduction of organic matter for animals or soil as well as energy are the significant problems of straw open burning after the harvest seasons (Mardoyan and Braun, 2015). According to Maroušek et al. (2016), biomass combustion is an important primary source of particles with adsorbed biomarker compounds in the global atmosphere. The introduction of natural product organic compounds into smoke occurs primarily by direct volatilization/steam stripping and by thermal alteration based on combustion temperature.

Straw burning ban has been implemented a few years ago, however, approximately 2000 straw filed burning sites were identified by satellites in ten different provinces during the autumn harvest 2014 and 2015. Although the local governments carry out severe punishments to forbid straw burning, farmers continue to do so as there is no profit in recycling it and leaving it on farmland affects the next season's crop growth. Burning is an easiest and economic option for the management of crop/biomass residues. Due to lack of awareness or unavailability of suitable technologies, it is a usual practice everywhere (Satyendra et al., 2012).

In order to prevent farmers from burning straw in 2016, Henan government invested 80 million RMB[1] to compensate the farmers returning straw to the field and agricultural machinery. Obviously, open burning of crop straw is still going on and the policy of burning ban is ill-performanced. We doubt whether it is not enough compensation for farmers or not enough attention paid to open burning of crop straw by government. An assumption of 80 million RMB paid to compensate for returning corn straw to the field, per unit (mu) of cropland can acquire just 24 RMB according to 3.3×10^6 ha of corn sown area in Henan. While the 80 million investment is not only for recycling corn straw but also for wheat straw and agricultural machinery's subsidy. Hence, to have a full understanding of the value of forbidding open burning of crop straw, we carry out the research to quantify urban residents' WTP for straw burning ban in Henan, which is important for policy makers when determining the investment and policy instruments in order to regulate environmental impacts of open burning. And the government may acquire additional funding from urban residents. According to our knowledge, there is no such economic valuation on straw burning ban for improving air quality in China. Also, the determinants of urban residents' WTP are important in our research because public participation determines the achievements of sustainable development as listed in the China's Agenda 21 (State

Council of the People's Republic of China, 1994). Specially, the urban residents are likely to be the primary group exposed to high levels of ambient air pollution and straw burning ban would distinctly benefit the urban residents. Since it is difficult to measure the benefit of straw burning ban, contingent valuation is an advanced instrument when dealing with this type of issue by obtaining a monetary value for an intangible good without a market price. In this study respondents were asked to state their WTP for straw burning ban to improve air quality during corn harvest time. The objectives of this study are (i) to assess how the urban residents value environment benefits through WTP for "straw burning ban" (ii) and to determine the factors influencing the urban residents' WTP. The Contingent valuation method (CVM), using a stated preference technique and questionnaires method, has been applied in the areas of environmental cost-benefit analysis, environmental impact assessment, and other nonmarket goods and services. The ultimate goal of a CVM survey is to obtain an accurate estimate of the benefits (or values) of a change in the level provided for the public good in question. Given the objectives of the study, the following hypotheses were formulated:

H1

Respondents who protect family members' health from air pollution in life are more willing to pay for straw burning ban.

H2

Those respondents who have participated in the environmental protection tended to be more willing to pay for straw burning ban.

H3

Those respondents who perceived the poor air quality during harvest time are more willing to pay for straw burning ban.

H4

The respondents whose health were negatively affected by air pollution because of straw burning are more likely to pay.

H5

The respondents whose life and work has been affected by air pollution due to straw burning are more willing to pay for straw burning ban.

H6

Socio-economic characteristics of the respondents have positive and significant effect on WTP.

2. Methodology

2.1. Description of study sites

The Henan province, which includes 18 cities, is located in China's center. It contained 4441×10^4 urban residents population in 2015 (Henan Provincial Bureau of

Statistics, 2016). A serious problem has existed in Henan: straw burning after wheat and corn harvest. Both in 2014 and in 2015, Henan had the most number of fire points detected by satellites during summer harvest in June (Figure 2-1). The serious air pollution occurred inevitably. Taking PM_{10} as an example, we analyzed the PM_{10} data of Taikang County, Zhoukou City, Henan Province in 2015. The analysis showed that PM_{10} levels became much higher during the harvest period than that before/after the harvest. It was recorded that the average daily PM_{10} concentration was around 92 μg/m³ and the daily maxima of PM_{10} was up to 214 μg/m³ during wheat harvest (concentrated from June 5 to June 25). In corn harvest (concentrated from September 23 to October 23), the average daily PM_{10} concentration was around 128 μg/m³ and daily maxima of PM_{10} was up to 276 μg/m³ (Figure2-2). Hence, the great air pollution caused by open burning in Henan was highlighted. We chose 7 cities where corn straw open burning occurred in 2015: Zhengzhou, Kaifeng, Shangqiu, Zhoukou, Xuchang, Luoyang and Hebi.

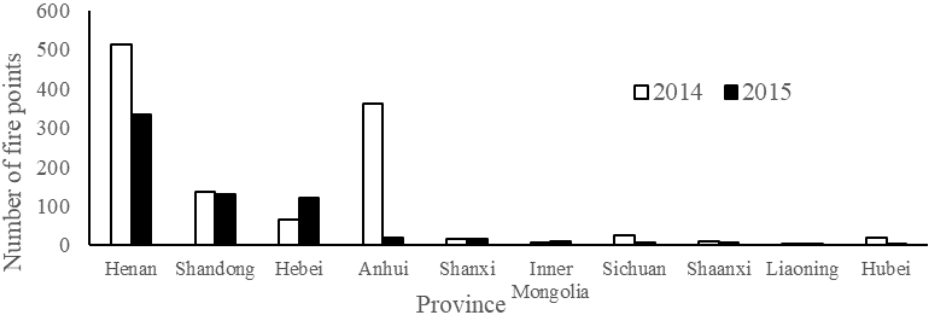

Figure 2-1: Number of fire points during wheat harvest in June 2014 and 2015

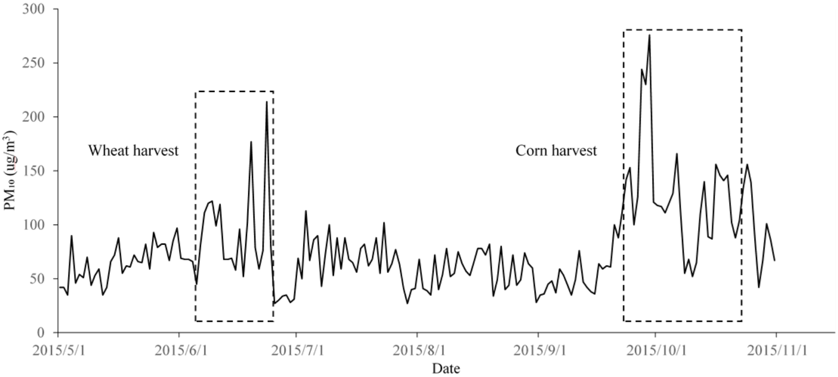

Figure 2-2: A daily variation of PM_{10} from May 1 to October 30, 2015 in Taikang County, Zhoukou,

2.2. Contingent valuation method, willingness to pay, and Payment card elicitation method

The valuation is difficult for non-market goods such as field of transportation, health, the arts and education, as well as the environment. Yet, such valuation on them can be essential for sound policy. Contingent valuation method (CVM), using a stated preference technique and questionnaires method, has been applied for placing monetary values on environmental goods and services not transacted in the market. It was first proposed by Ciriacy-Wantrup (1947) for finding benefits of soil conservation practice, in which he suggested that asking individuals directly how much they would be willing to pay for successive increments of favorable effects (public goods). The ultimate goal of a CVM survey is to obtain an accurate estimate of the benefits (or values) of a change in the level provided of the public good in question. The respondents are asked directly what they are willing to pay for the goods to be conserved, or what they are willing to pay for specified improvements in them. Some examples on environmental improvement are Desvousges et al (1987) water quality improvements in the Pennsylvania portion of the Monongahela River; Carlsson and Johansson-Stenman (2000) on air quality improvement in Sweden.

Unavoidably, CVM cannot avoid criticized such as being conducted under given hypothetical market scenarios with many assumptions (Lee and Han, 2002), depending on levels of information the respondent brings to the survey and the amount of information provided by the survey (Pate and Loomis, 1997). Moreover, an issue, the treatment of invalid responses such as protest zeros, missing bids outliers, is related to the testing of validity of the contingent valuation estimator. While protest zeros are usually selected based on responses to the question why individuals are not willing to pay, discarding the invalid responses may result in sample selection bias (Mekonnen, 2000). Investigators are essaying to reveal the true values of public good as accurately as possible by means of CVM surveys, just as is this survey.

Generally, WTP and Willingness to accept are interchangeable for identifying respondents' preferences for a change in the level of environmental goods and services. However, WTP is usually employed for a ‘proposed welfare gain’ due to improved environment or provision of public good. The main reason for applying WTP approach in our survey is to perceive the demand of the urban residents for the air quality improvement around the harvest period.

A payment card (PC) questionnaire was employed in the CVM survey to obtain the urban residents' WTP responses. An ordered list of threshold values was devised in the PC survey questionnaire where respondents are inquired simply to peruse the range of values and to pick out the maximum value they would be willing to pay. The superiority of PC elicitation technology includes avoiding the starting point bias on bidding and dichotomous choice methods, preventing the high nonresponse rate on open-ended and also saving time to make the survey more efficient. In the PC questionnaire, respondents can make a selection quite quickly with a considerably detailed group of thresholds, without the interviewers' prompting. Ryan et al., 2004 found that there is no evidence to show range bias or mid-point bias existing in PC responses when using WTP to value health care. Hence, we took PC method for WTP question. Respondents were told that payments would be used to support the ban policy with the goal of reducing open burning and hence improving the air quality.

2.3. Survey structure and data

The study was pre-tested from November 23th to 25th, 2016 by face to face interview administration and payment cards elicitation method in Zhengzhou of Henan to ameliorate the survey instrument and to adjust the final questionnaire form for assuring comprehension and clarity. Then the final questionnaire was confirmed and consisted of the following five sections: (1) a brief description of the study part; (2) basic activities about the environmental protection of respondents; (3) the effects of open burning during the summer and autumn harvest; (4) urban residents' WTP for straw burning ban; and (5) socio-economic characteristics of respondents.

The sampling respondents were urban residents living in the picked 7 cities of Henan. The minimum required sample size (384) is recommended by a 5% margin of error at a 95% confidence level as well as 44 million urban residents in Henan province (Denscombe, 2010). In practice, we collected 1919 residents' surveys and 1890 complete responses were effective, 234 from Zhengzhou, 234 from Xuchang, 318 from Zhoukou, 171 from Shangqiu, 270 from Kaifeng, 391 from Luoyang, and 272 from Hebi.

2.4. Empirical model

In CVM studies, Tobit econometric model (censored regression model) was used to analyze the determinants of WTP and the maximum amount of money that individuals are willing to pay. Zero-response data are inevitable in WTP surveys. Tobit model is often assumed that the true distribution of willingness bidding censored at zero and better suited in case of data with many zeros than ordinary least squares regression analysis which may be biased and inconsistent parameter estimates regression. Tobit model reveals both the probability of WTP and the maximum WTP of the respondents. Following Mcdonald and Moffitt (1980), the Tobit model, a standard one-equation censored model can be defined as:

$$WTP_i^* = X_i\beta + \varepsilon_i, \quad \varepsilon_i \sim \mathrm{N}(0,\sigma^2),$$

$$WTP_i = \begin{cases} WTP_i^*, if\, WTP_i^* > 0 \\ 0, \qquad if\, WTP_i^* \le 0 \end{cases} \tag{1}$$

Where for the *i*th individual, WTP_i^* is the latent (unobservable) WTP for straw burning ban policy; WTP_i is observed actually maximum WTP for straw burning ban policy (for corn straw burning ban in a year) and is censored at 0; X_i is vector of independent variables that are hypothesized to influence WTP theoretically; β is unknown parameter vector to be estimated; and ε_i is error term which are assumed to be normally distributed with mean zero and constant variance sigma square (σ^2). The standard Tobit model provides the expected value of WTP_i (Tobin, 1958):

$$\begin{aligned} E(WTP_i) &= \Pr(WTP^* \le 0)\cdot E(WTP_i \mid WTP_i = 0) + \Pr(WTP^* > 0)\cdot E(WTP_i \mid WTP_i > 0) \\ &= X_i\beta F(X_i\beta/\sigma) + \sigma f(X_i\beta/\sigma) \end{aligned} \tag{2}$$

Where F represents the cumulative distribution function of a standard normal random variable, f represents the normal density function, σ represents the standard deviation. In addition, the expected value of WTP for observations with positive WTP bids (Amemiya, 1973):

$$E(WTP_i \mid WTP_i > 0) = X_i\beta + \sigma\lambda(X_i\beta/\sigma) \tag{3}$$

Tobit model can be used to determine both changes in the probability of being above zero (i.e., the discrete decision of whether to pay) and changes in the values of WTP for the whole sample and for those observations which are above zero (Mcdonald and Moffitt, 1980). Afterward, the marginal effect of an independent variable on the expected value of WTP among the entire sample in the model is given by:

$$\partial E(WTP_i)/\partial X_i = \beta F(X_i\beta/\sigma) \tag{4}$$

The change in expected WTP value of those observations with positive WTP bids:

$$\partial E(WTP_i / WTP_i > 0)/\partial X_i = \beta\left[1 - \lambda(X_i\beta/\sigma)\left(X_i\beta/\sigma - \lambda(X_i\beta/\sigma)\right)\right] \tag{5}$$

where $\lambda(X_i\beta/\sigma)$ is the inverse Mills ratio, $\left[f(X_i\beta/\sigma)/F(X_i\beta/\sigma)\right]$.
The change in the probability of eliciting positive bids:

$$\partial \Pr(WTP_i > 0)/\partial X_i = \partial F(X_i\beta/\sigma)/\partial X_i = f(X_i\beta/\sigma)\beta/\sigma \tag{6}$$

The Tobit coefficients do not straightly show the marginal effect of an independent variable on the dependent variable. But signs of the regression coefficient show the orientation of change in probability of WTP and the marginal intensity of WTP as the respective independent variable changes.

3. Results

3.1. Descriptive statistics of variables

The following variables in Tobit model presented in Table 2-1 are individual WTP for corn straw burning ban (*WTP*), household’s annual expenditure for reducing negative effects of air pollution on health or life (*Expenditure*), experience of participation in environmental protection activities (*Participation*), effect of straw burning on air quality (*Air quality*), effect of straw burning on health (*Health*), effect of straw burning on life and work (*Life and work*), respondents’ age (*Age*), respondents’ gender (*Gender*), respondents’ education (*Education*), respondents’ job category (*Job*), income level (*Income*), number of people per household (*Family size*). As can be seen from Table 2-1, the mean age of the respondents was 40.92 years. The average number of years the respondents spent on school was 12.29 years. The per capita annual disposable income of urban households was 20637.76 RMB. The mean family size of the respondents was estimated to be 4 persons and the household’s average annual expenditure to reduce negative effects of air pollution on health or life was 350.22 RMB.

Table 2-1: Definition and descriptive statistics of variables

Variable	Definition and unit	Mean	Standard deviation
WTP[†]	Individual WTP for corn straw burning ban	75.58	132.01
Expenditure	Household's average annual expenditure for reducing negative effects of air pollution on health or life (RMB)	350.22	777.89
participation	1 if respondent has experience of participating in environmental protection activities	0.23	0.42
Air quality	1 if respondent felt that air quality became worse during the corn harvest period	0.53	0.50
Health	1 if respondent's health was negatively affected because of straw burning	0.36	0.48
Life and work	1 if respondent's life and work was affected because of straw burning	0.38	0.49
Age	Age in years	40.92	15.80
Gender	1 if male	0.52	0.50
Education	Education in years	12.29	3.50
Job	1 if respondent is outdoor worker	0.17	0.38
Income	Per capita annual disposable income of urban households (RMB)	20637.76	14257.86
Family size	Number of family members per household	4.10	1.35

[†] The WTP value of sample data is the mean value: 1 ~ 50 RMB, 25.5 RMB; 51 ~ 100 RMB ,75.5 RMB; 101 ~ 150 RMB, 125.5 RMB; 151 ~ 200 RMB, 175.5 RMB; 201 ~ 400 RMB, 300.5 RMB; 401 ~ 600 RMB, 500.5 RMB; 601 ~ 800 RMB, 700.5 RMB; 801 ~ 1000 RMB, 900.5 RMB.

3.2. Willingness to pay responses

1890 responses obtained in the CVM survey. A summary of survey results is shown in Table 2-2. As can be seen, 53% of respondents felt open burning reduced the local air quality during corn harvest period. 36 % of respondents expressed their health problems caused by straw burning and 38% of respondents said life and work were interfered by straw burning. Although only 23% of respondents having ever participated in environmental protection activities, 1129 respondents , accounting for 60% of the total sample, were willing to pay for corn straw burning ban to promote the local air protection during the harvest time.

Table 2-2: Statistics of respondent' choice and the reasons for not WTP

Items	Options	Sample size	Proportion (%)
Have you ever participated in environmental protection activities?	Yes	429	23
	No	1461	77
Do you feel that the air quality became worse during corn harvest period?	Yes	999	53
	No	891	47
Have your health been negatively affected because of straw burning during the harvest periods?	Yes	682	36
	No	1208	64
Have your life and work was affected because of straw burning during the harvest periods?	Yes	723	38
	No	1167	62
WTP for corn straw burning ban policy.	Yes	1129	60
	No	761	40
Reasons for not WTP			
1. I have no ability to pay because of low income.		219	29
2. "Straw burning ban" is government' responsibility.		404	53
3. I have adapted to the air pollution during harvest period so I do not want to participate.		92	12
4. Air pollution is not so serious during harvest time because the strict straw burning ban of the government.		28	4
5. Others		18	2

761 respondents were not willing to pay, accounting for 40% of the total sample.

The biggest group of respondents (53%) thought the central and local government should take full responsibility for the straw burning ban, which was the primary reason why the public are unwilling to pay. The second biggest group, accounting for 29% of respondents, were subjected to low income to have no ability to pay, even though they approbated this ban policy will improve air quality. Interestingly, 12% of respondents did not want to pay because they were adapted to the environment with air pollution.

3.3. Mean willingness to pay and aggregate value of corn straw burning ban

Table 2-3 shows the mean WTP and aggregate value of corn straw burning ban for urban residents living in Henan. Considering the Tobit model, the expected WTP for corn straw burning ban was about 77 RMB per year using the total sample and 143 RMB per year using the sample with positive bids, respectively. The expected WTP value for the total sample accounts for 0.4% of the per capita annual income. For the sample with positive bids, the expected WTP value accounts for 0.7% of annual income level. The survey was designed and intended to elicit the individual WTP and aggregate value based on the urban population in Henan. According to Census data and our survey data, there were 44.4 million urban residents population (Table 2-3). In this study, the aggregate value based on the mean WTP for the total sample was estimated to be 3.4 billion RMB using the population figure. Accounting for non-response rate, the aggregate value based on the mean WTP for the observations with positive WTP bids was estimated to be 3.9 billion RMB.

Table 2-3: Mean WTP and aggregate economic value of corn straw field burning ban

Description	Mean WTP (RMB per year)	Urban residents population (Million) ‡	Aggregate value (Billion RMB)
Sample mean	76	44.4	3.4
Expected WTP§	77	44.4	3.4
Expected WTP¶	143	44.4	3.9

‡ Data is from Henan Statistical Yearbook 2016.

§ Expected WTP for total observations

¶ Expected WTP for observations with positive WTP bids

3.4. The determinants of urban residents' WTP for corn straw burning ban

Results of the estimated parameters and their marginal effects of the independent variables hypothesized to affect WTP for corn straw burning ban are shown in Table 2-4. The dependent variable is a continuous variable that is respondents' maximum WTP for corn straw burning ban in the study sites. A total of 11 independent variables were considered in our Tobit model, out of which 9 variables were found to significantly influence maximum WTP ($p<0.1$).

In the model, the estimated coefficient on *EXPENDITURE* had positive and significant ($P<0.01$) effect on WTP, implying respondents usually spending much to protect family members' health from air pollution in life are more willing to pay for straw burning ban. The marginal effect results presented in Table 2-3 shows that when the expenditure increases by 1000 RMB, it will increase the probability of WTP for straw burning ban by 10.11%, holding all other variables at their mean values. Also, when the expenditure increases by 1000 RMB, the expected amount of cash the respondents could pay may increase by 23.43 RMB for the total observations and by 16.76 RMB for the observations with positive WTP bids.

PARTICIPATION was another variable found to be significant at the 1 per cent level. The parameter estimate was positive. The urban residents who had environmental practices in life tended to be willing to pay more than the other ones, suggesting the participation of environment-protection activities make people well understand the impact of open burning and the importance of air protection. The marginal effect result shows that the respondents participating in environmental protection activities, the probability of WTP for straw burning ban increased by 7.53%.

The estimated coefficient for *AIR QUALITY* had a positive and significant ($P<0.01$) effect on WTP. This may occur because the feeling of the air quality changing varies in people. The respondents who perceived the poor air quality during harvest time were more willing to pay for improving air quality of the harvest period and their probability of WTP for straw burning ban was 6.45% higher than those respondents who did not recognize the air quality was getting worse. Moreover, the former respondents were willing to pay 14.91 and 10.68 RMB more, among the whole population and for sample with positive bids, respectively, for straw burning ban than those who did not feel air quality worse.

As expected, the respondents whose health were negatively affected by air pollution because of straw burning (*HEALTH*) were far more likely to pay. Holding all other variables at their mean values, the probability of urban residents' WTP for straw burning ban would be 5.58% higher than that of urban residents without health problems due to air pollution during this period. Also, the expected WTP amount of respondents whose health have been influenced was 13.15 RMB higher for the whole population and 9.38 RMB higher for observations with positive bids than those respondents without health problems, respectively, ceteris paribus.

Similarly, the impact of air quality decline on life and work (*LIFE AND WORK*) was positively and significantly ($P<0.1$) related to WTP. The respondents, whose life and work has been affected by air pollution due to straw burning, would have 4.68% more probability of WTP for straw burning ban. Furthermore, they might increase WTP by 10.98 and 7.84 RMB among the whole population and the observations with positive bids, respectively.

Although *AGE* and *GENDER* had positive relationship with the probability of WTP, they are not statistically significant. As anticipated, *EDUCATION* was found to have positive and significant ($p<0.01$) effect on WTP, indicating that the more educated respondents are more willing to pay than the less educated ones. The marginal effects results show that when education level of the respondent increased by one unit, other things constant, the probability of a respondent's WTP would increase by 2.62%. Besides, an additional increase in education level of respondent might increase the WTP for corn straw open burning by 6.07 RMB among the whole population and 4.34 RMB among the observations with positive bids.

Strangely, *JOB* had a negative and highly significant effect for WTP ($p<0.01$). It means that outdoor workers, having been exposed to the outside environment for a long time, are less likely to pay for straw burning ban. This may because the outdoor workers have been long-term exposed to kinds of environmental pollution they are more adapted and used to the contaminated environment than indoor workers. The marginal effect reveals that outdoor workers will decrease the probability of WTP by 12.53%. Also, 26.81 and 19.54 RMB reduction of WTP for straw burning ban happen to outdoor workers among the entire population and the observations with positive bids, respectively.

INCOME showed that the richer respondents were more likely to pay for straw burning ban ($p<0.01$). When the income increased by 10000 RMB, it would increase the probability of willingness of the respondent to pay for by 3.53%. In addition, the richer respondents' WTP also increased on average by 8.18 RMB for the whole sample and 5.85 RMB for the sample with positive bids, ceteris paribus.

The estimated coefficient of *FAMILY SIZE* was found to be statistically significant with the expected positive sign ($p<0.01$), indicating the probability of WTP to support the straw burning ban increases as the family size increases. Holding the influence of other factors constant, an increase in household size by one member, the probability of WTP increased by 2.29%. According to the marginal effects, as the family size increases by one person, the expected WTP value increases by 5.31 RMB for the entire population and 3.80 RMB for the observations with positive bids.

Table 2-4: Tobit regression for WTP for corn straw burning ban

Independent variables	Estimated coefficients	t-value	Marginal effects		
			1	2	3
Expenditure (1000 RMB)	43.58***	7.82	0.1011	16.76	23.43
Participation	32.73***	3.09	0.0753	12.99	18.27
Air quality	27.83***	2.79	0.0645	10.68	14.91
Health	24.11**	2.29	0.0558	9.38	13.15
Life and work	20.22*	1.93	0.0468	7.84	10.98
Age	0.39	1.17	0.0009	0.15	0.21
Gender	8.28	0.94	0.0192	3.18	4.45
Education	11.29***	6.93	0.0262	4.34	6.07
Job	-54.01***	-4.31	-0.1253	-19.54	-26.81
Income (10000 RMB)	15.22***	4.55	0.0353	5.85	8.18
Family size	9.88***	2.84	0.0229	3.8	5.31
Constant	-259.45***	-7.48			
Log likelihood	-7905.0399				
LR $\chi 2$ (11)	365.46***				
Pseudo R2	0.0226				

***, ** and * shows significance level at 1%, 5% and 10% respectively

[1] Marginal effects on the probability of being censored

[2] Marginal effects on the truncated expected value (Observations with positive WTP bids)

[3] Marginal effects on the censored expected value (The total observations)

4. Discussion

According to the Tobit model, the expected WTP for corn straw burning ban was 77 and 143 RMB per person per year for the total observations and for the observations with positive WTP bids, respectively. Then the aggregate economic value was 3.4 and 3.9 billion RMB per year which are 12% and 13% of the total investment 29.5 billion RMB in the treatment of environmental pollution of Henan province 2014. There is little research on the economic valuation for banning open burning using CVM in China, but there are surveys on air quality improvement. Wang and Zhang (2009) adopted open-ended CVM to measure individual WTP for air quality improvement in Ji'nan City, Shandong Province, China. The mean WTP to improve air quality in Ji'nan was estimated to be 100 RMB per person per year in 2006.Wang et al. (2016) used

CVM to explore WTP to tackle smog pollution in Zibo city, Shandong province, China. The individual WTP from urban residents to tackle smog control and prevention in Zibo, after the respondents' recognition of the causes and health impacts of smog, was 48 RMB. The different WTP value may come from the differences in survey sites and time, the samples and familiarity with the questions, the question format and the income level, and experiences with the surveys contribute to the differences in the results. Generally, according to the previous studies about WTP for air quality in China (Wang et al., 2006; Wang and Mullahy, 2006; Wang and Zhang, 2009; Sun et al., 2016), the ratios between WTP and income level range from 0.4% to 2.1% and the similar ratios (0.4% for the total observations and 0.7% for observations with positive WTP bids) was shown in our survey.

Wang et al. (2008) calculated the direct economic loss from air pollution caused by straw burning of China and Shandong Province 2004 in the view of the loss of human capital and agriculture production as well as the increased cleaning costs. The result shows that the economic loss of straw open burning for China is 19.7 billion RMB. Besides, the economic loss for Shandong Province, adjacent to Henan and also a province with a large amount of crop straw, is about 2.5 billion RMB, showing the assessment of straw burning ban from urban residents of Henan is much higher than the value calculated by using the economic lost method. One difference between Henan and Shandong may be the big discrepancy and the other difference may be due to the fact that respondents often give a high WTP in CVM survey. In our survey, the economic value of preventing farmers burning corn straw has occupied not a small proportion, over 10%, of the total environment investment. However, the actual investment for preventing farmers burning straw of Henan Province in 2016 is just 80 million RMB which is far less than the economic valuation for corn straw burning ban from the urban residents.

Most respondents may know more whether their health, life, and work were negatively influenced by the air pollution around the harvesting time. So, we asked the questions like “Have your health, life, and work been negatively affected because of straw burning during the harvest periods?” to make the respondents easily understand the WTP expressed for the straw burning ban to improve air quality. It shows that people would undoubtedly be willing to pay for changing the status quo when personal interests are affected. Respondents, who have paid great expenditure to prevent their own health from being affected by air pollution in the usual life, are more willing to pay for straw burning ban also. It shows that respondents, who invest more on their own health, correspondingly, will more possibly support straw burning ban as a type of investment for their future health. In China, more and more people have realized the importance of physical health which, to a large extent, determines the career success and quality of life and people increasingly assign a certain amount of money for health. Similarly, the income had a positive and significant influence on WTP, as expected. As income increases, the probability and cash amount of urban residents' WTP for straw burning ban increase. On the one hand, it shows the ability of the high-income group to pay, and on the other hand, it suggests the more urgent requirement of the environment improving of this group than the relatively low-income group. The latter may become a new social problem worthy of the public and government attention. Besides, the neat air is perhaps still deliberated as a luxury good among the Chinese (Wang and Mullahy, 2006). Needless to say, air pollution by the behavior of burning straw, for Chinese farmers who are the economically disadvantaged group, may be negligible.

Based on its chemical composition, straw could be a perfect source for biochemical processes (Maroušek, 2013a). According to Maroušek (2012), steam explosion technology enables cost-effective and environmentally friendly utilization of the lignocellulosic wastes such as B. napus straw without any additional chemicals. Maroušek et al. (2012) conducted a study to verify the economic advantage of the upgraded steam explosion technology linked to the biogas station at a commercial scale for straw methanogenesis. They concluded that inserting the material heater before the continuous high pressure reactor reduced the fluctuations' pressure inside the continuous high pressure reactor. Also, the utilization of the heat from hot exhaust gases (490 °C) from the cogeneration unit is useful because it considerably (93%) reduces the energy consumption of the entire technology.

Our research also found that those respondents who have participated in the environmental protection tended to be willing to pay more than others. This result brings the fact to light that environmental awareness is very important to the success of pollution prevention, consisting with the related studies (Arcury, 1990). It is important to note that those most unwilling respondents (404 out of 761 respondents; 53%), had quite high expectations from the government. This shows that urban residents in Henan still have relatively low environmental awareness and the same result was also found in the study of Wang and Zhang (2009).

Burning of straw can be avoided by adopting different biochemically/thermo-chemically induced techniques. Technologies available for harnessing energy from crop residues are direct combustion, gasification, carbonisation, ethanol production, liquefaction, bricking, and pyrolysis. Alternatives of straw management should be paid enough attention. Phytomass cultivation for energy use is increasingly popular for high profits guaranteed by subsidy. Nevertheless, the hazards of phytomass combustion were confirmed by Maroušek (2013b). According to him, it can be assumed that the risks are higher in lower temperatures of combustion, like in imperfect combustion conditions. Biochar refers to carbon-based dusty residues obtained from biomass pyrolysis (Maroušek et al., 2017). Biochar is a soil-improving substrate made from phytomass pyrolysis. According to Maroušek et al. (2015a), the application of environmentally friendly biochar increases the soil fertility by an average of 17% after the first application. In another study, Maroušek et al. (2015b) analyzed the carbon powder as a solid biofuel instead of biochar. Their results show carbon powder outperforms many of the conventional solid biofuels not only in technological and environmental indicators, but also from the economical point of view.

5. Conclusion

According to the results, the respondents usually spending much to protect family members' health from air pollution in life are more willing to pay for straw burning ban. Accordingly, the first hypothesis is accepted. Based on the results, the following respondents were more willing to pay for straw burning ban: the urban residents who had environmental practices in life; the respondents who perceived the poor air quality during the harvest time; the respondents whose health were negatively affected by air pollution because of straw burning; and the respondents whose life and work has been affected by air pollution due to straw burning were more willing to pay for straw burning ban. Accordingly, second, third, fourth and fifth hypotheses are accepted. According to the results, age, gender, education, income and family size had a positive relationship with the probability of WTP, but job had a negative and highly significant effect on WTP. Accordingly, the sixth hypothesis is rejected meaning that all socio-economic characteristics of respondents do not have positive and significant effect on WTP.

The straw burning and pollutants from the rural area to the adjacent cities have caused the urban residents' concerns and have increased their need for banning open burning around the world. Although the governments have taken some measures to prevent open burning, the burning repeats every year. This shows the current measures of banning are unsatisfactory despite numerous studies conducted, or still not enough attention has been given to the open burning. Thus, in this paper, we explored CVM to assess the individual WTP of urban residents for straw burning ban to improve air quality during corn harvest time and to identify the determinants of WTP among the urban residents in Henan province, China. The results of the study will be useful for policy makers when making up their mind about how many funds should be invested and what kinds of policy instruments could be suitable to ban straw burning.

The difference between the less investment and the strong demand for banning straw burning significantly shows the high expectations from the government. Therefore, it is beneficial for the policy makers to know the importance and urgency of forbidding straw burning. The government should make more appropriate allocation funds to compensate for recycling straw, combining the punishment of open burning. This result also shows that environmental awareness is very important to the success of pollution prevention. Therefore, how to increase public environmental awareness and knowledge is an important subject in China.

Several limitations exist in this study. Firstly, the survey respondents in our study do not include farmers. This is based on the thought that farmers are the implementers of burning straw and their expectations for environmental improvement may be low. Hence, the economic value of straw burning ban just represents the urban residents not all Henan's people. Secondly, it will be interesting to test the results of the WTP estimates by carrying out the CVM survey in other provinces with the same wheat corn rotation system and similar socio-economic characteristics.

3

CHAPTER 3. DETERMINANTS OF FARMERS' WILLINGNESS TO PARTICIPATE IN CORN STRAW RETURNED TO FIELD AND WILLINGNESS TO ACCEPT AMOUNT: EVIDENCE FROM QUESTIONNAIRE SURVEY IN HENAN, CHINA

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(The environmental protection policy of this research is agricultural straw open burning ban policy. The implementation of burning ban policy in China is inseparable from the participation of farmers in which farmers return crop straw to the field to help reduce straw burning. Chapter 3 is one part of research to develop the reasons of farmers' unwilling to adopt this environmentally friendly agricultural production technology (straw return) and to assess farmers' willingness to accept compensation amount if they use this technology. By understanding the views of population inside of the farm, we hope this could help the Chinese government to formulate better policies to promote farmers' straw return.)

Whereas the Chinese government has issued and enforced regulations prohibiting open burning of agricultural straw. In Chapter 2, the economic value of burning ban policy has been conducted to support government's policymaking; however, with the aim of reducing air pollution, this policy is unlikely to provide a long-term solution. Options for reducing emissions, apart from the ban on burning, include the comprehensive utilization of agricultural straw. Precise identification of activities for addressing environmental goals often requires the development and adoption of specific technologies.

In the past, agricultural straw was used by some farmers in China as domestic fuel. However, in recent years, because of the extensive use of electrical power and natural gas in rural areas, the majority of famers have abandoned this practice. Whereas the use of agricultural straw for generating power has been explored in China, such initiatives have largely failed because of the low efficiency and high costs of straw cutting, collection, transportation, and storage. Some enterprises that use agricultural residue to generate power receive a certain amount of funds as government subsidies that correspond to the amount of crop residue that is consumed. New, practical methods of managing the remaining organic substrate are required to persuade farmers to abandon the practice of burning this residue. The easiest option is mechanical removal through ploughing. Straw can be chopped up and directly decomposed in the soil or composted outside fields as nutrients and organic materials. Returning agricultural straw to the field is the most effective way of absorbing significant amounts of agricultural residue in China.

However, perceptions of straw usage differ among European and Chinese farmers. Agricultural straw is a by-product and not a waste product; it is used for animal bedding and can be returned to the soil as organic matter. In particular, crop residues are considered a reliable resource for energy production, reflected in the EU's commitment to ambitious renewable energy and bioenergy targets. Consequently, the contribution of these forms of energy to the gross final energy consumption is expected to rise from 2,458 picojoules (PJ) in 2005 to 4,605 PJ by 2020 (Monforti et al., 2015). However, the environmental impacts of the potential large-scale use of crop residues for biofuel are of concern. In particular, incentivizing the collection and use of crop residues that would have been otherwise retained in fields can affect soil carbon and soil quality. The implementation of policy measures to regulate the use of crop residues could mitigate this risk. European farmers share the view that whereas a part of the residue can be removed and used to produce bio-based materials and energy, a significant portion must be left in the field to preserve the soil structure and fertility and to maintain ecosystem services.

A major proportion of the total annual production of biomass comprises field residues, which are an important source of organic soil matter in EU member countries. Relevant EU legislation pertaining to crop residues has been aimed at preventing the overharvesting of residues for biofuel. The rules enacted under the Common Agriculture Policy (CAP) on cross-compliance, in accordance with Article 6 (1) of the Council Regulation 73/2009 (Council of the EU, 2009), constitute the main EU legislation regulating crop residues. CAP provides for direct payments made to farmers within EU member states and stipulates that they must comply with the GAEC standards as one of the requirements for receiving this aid. The minimum GAEC requirements comprise a set of standards for securing the protection of broad environmental parameters. Soil quality is included in the following GAEC standards: (1) minimum soil cover and land management practices for limiting soil erosion, (2) maintaining soil organic matter, and (3) maintaining soil structure.

Hence, returning crop straw as organic matter to the soil is a widely accepted agricultural technology both in China and in Europe. However, in China, the process of returning straw is more complicated. This is because of the Chinese crop rotation system (two crops a year region, three crops two years region), resulting in the production of significant amounts of crop residues that exceed the amounts produced in Europe. The high level of mechanization in Europe enables the amount of crop residue harvested to be controlled, which significantly reduces negative impacts on ecosystem services and ensures compliance with policy requirements. Because of their limited access to mechanization, Chinese farmers are unable to collect agricultural straw according to their preferred ratios. In China, the return of straw to the soil entails the return of the entire amount of straw. Evidently, efficient mechanization is also limited by the small areas of the fields. Therefore, returning straw to the fields does not produce a satisfactory outcome for Chinese farmers, which also accounts for their practice of open burning of agricultural straw in their fields.

This chapter explores the factors that influence farmers' willingness to return corn straw to their fields with the aim of improving the implementation of the technology applied for returning straw to the soil in China. The findings are expected to yield useful recommendations for improving straw return in terms of the quantity of straw returned and the identification of appropriate machinery for achieving this. The amount that famers are willing to accept for returning corn straw to their fields is also considered in this study. Subsidy policies are an effective incentive tool for government regulation and technology adoption. Thus, this chapter seeks to answer the following three questions. (1) What are the critical factors affecting farmers' willingness to engage in straw return? (2) What are the determinants affecting farmers' willingness to accept financial compensation for straw return? (3) How much are farmers willing to accept as compensation for implementing straw return?

Abstract

Characteristics making straw useless for farmers, as well as high retrieval costs for enterprises, result in straw being left in the field as rubbish to be continuously openly burned with the atmosphere being polluted. Straw return is promoted by the government as a promising clean technology to avoid open burning, quickly digest straw on the spot and provide an environmental benefit. However, the implementation of this technology has encountered obstacles. The present study aims to examine the factors affecting farmers' willingness to participate in corn straw return and WTA in rural areas of Henan, China. The present study was conducted by a questionnaire survey and face-to-face interviews with respondents. A stratified random technique was applied for selecting 925 farmers. A logistic regression model was used for the adoption analysis, and a Tobit model was developed for WTA analysis. The results showed that machinery cost, amount of returning, quality of straw crushed, decomposing rate, soil fertilizer, corn sown area and gender were key factors negatively influencing adoption of corn straw return. Respondents' WTA compensation was significantly influenced by machinery cost, amount of returning, decomposing rate, soil fertilizer, corn sown area, age, education and household income. The mean WTA of respondents was 47 RMB per mu. The results of the study indicate that the specification of good quality for straw return might encourage farmers to return straw to the field and these results will be useful for policy makers when developing technical standards and subsidy policy for returning corn straw to the field.

1. Introduction

Chinese production of crop straws has reached approximately 1 billion tonnes (Shi et al. 2017), and straw disposal is a challenge for agriculture in China. Open burning is an inexpensive means to effectively tackle crop straw and inevitably causes air pollution. Other complications, such as human health risks, atmospheric visibility reduction, fire hazard and global climate change, add to the existing problems of open burning. To forbid or limit agricultural open burning and protect the atmosphere, the Ministry of Environmental Protection of the Peoples' Republic of China and 5 other departments of the State Council promulgated the "Straw burning ban and comprehensive utilization of management approach" in 1999. However, the phenomenon of straw burning, especially during wheat, corn and rice harvesting periods, remains common every year.

To root out open burning, the Chinese government currently considers two measures. The first measure is developing an interception policy, which involves setting up a responsible system for supervision and administration. The burning ban interception policy fines and detains farmers that burn straw in the open field. Nevertheless this policy is unlikely to provide a long-term solution. Options for reducing pollutant emissions, apart from the ban on burning, include the comprehensive utilization of agricultural straw. Hence the second strategy is a guiding measure in which multiple recycling methods of agricultural crop residue are encouraged and explored such as using straw as a fertilizer, as animal fodder, as a mushroom growth substrate, or as a material for bioenergy production, etc. Based on many years of experience, the government proposed that “the guiding measure” of recycling utilization is key to finally ending straw burning.

However, many problems restrict the development of recycling utilization; for instance, there is no a sound straw collection system in China because of the high cost of collection, transportation and storage. The easiest option is mechanical removal through ploughing. Hence, the technology of directly returning straw to the field under mechanization without these restrictions is recommended as the most effective and sustainable means to recycle crop straw in the current situation (Ma and Qin 2009).

From 1995 to 2005, China produced about 630 million tonnes of crop residue per year (Liu et al. 2008). Typically, 406 million tonnes of the total crop residue was reused, while the rest was lost during collection, discarded or burned in the field. The largest part of this reused crop residue is used as fuel to be combusted by farmers for cooking and heating. The second largest part (145 million tonnes) was used for animal feed. Just 25 million tonnes of this crop residue was used in industries as a raw material. Ten years later, the proportion of straw utilization changed. In 2015, the theoretical amount of crop residue was 1040 million tonnes (National Development and Reform Commission 2015). Around 720 million tonnes of the total crop residue was reused as fertilizer, feed, energy, substrate, and raw materials, accounting for 54%, 24%, 14%, 5% and 3% of these 720 million tonnes. Currently, production of crop fertilizers is the main method of straw recycling. However, some farmers are still unwilling to return straw to the field and they discard straw or burn their straw in situ, the amount of which is about 180 million tonnes (National Development and Reform Commission 2015).

Straw is typically returned to the field as a chopped crop residue of 3-5 cm, which is spread onto the soil surface or incorporated into the soil by plowing. Straw return has manifold benefits, and successful application of straw return not only consumes straw but also produces environmental benefits by reducing air pollution, improving soil fertility and soil structure (Turmel et al. 2015; Henryson et al. 2018). Especially, straw return produces greater crop yield (Malhi et al. 2011), and straw removal may have an adverse impact on crop production and could decrease crop yields (Blanco-Canqui et al. 2006).

However, "side effects" of straw return such as long straw length after mechanical crushing, slow decomposition rate, and more pests appeared increases the difficulty of returning straw to the field and the farmers' cultivation costs in China. Moreover, the quantity of straw that can be accepted per hectare is limited. While in the winter wheat and summer corn rotation system, straw return means that the total amounts of wheat and corn residues are returned to the field. In addition, the complicated operation of returning straw to the field, generally including 2 crushed, 1 deep plow, 2 rotations and 2 repressions to make sure good quality of straw return, has increased the production cost of farmers and affected the enthusiasm of farmers for returning straw to the field.

As the return of straw to the field could be sustainable, determining the factors affecting and motivating farmers' willingness to participate in the return of straw to the field is important for policy makers to decide the relevant policy instruments. Since 2009, some studies have examined the factors influencing the acceptance of straw return by farmers (Rui et al. 2009; Liu and Lu 2013; Liu et al. 2014; Tong and Liu 2017). Most of these studies, based on actual observations, concluded that willingness to participate in straw return is a function of farmer characteristics. However, previous studies have paid little attention to the difficulties in the implementation of straw return, and these existing difficulties may affect farmers’ costs and benefits.

Obviously, returning straw to the field is relatively expensive and less convenient than open straw burning. Farmers, however, place greater emphasis on their own interests from the technology adoption. Consequently, there is a different objective in straw disposal options between the government and farmers. The government is needed to coordinate the contradictions between protecting the environment and potential loss of interest in straw return. Subsidy policy is an effective incentive for government regulation (Vanslembrouck et al. 2002; Kurkalova et al. 2006), such as the approach of the European Commission in Regulation 2078/92 and Agenda 2000 has proposed a new framework based on payments to farmers in return for the provision of environmental services. In China, local governments have only recently provided subsidies to farmers for straw return on a small scale, and there is no sufficient data to support subsidy standards.

Therefore, the objectives of the present study is (i) to determine the critical factors affecting farmers’ willingness to participate (ii) to assess how much is the farmers' willingness to accept for corn straw return in Henan? (iii) to determine the factors affecting farmers’ willingness to accept for corn straw return. Given the objectives of the study, the following hypotheses were formulated:

H1

Respondents who think machinery cost for returning corn straw to the field is too high are more unwilling to participate in corn straw return and willing to accept more compensation.

H2

Those respondents who think it is not good to return whole corn straw into soil tended to be more unwilling to participate in corn straw return and willing to accept more compensation.

H3

Those respondents who think the quality of corn straw crushed is poor are more unwilling to participate in corn straw return and willing to accept more compensation.

H4

The respondents who think decomposing rate of corn straw in the soil is slow are more unwilling to participate in corn straw return and willing to accept more compensation.

H5

The respondents who think corn straw return improves soil fertility are more willing to participate in corn straw return and willing to accept less compensation.

H6

The respondents who think straw return protects the atmosphere are more willing to participate in corn straw return and willing to accept less compensation.

H7

The respondents who think corn straw return is beneficial to the growth of wheat are more willing to participate in corn straw return and willing to accept less compensation.

H8

Sown area has significant and positive effect on adoption of corn straw return and negative effect on WTA.

H9

Socio-economic characteristics of the respondents have significant and positive effect on adoption of corn straw return and negative effect on WTA.

2. Methodology

2.1. Study sites and data

The study was conducted in the rural areas of Henan province that possess the largest 14425×10^3 ha sown areas of farm crops in China. Winter wheat and summer corn rotation is the main cropping system, accounting for 38% and 23% of Henan's total sown areas of farm crops, respectively. Henan had the most number of fire points in China both in 2014 and in 2015 during harvest period. Henan has great pressure of disposing crop straw especially when harvesting wheat and corn. A stratified random sampling method was used for selecting the famers to be surveyed. Firstly, typical cities of Henan province were determined including Zhoukou and Shangqiu (eastern region), Kaifeng and Xuchang (central region), Luoyang (western region) and Hebi (northern region) (Figure 3-1). Secondly, in each city, two or three counties were randomly selected. Thirdly, in each county, two or three small towns were randomly chosen. Fourthly, five villages were randomly chosen from each town. Fifthly, in each village, families were selected associated with households in the list from village committees by systematic random sampling method. Finally, one household member was randomly selected to interview.

The study was pre-tested in Henan, and the data was collected through a survey of the farmers based on a questionnaire. A first draft of the questionnaire was designed according to the research purpose to obtain insights into the main driving forces determining the participation of straw return in rural areas in Henan. From the results of this pretesting survey, the questionnaire was refined, and subsequently a large-scale investigation was performed by face-to-face interviews with farmers. The minimum required sample size (384) is recommended by a 5% margin of error at a 95% confidence level as well as 50 million rural residents in Henan province (Denscombe, 2010). In practice, 931 farmer surveys were collected and 925 complete responses were effective, i.e., 220 questionnaires from Zhoukou, 258 questionnaires from Shangqiu, 85 questionnaires from Xuchang, 99 questionnaires from Kaifeng, 103 questionnaires from Luoyang, and 160 questionnaires from Hebi. The interview lasted 25-30 minutes and was administered by nine well-trained students, including six master candidates, two doctoral candidates and one post doctorate fellow, who have a good knowledge of rural development and communication skills with farmers in Henan Province.

The survey was based on actual observations, and the farmers were asked whether or not they were willing to participate in straw return. The farmers were also asked about their WTA for corn straw return, as shown below.

Straw returned to field is a clean production technique that can reduce environmental pollution in contrast to open burning. However, straw returned to the field will increase the burden on farmers. We proposed that the government promote corn straw return to the field by paying farmers who employ the technique. Therefore, we asked "what is the minimum amount of money you would accept to return corn straw to the field_______RMB per mu (1 mu = 1/15 hectare)?"

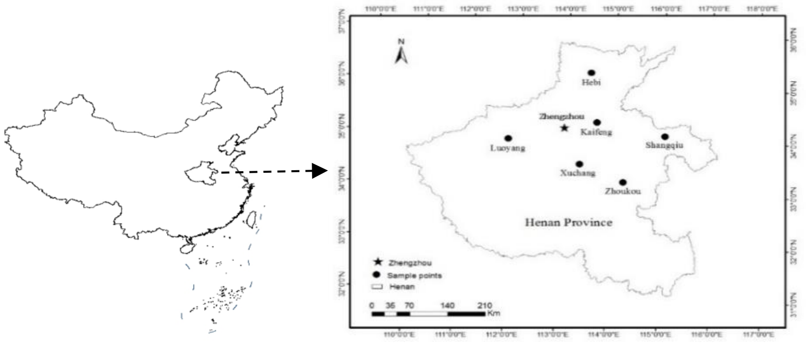

Figure 3-1: Study area of Henan, China (Black dots indicate respondent farmers were selected from the six cities)

2.2. Open-ended elicitation method

In an open-ended format of WTA elicitation, the respondents are directly asked what is the minimum money you are WTA. However, open-ended question often befalls high rates of non-response and/or resulting in lots of zero as well as much big values (Eberle and Hayden 1991). This elicitation method may be abandoned owing to respondents have no idea how they should value environmental goods. While open-ended questions might be the best way to elicit respondents' maximum or minimum prices (Van den Berg et al. 2005) and work well when respondents are familiar with the concept under valuation (Mitchell and Carson 1986).

The reasons of choosing open format method in this survey are as follows. First, respondents are very familiar with straw return technology which is significant technology introduced suggested by the government. Many respondents can articulate the advantages and disadvantages of straw return. Second, non-response rate in this survey was very low. Third, suggesting values would have been difficult. If the suggested values were perceived as being 'too low', farmers would be upset and suspect sincerity and attitude of the government. On the other hand, suggesting large values might stimulated high WTA value or would make the study proposed not credible. Hence, open-ended method was used in which respondents were asked what is the minimum compensation per mu that you would have to receive in order to participate in returning corn straw to the field?

2.3. Models

2.3.1 Binary Logit model

In our survey, logistic regression model was applied to investigate the determinants influencing farmers' willingness to participate in straw return. The dependent variable, willingness to participate, is binary (Yes is 1 and No is 0). Logistic regression is used when the dependent variable is dichotomy and the independent variables are of any type. This logistic model was well applied for adoption analysis (Kabir et al., 2013; Sheikh et al., 2003; Vanslembrouck et al., 2002) and employed to estimate the possibility of occurrence of a certain event by fitting data to a logistic distribution function (Morgan and Teachman, 1988). The dependent variable becomes the natural log of the odds and the logistic model is specified as:

$$\ln\left[P/(1-P)\right]=\sum\beta X \tag{1}$$

where P is the probability that farmer is willing to participate in straw return, β is the coefficients to be estimated, X are independent variables.

2.3.2 Tobit model

Tobit model was employed to analyze the determinants influencing farmers' willingness to accept for straw return. Because if the dependent variable is censored (left-, right-, or bi-censored) for a significant fraction of the observations, parameter estimates obtained by ordinary least squares regression are biased. The standard Tobit model (Tobin, 1958) is that the dependent variable y is left-censored at zero:

$$y_i^*=X_i\beta+\varepsilon_i,\quad \varepsilon_i\sim\mathrm{N}(0,\sigma^2) \tag{2}$$

$$y_i = \begin{cases} y_i^*, if\, y_i^* > 0 \\ 0, \quad if\, y_i^* \le 0 \end{cases} \tag{3}$$

Where for the *i*th individual, y_i^* is the latent (unobservable) variable; y_i is observed; X_i is vector of independent variables; β is unknown parameter vector to be estimated; and σ^2 is error term which are assumed to be normally distributed with mean zero and constant variance sigma square (σ^2). Moreover, in the generalisation of the standard Tobit model, the dependent variable can be censored either or both sides and the lower and/or upper limit of the dependent variable can be any figure:

$$y_i^* = X_i\beta + \varepsilon_i, \quad \varepsilon_i \sim \mathrm{N}(0,\sigma^2) \tag{4}$$

$$y_i = \begin{cases} a, \quad if\, y_i^* \le a \\ y_i^*, if\, a < y_i^* < b \\ b, \quad if\, y_i^* \ge b \end{cases} \tag{5}$$

where a is the lower limit and b is the upper limit of the dependent variable. In the analysis of the farmers' WTA for straw return, a is 0 and b is 100.

3. Results

3.1. Descriptive Analysis

3.1.1 Socio-Economic and Demographic Characteristics of Households

The data used for this study was collected from a randomly selected 925 sample farmers. Of the total sample surveyed farmers, 277 were female headed and the remainder 648 were male. The average age of the total sample was 56 years. The samples' age are with a minimum of 20 and a maximum of 80. The average income of the sample was 7093 Chinese Yuan (RMB). The average education level of the sample was 8 years.

3.1.2 Responses of participation in corn straw return

A summary of the survey results is shown in Table 3-1. Surprisingly, only 81 farmers did not return corn straw to the field. However, although 844 farmers returned corn straw to the field, 24% of them (199 respondents) expressed that they were actually not willing to return corn straw to the field in the question "Are you willing to adopt corn straw return to field for protecting the atmosphere?" The reasons for unwillingness to participate of the 199 respondents are the influence of wheat sowing and seedling emergence as well as the high machinery cost for corn straw return (Table 3-2). The remained 76% of them (645 respondents) were willing to adopt corn straw return technology, however, 181 respondents of them answered that they returned corn straw owing to the pressure of burning ban policy (Table 3-3). 20% of the total respondents answered that they preferred to burn corn straw in the open field compared to corn straw return if there is no governmental burning ban.

Even though 99% of respondents admitted crop straw return to field can protect the atmosphere, the numbers of respondents who were willing to adopt corn straw return to protect the atmosphere decreased, and 27% of respondents were still not willing. Moreover, 98% of respondents thought the government should compensate them for corn straw return.

Most respondents (39%) without willingness to participate thought corn straw return would affect subsequent wheat sowing, which was the primary reason for their unwillingness to return corn straw. The second largest group, accounting for 29% of respondents, was subjected to high machinery costs to pay for straw return. The third largest group (24%) of respondents did not want to participate because corn straw return affects wheat germination.

Note:

1. Mean size of farmland in the survey is 6.7 mu per household (1 mu = 1/15 hectare).

2. 81 respondents did not return corn straw to the field, and 17 of the respondents' corn straw were discarded at the field border, 15 of the respondents' corn straw were collected for cooking, 13 of the respondents' corn straw were taken away by others freely, 11 respondents' corn straw were transported and buried somewhere, 8 of the respondents' corn straw were collected as animal feed, 6 of the respondents' corn straw were sold. In addition, 25 respondents burned corn straw in the field, 11 of them also returned some part of land's corn straw to the field, 1 respondent landfilled corn straw and 1 respondent collected corn straw for cooking.

3. Major cropping system in the survey area is summer corn and winter wheat rotation system. 925 respondents were surveyed, of which 203 respondents not only cultivated summer corn and winter wheat but also planted other crops. The residues of other crops were not considered in this survey.

Table 3-1: Statistics of respondent' choice and the reasons for not willingness to participate

Items	Options	Sample size	Proportion (%)
Did you return straw to the field in 2015?	Yes	844	91
	No	81	9
Do you think crop straw returned to field can protect the atmosphere?	Yes	916	99
	No	9	1
Will you openly burn corn straw if there is no governmental ban on straw open burning?	Yes	183	20
	No	742	80
Do you think the government should make compensatory payments to farmers who returned corn straw to field?	Yes	909	98
	No	16	2
Are you willing to adopt corn straw return to field for protecting the atmosphere?	Yes	675	73
	No	250	27
Reasons for not willingness to participate			
1 Affect wheat sowing		97	39
2 High machinery cost		73	29
3 Affect seedling emergence of wheat		61	24
4 Others		19	8

Table 3-2: Reasons for unwillingness to participate of 199 respondents with corn straw return

1 Affect wheat sowing	83
2 High machinery cost	54
3 Affect seedling emergence of wheat	53
4 Others	9

Table 3-3: Reasons for willingness to participate of 645 respondents with corn straw return

1 To improve soil fertility	379
2 The burning ban policy	181
3 Cost-saving in fertilizer input	61
4 Others	24

3.2. Determinants influencing farmers' willingness to participation and accept amount for corn straw return

The variables to be used in the models (Logistic and Tobit) are introduced in table 3-4. In the willingness to participate model (Table 3-5), the log likelihood did not vary at a value -441.49 after 4 iterations. The LR χ^2 value for the model was 196.54 and is significant at the 1% level, showing that the coefficients of the independent variables are not equal to zero. A total of 12 independent variables were considered in the model, out of which 7 variables were found to significantly influence willingness to participate in corn straw return and 9 variables were found to significantly influence minimum WTA ($p<0.1$).

A significant negative coefficient for machinery cost and no significant coefficient for income variable indicated that the farmers think that machinery costs for returning corn straw to the field are too high to be willing to participate, and this thought has nothing to do with their economic ability. These farmers showed 12.63% less probability of willingness to participate in corn straw return, suggesting that some farmers are able but unwilling to pay for the increased costs caused by returning corn straw to field. Alternatively, this result may indicate that farmers attach great importance to the mechanical cost of straw return, which is a significant barrier to participation.

The amount of corn straw return was among the statistically significant ($p<0.01$) factors determining the participation decision and had a negative influence on the behavior toward returning corn straw to the field. Farmers who think that it is not proper to return whole corn straw into soil are less inclined to return corn straw. The marginal effect shows that the likelihood to participate of these farmers decreased by 24.30%.

The quality of crushing of corn straw had a significantly ($p<0.05$) negative relationship with the willingness to participate in corn straw return. The marginal effect revealed that the poor quality of crushing of corn straw would decrease the probability of a farmer's willingness to return corn straw by 6.67%.

Another statistically significant ($p<0.01$) and important variable in the participation attitude is the speed of corn straw decomposition in the soil. The slower the decomposition, the less likely the farmer is to return corn straw, which may decrease the probability of returning corn straw to the field by 6.90%.

Soil fertility had a positive and significant ($P<0.01$) effect on farmers' decisions. Farmers who perceive that corn straw return can improve soil fertility are more willing to participate, and their probability of willingness to participate was 10.13% higher than those farmers who think there is no difference in the soil fertility after corn straw return, indicating that farmers value the soil quality. Moreover, atmosphere and wheat growth had no statistically significant effects on farmers' decisions, showing that while these farmers agree that straw return can protect the atmosphere, the farmers' demand for good air quality is not high, and although corn straw return is good for crop growth, there may not be a significant change wheat growth.

The sown area was positively associated with the willingness to return corn straw, and this effect is statistically significant ($p<0.1$). Farmers with larger sown areas are more likely to return corn straw than farmers with smaller sown areas. An increase of one mu in the sowing area would increase the likelihood of farmers to participate in corn straw return by 0.49%.

Interestingly, gender also significantly ($p<0.1$) influenced the farmers' willingness to return corn straw. Male farmers were more negative than female farmers toward participation in corn straw return. Women farmers are more likely to return corn straw, and the probability of women returning corn straw was 4.95% higher than that of men.

In the WTA model, nine variables significantly affected the farmers' WTA amount (Table 3-6). Machinery costs, returning amount, decomposition, soil fertilizer, growth, sown area, age, education and income level were significant determinants. High machinery cost, the whole corn straw returned to soil, and corn straw decomposition at a slow speed increased the amount of farmers' WTA. Soil fertilizer was negatively ($P<0.01$) associated with farmers' WTA amount. Soil fertilizer and the growth of the subsequent wheat were benefit variables that were both negatively ($P<0.01$) associated with farmers' WTA amount. The farmers who think that corn straw return can improve soil fertility and is beneficial to the wheat growth are willing to accept less compensation for corn straw return. The larger corn sown area decreased the WTA amount. The estimated coefficient for farmers' age had a negative and significant ($P<0.1$) effect on WTA amount. This negative signs of the estimates for age variable reveals that aged farmers have a lower expectation for WTA amount than the young farmers. The Tobit regression results also revealed that the year of education of farmers was negatively correlated with WTA amount ($p<0.01$). The negative signs of the estimates for the education showed that WTA decreases with increasing education of the farmers. In the case of corn straw return, education is likely to ensure a better understanding of the benefits (soil fertility, atmosphere and wheat growth) linked to the corn straw return. The household's income showed that the wealthier farmers, as expected, are more likely to accept less compensation for corn straw return.

Table 3-4: Definition and descriptive statistics of explanatory variables

Variables	Definition and unit
Machinery cost	1 if the farmer thinks machinery cost is too high
Returning amount	1 if the farmer thinks there are some problems or it is not good to return whole corn straw into soil
Straw crushed	1 if the farmer thinks there is poor quality of crushing of corn straw
Decomposition	1 if the farmer thinks decomposing rate of corn straw in the soil is slow
Soil fertility	1 if the farmer thinks corn straw return improves soil fertility
Atmosphere	1 if the farmer thinks straw return protects the atmosphere
Growth	1 if the farmer thinks corn straw return is beneficial to the growth of wheat
Sown area	The farmer’s family corn cultivated land area (mu)
Gender	1 if male
Education	Education in years
Income	Per capita annual disposable income of rural household

Table 3-5: Regression results for farmers’ willingness to participate

variables	Coefficients	z-value	Average marginal effects
Machinery cost	-0.819***	-3.68	-0.1263
Returning amount	-1.576***	-8.29	-0.243
straw crushed	-0.432**	-2.33	-0.0667
Decomposition	-0.448***	-2.47	-0.069
Soil fertility	0.657***	2.59	0.1013
Atmosphere	1.015	1.27	0.1565
Growth	0.157	0.78	0.0241

Sown area	0.032*	1.6	0.0049
Age	-0.001	-0.1	-0.0001
Gender	-0.321*	-1.6	-0.0495
Education	0.003	0.09	0.0005
Income 1000	-0.002	-0.29	-0.0004
Constant	0.936	0.87	
Log likelihood	-441.4938		
LR χ2 (12)	196.54***		
Pseudo R2	0.1821		
Sample size	925		

***, ** and * show significance levels at 1 %, 5 % and 10 %, respectively

Table 3-6: Regression results for farmers' willingness to accept compensation

variables	Coefficients	t-value	Marginal effects¶
Machinery cost	11.000***	7.9	10.909
Returning amount	2.777*	1.83	2.761
straw crushed	0.146	0.1	0.145
Decomposition	3.346**	2.41	3.326
Soil fertility	-5.196***	-2.57	-5.167
Atmosphere	-1.407	-0.23	-1.400
Growth	-3.909***	-2.8	-3.886
Sown area	-0.288**	-2.2	-0.287
Age	-0.102*	-1.67	-0.101
Gender	1.875	1.35	1.864
Education	-0.720***	-2.95	-0.716
Income 1000	-0.163***	-2.54	-0.162
Constant	58.324***	7.38	
Log likelihood	-3876.879		
LR χ2 (12)	147.03***		
Pseudo R2	0.0186		
Sample size	925		
Uncensored observations	886		

¶Marginal effects on the censored expected value.

***, ** and * show significance levels at 1 %, 5 % and 10 %, respectively

Approximately 98 % of farmers interviewed wanted the government to compensate the corns straw return, and the mean WTA of the total sample was 47 RMB per mu (Table 3-7). In reality, the existing government subsidy for corn straw return in Henan is zero or just 5-15 RMB per mu per year which is far less than the farmers' WTA value, indicating that the existing level of compensation for corn straw return is too low to drive farmers to participate.

Table 3-7: Mean WTA versus actual government subsidy (RMB mu^{-1} $year^{-1}$)

	Sample mean WTA	Actual government subsidy
Corn straw return	47	0, 5-15

4. Discussion

For the government, compared to the negative externality caused by open burning of crops straw, returning straw to the field is currently an inexpensive and clean technique to consume a large amount of crop straw. However, some farmers still burn straw openly and do not really accept the technology of straw return. The reasons for resistance to straw return were explained in this research. Seeking out the factors influencing farmers' willingness to participate in corn straw return and their WTA will show signs of unwillingness to facilitate the development of straw return and will provide data for subsidy policy. We performed a survey study and 925 valid questionnaires were acquired with sampled farmers in Henan, China.

According to the results of farmers' responses to corn straw return, although most of the farmers returned corn straw to the field and admitted that straw return can protect the atmosphere, in fact, some of these respondents who returned corn straw to the field are not voluntary. This is the helpless choice under the burning ban policy. In addition, many farmers still adhered to their choice of open burning if there was no government policy of forbidding open burning. These results reveal that the willingness of farmers to choose straw return to the field may be not positive, and some farmers are forced to return straw to the field against their will. In this situation, the government should not blindly emphasize the benefits and importance of straw direct return but should strengthen the investigation of the actual problems of straw return, which is also why we conducted the present research.

The results of the logit model showed that farmers' willingness to participate in corn straw return is significantly negatively influenced by machinery cost, returning amount, straw crushed and straw decomposition, indicating that not only the direct money costs but also the indirect problems occurring in the process of straw return have determinant influences. The government should attach importance to the specification of technical requirements for straw return.

For instance, first, China has a vast territory, in which climate and soil as well as crop planting and rotation systems vary across regions; a uniform requirement for straw return is not desirable. Excessive corn straw cannot be buried in the soil and will affect wheat sowing quality and endanger the root growth of subsequent wheat. Moreover, thick crop residues can hinder crop emergence and may reduce crop emergence rate (Wu et al. 2002). Based on the actual situations, the local governments should determine where and how much crop straw could be directly returned. Otherwise, excessive corn straw can either be manually removed or more evenly distributed deeper into the soil through machine operations.

Second, the quality of mechanical work should standardized, such as the length of crushed straw and the depth of plowing. The appropriate length of corn straw return is 3-5 cm. However, after mechanical crushing, the straw length may still be too long, making it difficult to mix with the soil, which affects wheat sowing, emergence and growth. Hence, farmers will need to pick up long straw or employ more mechanical crushing.

Third, the decomposition rate of corn straw in the soil is a key factors influencing farmers' adoption of corn straw return. Corn straw returned to the field does not decompose for a long time, while the seedling growth of winter wheat can be negatively affected when seedling roots encounter unweathered corn residues (Wuest et al. 2000). However, the decomposition of straw is related to soil moisture and the available C and N in the soil (Reinertsen et al. 1984). Straw returned to the field will absorb part of the nitrogen when the soil is decomposed. The subsequent wheat may be yellow owing to lack of nitrogen. Either additional irrigation for wheat planting, a reasonable amount and type of fertilizer or straw-decomposing inoculant are important for straw decomposition. Hence, to quickly decompose straw, the farmers should know how and when to irrigate, and the fertilizer types and fertilizer amounts that should be applied.

The farmers owning larger sowing areas are significantly more willing to participate in corn straw return. According to Zuo (2011), the different result showed that the scale of farmer planting is positively correlated with the probability of straw open burning, showing that the larger-scale farmers are more likely to select open burning. A potential explanation for this finding is that farmers with larger planting areas have higher risks related to the environment, personal safety and punishment for open burning, or these individuals can fight for a lower cost of mechanical work for returning straw because of larger planting areas and have scale efficiency of crop farming.

The present study also found that almost all farmers think that the government should compensate for the returning of straw. In the WTA analysis, machinery cost, returning amount and decomposition significantly positively affect farmers' WTA. This result, combined with results of the participation model, suggest that these three variables may be the main reasons why farmers do not want to return straw to the field. If farmers can be satisfied with these three aspects of straw return, we may acquire the support of straw return and achieve the sustainability of straw return. Soil fertility improved and good growth of the next wheat decrease farmers' WTA, as expected. Similarly, the income and education had negative significant influence on WTA. As level of income and education increase, the compensation amount for straw return decrease. It shows the low-income responses expect higher compensation and suggests the more educated farmers are supposed to better understand the advantage of straw return and be aware of the negative effects of straw open burning on the environment.

More importantly, the farmers' desired WTA for straw return is far greater than the actual compensation; therefore, the government should adopt a subsidy level that meets the level of willingness of farmers to accept, which will encourage farmers to return straw to the field. According to the analysis in the present study, farmers really attach importance to their cost of returning straw.

5. Conclusion

According to the results, machinery cost paying for returning corn straw to the field is the key factors influencing farmers' willingness to participate and WTA for straw return. Thereby, the first hypothesis is accepted. Based on the results, the following key factors decreased farmers' willingness to adopt straw return technology: the whole amount of straw return, slow decomposing rate and the poor quality of crushing were negative factors influencing farmers' willingness to participate and positive factors influencing farmers' WTA. Thereby, second, third and fourth hypotheses are accepted. Based on the results, the farmers who think corn straw return improves soil fertility are more willing to participate in corn straw return and willing to accept less compensation amount. And farmers who have more sown area are more willing to participate in corn straw return and willing to accept less compensation amount. Accordingly, fifth and eighth hypotheses are accepted. According to the results, age, education, income had no significant effect on willingness to participate, moreover, gender had negative and highly significant effect on willingness to participate. Accordingly, the ninth hypothesis is rejected meaning that all socio-economic characteristics of respondents do not have positive and significant effect on willingness to participate in corn straw return and negative effect on WTA.

Straw return is currently a key clean technology to tackle the large amounts of crop straw and reduce farmers' open burning of straw. While developing straw returning, we encountered the opposition and resistance of many farmers. Thus, it is meaningful to investigate the factors influencing the farmers' willingness to participate and WTA for straw return to maintain the sustainable development of straw return. The results of the study will be useful for policy makers when making up their mind about what kinds of technology instruments could be suitable to promote straw return technology and how much money could suitable to compensate farmers.

4

CHAPTER 4. AN EVALUATION OF MINIMUM TILLAGE IN THE CORN-WHEAT CROPPING SYSTEM IN HEBEI PROVINCE, CHINA: WHEAT PRODUCTIVITY AND WATER CONSERVATION

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(To reduce straw is one way to reduce open burning which means air pollution will also be reduced. Agricultural production is an important outlet to reduce straw. Chapter 4 is one part of research to explore the effects of corn straw return under tillage on wheat growth. By understanding the effects of straw return in agricultural production, we hope this could provide technical support for the Chinese government to popularize the technology of straw return.)

Agricultural straw has been found to be rich in organic material and soil nutrients. Therefore, there is growing recognition of its importance as an organic fertilizer. Farmers are also becoming increasingly aware that returning straw to the field not only provides a valuable source of plant nutrients but can also help to maintain or build up levels of soil organic matter. This is one of the major factors affecting soil properties and functions, including a range of physical characteristics, such as water-holding capacity, water infiltration, and aggregate stability.

Returning straw to the fields is usually achieved using full or conservation soil tillage technology. Tillage prepares seedbeds, incorporates organic material and fertilizer, and suppresses weeds and some diseases and insect pests. Full tillage is combined with the use of the moldboard plow to invert the top 20-25 cm of soil and bury plant debris, leaving a soil surface that is almost bare. The moldboard plow is used to incorporate the chopped straw into the soil. This technology, which combines straw incorporation and full tillage, is the most widely practiced form of tillage in mechanized agriculture. Until recently, cultivation of agricultural soils has been achieved mainly by inverting soil using tools such as the plow.

Soil erosion and infertility and water deficiency are the main factors limiting crop growth in semiarid areas of China (Mupangwa et al., 2008). A recent study from China has shown that straw collected from previous harvests can help to increase crop yields and improve the efficiency of water use in arid regions. By testing different techniques for improving water efficiency, the researchers found that the most effective method of promoting water efficiency when cultivating corn and wheat together during the same growing season was to cover the soil with straw. Agricultural straw mulching can increase water intake and storage (Mulumba and Lal, 2008), protect the soil against the impacts of rainfall and reduce erosion rates (Sadeghi et al., 2015), decrease concentrations of sediment and nutrients in runoff (Gholami et al., 2013), and enhance the physical conditions of soil in terms of its structure and organic content (Karami et al., 2012). Straw mulching usually entails the application of conservation tillage which is the appropriate method of tillage for managing crop residue on the soil surface with minimal or no tillage. The goal of conservation tillage in relation to crop residue management is to leave enough plant residue on the soil surface at all times for controlling water and wind erosion, reducing energy consumption, and conserving soil and water (Unger and McCalla, 1980).

In the 1930s, the United States underwent a process of desertification involving soil loss through water and wind erosion that resulted in a wide range of environmental problems. Consequently, soil conservation techniques were first developed in the United States to combat soil loss and preserve soil moisture. However, in Europe, soil degradation has only recently been identified as a widespread problem along with the discovery that a significant proportion of Europe’s cultivated land (16%) is prone to soil degradation. Serious water erosion as a consequence of degraded soil conditions occurs on 12% of the total European land area and wind erosion occurs on 4% of this area (Oldeman et al., 1991). The European Conservation Agriculture Federation (ECAF) was established in 1999 to identify and draw attention to problems in agriculture and to promote conservation agriculture in EU member states (ECAF, 2001).The area under cultivation, in which minimum tillage is applied, is increasing in Europe, primarily because of efforts to reduce production costs but also as a way of preventing soil erosion and retaining soil moisture (Holland, 2004). European organic farmers are motivated to implement cover crop mulch–based nontillage to improve soil fertility and achieve further managerial benefits, such as savings in labor and costs (Vincent-Caboud et al., 2017). In a study conducted in southern Europe by Peigné et al. (2016), 34% of the 50 interviewed farmers reported the use of no tillage, with only 48% implementing a cover crop.

Both in China and in Europe, farmers as well as researchers are faced with challenges that constrain the expansion of crop mulch–based conservation tillage in organic farming conducted in temperate climates. Studies conducted by Armengot et al. (2015) and Mäder and Berner (2012) reported low levels of adoption of organic crop mulch–based non-tillage and living or mulch cover crop-based techniques among European farmers, partly because cover crops were regularly destroyed in the absence of synthetic herbicides. In China, farmers have expressed doubts about the effects of straw mulch and conservation tillage on subsequent crop yields. Previous studies also reported that straw return could negatively affect the growth of subsequent crops (Unger, 1978; Kaspar et al., 1990). In particular, there are doubts about the effect of a combination of corn straw mulching and conservation tillage on subsequent yields of wheat crops (Xie et al., 2007).

Chapter 3 discussed the factors that influence farmers’ willingness to return corn straw to their fields. In this chapter, we examined experimental results relating to the effects of corn straw return on the soil associated with conservation and full tillage. The selected study area was Hebei Province in China, where the main crop rotation system is conducted for winter wheat and summer corn. This chapter was aimed at providing answers to the following three questions: (1) What are the effects of minimum tillage with corn straw return on winter wheat yields? (2) What are the differences in soil water content under various tillage practices? (3) If conservation tillage is effective in conserving soil water, what then are the effects of straw return under conditions of minimum tillage and reduced irrigation on yields in North China?

Abstract

In North China, where the main crops are winter wheat and summer corn, current agricultural practices involve minimum tillage for corn and full tillage for corn or wheat, which use large amounts of irrigation water, especially during the wheat growing season. Conservation tillage (CT) is a promising method for water conservation, but local farmers still question whether it will affect the yield of winter wheat. We conducted fieldwork during 2011-2014 in Xushui, Hebei, China, to compare the effects of various methods of tillage, mulching, and irrigation on the yield, soil moisture, and soil temperature under a summer corn-winter wheat double cropping system. Wheat grain yield in 2012-2013 did not differ significantly because of tillage, residue and irrigation treatments. This means that reduced irrigation did not affect grain yield for all the treatment. However, in 2013-2014, yield for Minimum tillage with residue mulch (MT_m) was slightly but not significantly higher than the yield under full tillage with residue incorporation (FT_i). Yields for MT_m with reduced irrigation were 10.2% significantly higher than FT_i with reduced irrigation. The positive crop response to MT_m may have been due to relatively higher topsoil moisture and soil temperature under MT_m than FT_i during the winter period. Minimum soil temperature for the inter-row at the 5cm depth under MT_m remained slightly higher than that of the FT_i during winter in 2012-2013 with colder weather than 2013-2014. Hence, we concluded, after our two-year field experiment, that MT_m resulted in higher grain yields compared with FT_r probably due to higher topsoil water content; MT_m with reduced irrigation maintained high yields despite eliminating one round of irrigation. Therefore, MT_m with reduced irrigation was more beneficial for winter wheat crop production in North China.

Key words: crop residue, soil temperature, soil water content, yield

1. Introduction

North China possesses approximately 3.6×10^7 ha of arable land, accounting for approximately 30% of China's total, and produces up to 42% and 79% of China's corn and wheat, respectively (Du, 2013). In this area, grain yield depends largely on irrigation; consequently, agricultural irrigation consumes more fresh water than that for other uses. North China is currently confronted with ever-greater demands for water and widespread water shortages have developed. Excessive use of groundwater for large-scale agricultural irrigation to produce high grain yields, and the decreasing water table in North China are receiving increased attention, not only from local residents, but also from government agencies and researchers (Zhang et al., 1999; Zhang et al., 2003; Qin et al., 2006; Pan et al., 2011). It is important to develop a new system of crop rotation that is designed to conserve water, while maintaining stable grain production.

Conservation tillage (CT) is well-known and acknowledged as a promising tillage practice that focuses on reducing soil erosion and enhancing soil water conservation (Mannering and Fenster, 1983). CT generally involves no-tillage (NT), minimum tillage (MT), or at least reduced tillage, as well as crop residue mulching (Uri, 1997; Kong et al., 2009; Van den Putte et al., 2010). MT for corn has been the accepted and prevalent water conservation practice for some areas in North China. Kaspar et al. (1990) reported that CT retards the growth of the crops and Unger (1978) reported CT inhibits early growth of crops. CT may negatively affect winter wheat growth in the double cropping system of China. However, information regarding CT is contradictory. Xie et al. (2007) reported that the practice of CT results in a decrease in wheat yield because of the relatively low tiller number and soil temperature compared with FT. These characteristics of CT prevent its full implementation with wheat plantings in China. However, other researchers have demonstrated positive effects of CT on crop yield because of improved soil conditions (Li et al., 2007; Su et al., 2007; He et al., 2011).

Therefore, the purpose of this experiment was to demonstrate the effects of MT and FT on winter wheat yield and tiller number, and to evaluate the effects of MT on water conservation in North China. We hypothesized that the practice of reducing agricultural irrigation under MT_m will help conserve the limited ground water, while maintaining adequate yield. We conducted our research I n a double cropping system by monitoring soil water content and soil temperature throughout the life of the crop. Little work has been conducted on this important topic.

2. Materials and methods

2.1. Site description

The experiment was conducted during 2011-2014 in Xushui County, Hebei Province, China (37.8°N, 114.7 °E). Elevation was 8-447 m above sea level, mean annual rainfall was approximately 500 mm, and mean annual temperature was 12°C over the past two decades (1993-2012, Figure 4-1). The main crop rotation system is for winter wheat and summer corn, with growth periods from early October to the middle of June, and from the middle of June to the end September, respectively. Precipitations during wheat growth season and corn growth season during our study years (2012-2013) were 164 mm and 430 mm, and that of 2013-2014 were 74 mm and 253 mm, respectively. Average temperature (-5.3°C) in December 2012 in the Hebei Province, however, was 2-3°C lower than that of the average and reached record low temperatures (Sun et al., 2014). The soil at the experimental is classified as Haplic Luvisol (FAO classification), with silty clay loam texture (clay 20.3%, silt 55.7%, sand 24.0%), which is locally called cinnamon soil, one of the prominent soil types in North China. It had a pH of 7.5, soil organic carbon of 11.5 g/kg, and soil total nitrogen of 1.1 g/kg in 2011. Inorganic soil N (NH_4^+-N: 5.9 mg/kg, NO_3^- -N: 14.3 mg/kg), available soil P (17.1 mg/kg by Olsen method), and available soil K (134.3 mg/kg determined by frame photometry after extraction with NH_4OAc solution) in the upper 20 cm soil layer.

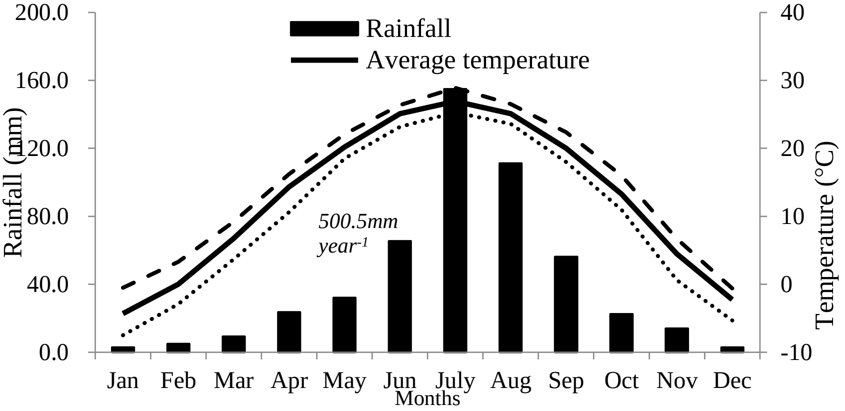


Figure 4-1: Mean monthly rainfall and temperature at the experiment site (1993-2012)

2.2. Experimental design and methods

A randomized complete block design with three replications was used for the tillage treatments. The 4 m × 5 m plots were separated by vertical barriers composed of waterproof plastic sheet buried to a depth of 1 m at the beginning of the experiment in 2011. The experiment involved various methods of tillage, mulching, and irrigation (Table 4-1). Soil under the full tillage (FT) treatment was tilled to a depth of approximately 20 cm by a rotary cultivator machine to ensure full incorporation of the preceding corn residue (FT_i); this was followed by dragging a board attached to the machine across the ground to level the surface. The MT treatment was designed to minimize soil disturbance using a tilling depth of only 10 cm and a width of 20 cm for seed and fertilizer placement in-row alternatively with no tilled inter-row with 20 cm wide using a small rotary tiller (Figure 4-2). First, fertilizer was placed in row in the middle of tilled area, then stripe sowing was conducted in two lines at both sides of the fertilizer line. The chopped corn residue with size of 3-4 cm was spread evenly on the soil surface after sowing in the MT_m treatment. Farmers in this area typically apply irrigation water just after wheat sowing, before winter, at the green up and head development stages in spring each year. In this study, the reduced irrigation was conducted without irrigation at the stage of head development for the MT_m and FT_i treatments. Following the farmers' irrigation behavior, conventional irrigation frequency in 2012-2013 and 2013-2014 was four-times irrigation and three-times irrigation. The total water volume of conventional irrigation of was 200 mm and 175 mm, and that of reduced irrigation was three-times irrigation for 150 mm and two-times irrigation for 125mm, respectively. Thus, the reduced irrigation treatment conserved 25-29% of the irrigation water.

Seeds of a local variety, 'Bao Mai No. 9', were sown at a seeding rate of 275 kg/ha in 2011-2012 and 300 kg/ha in both 2012-2013 and 2013-2014. As basal application, composite fertilizer was applied at a rate of 130 kg N, 159 kg P_2O_5 and 43 kg K_2O per hectare for all the plots. As topdressing, urea was applied at a rate of 70 kg N per hactor at green up stage; April 22nd (197 days after planting (DAP) for 2012-2013, April 12th (188 DAP) for 2013-2014, respectively.

Table 4-1: Experimental design of treatment groups with differing tillage, residue, and irrigation.

	Residue treatment	Irrigation treatment
FT	Incorporation (FT_i)	Conventional
		Reduced
	Removal(FT_r)	Conventional
MT	Mulch (MT_m)	Conventional
		Reduced
	Removal (MT_r)	Conventional

Conventional irrigation is the application of irrigation four times during the wheat growth season in 2012-2013 and three times in 2013-2014 according traditional farmer practices. Reduced irrigation eliminated one round of irrigation as compared with conventional irrigation

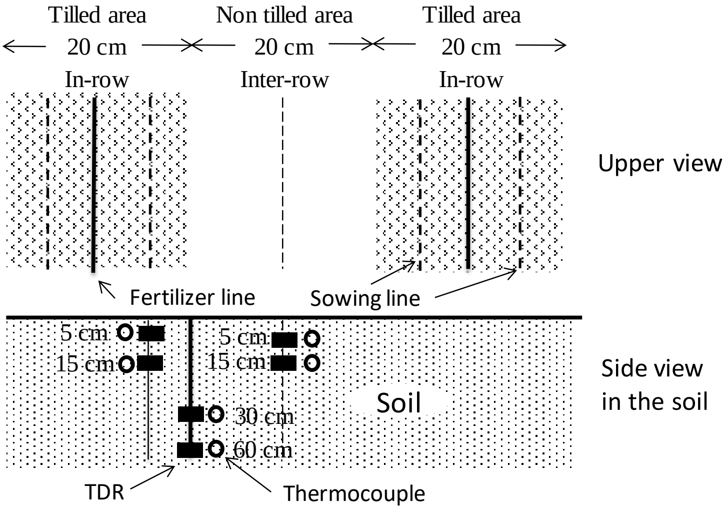


Figure 4-2: Pattern of tilled and non-tilled areas of wheat cultivation and locations of time-domain reflectometer sensors and thermocouples.

2.3. Monitoring of soil water content and temperature

Time-domain reflectometers (TDR, CS 616, Campbell Scientific, Logan, UT, USA) were installed horizontally at the in-row and inter-row areas at depths of 5 and 15cm, and at the border between the two at depths of 30, and 60cm (Figure 4-2). In case of FT treatment, although all soil surface was tilled, location of TDR was same as MT. Volumetric soil water content was recorded at 20 min intervals. Stored soil water content in the profile was calculated at each soil layer; 0-10, 10-20, 20-40 and, assuming that volumetric water content at depths of 5, 15, 30 cm represents each soil layer, respectively. As for soil layers of 0-10 and 10-20 cm, it was calculated after averaging values of in-row and inter-row. Soil temperature thermocouples made from copper-constantan wire were installed horizontally at depths of 5, 15, 30, and 60 cm adjacent to the sensors of the TDRs.

2.4. Crop growth and yield

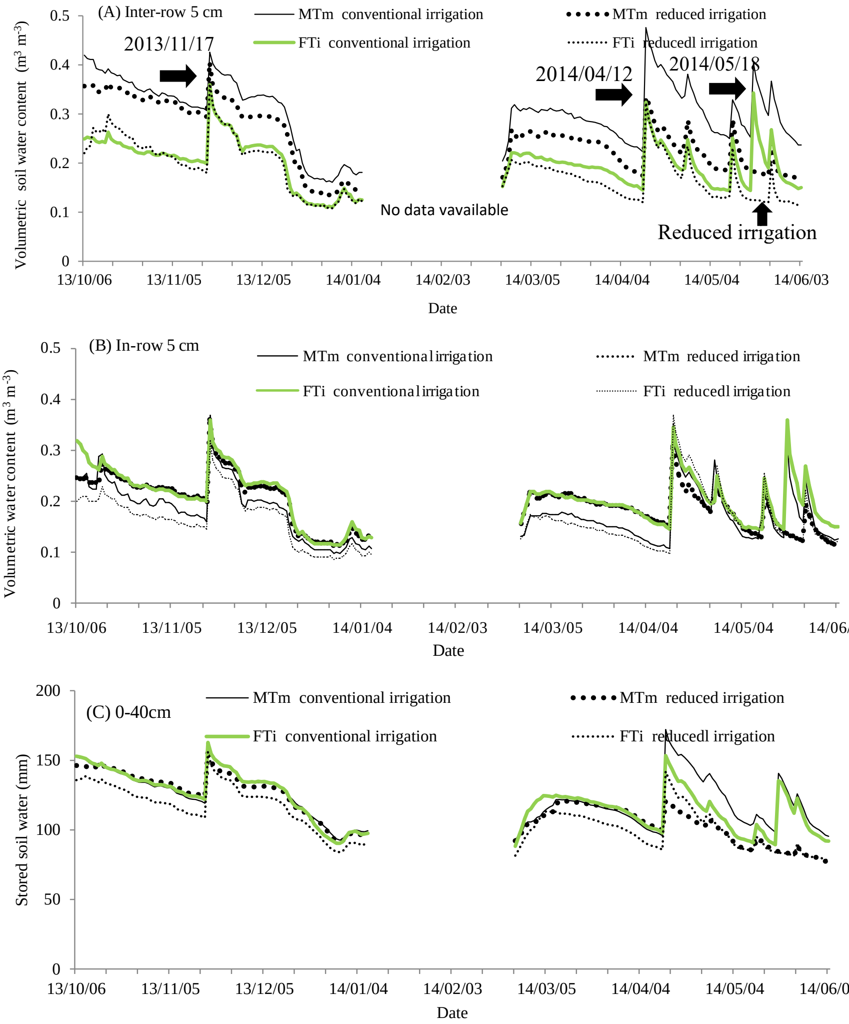
Because the past condition of fields greatly influenced winter wheat production during 2011-2012, the wheat yields during 2012-2013 and 2013-2014 are discussed in this paper. Four 0.5m-long rows per plot were selected for measurement of total tiller number (collected four times): during the seedling emergence stage (October 25, 2013), the winter period (December 06, 2013), green up stage (April 8, 2014), and at the harvest-ready stage (June 11, 2014). Similarly, six 1m samples were hand-harvested and weighed at the date of maturity; two of these samples with outlying data were excluded from the analysis. The wheat grain was air-dried first after separating from the stem. The dry grain weight was determined after drying with an oven at 80 °C for 24 hours. Then, grain yield and yield components were calculated. To compare the effects of the tillage treatments, an analysis of variance (ANOVA) was conducted using the SPSS analytical software package (IBM Corp, USA).Tests of significant differences were determined by Turkey's HSD ($P < 0.05$).

3. Results and discussion

3.1. Change in water content during cropping period

Figure 4-3 shows the changes in soil water content during the cropping period in 2013–2014. Soil water content at MT_m was much higher than FT_i at the inter-row at the 5 cm depth (Figure 4-3A). However, there was no clear difference in water content between FT_i and MT_m at the in-row 5cm depth (Figure 4-3B). Together with Figure 4-3A, soil water content at FT_i during the initial stage ranged between 0.2 and 0.3 m^3/m^3 while those at non-tilled soil (inter-row at MT_m in Figure 4-3A) between 0.3 and 0.4 m^3/m^3. The increased macro-pores due to tillage may have resulted in lower soil water content. In addition to that, the soil at MT_m was mulched by corn residue, which maintained soil water content higher (Figure 4-4). There was a relatively higher discrepancy in soil water content at the in-row 5 cm depth for both FT_i and MT_m. It was probably due to more variable micro-environments around TDR sensors because of tillage. No major differences among treatments were observed at 15, 30, and 60 cm depths (data not shown).

There was no significant difference among the treatments in stored soil water of the 0-40 cm soil layer during the cropping period (Figure 4-3C) while that at the surface layer (0-10 cm) of MT_m was much higher than that of FT_i (Figure 4-3D). It was mainly due to higher soil water contents at the inter-row (non-tilled soil). Soil water content in shallow soil is believed to be a critical factor for the successful production of crops during the initial and flowering stages (Alvarez and Steinbach, 2009); likewise, in this study, MT_m treatment resulted in improved grain yield as shown in Table 4-2.



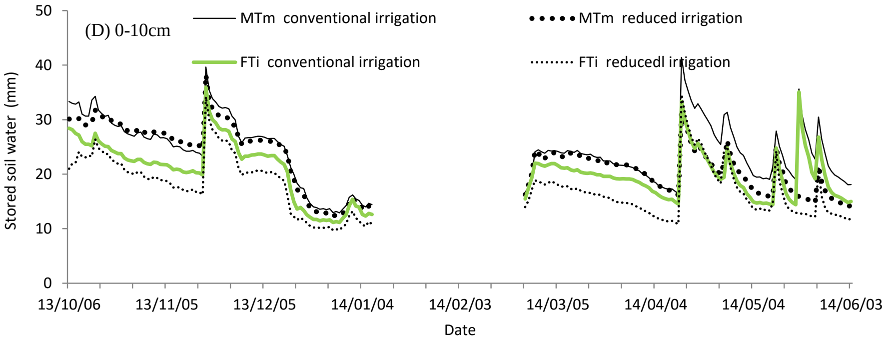


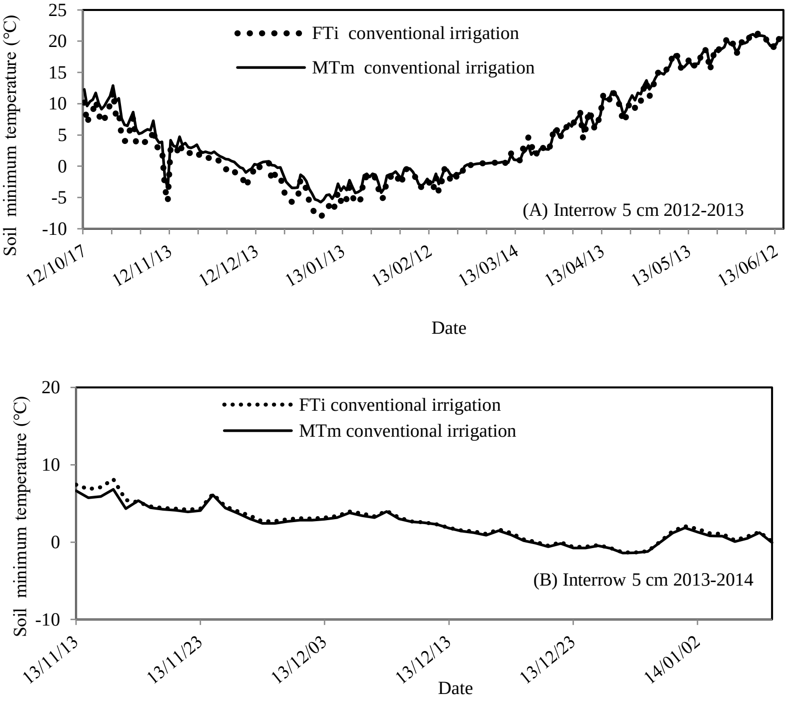
Figure 4-3: Change in soil water content and stored soil water for the four tillage systems during cropping period. Volumetric soil water content at (A) inter-row sites at 5cm depth and (B) in-row sites at 5cm depth. Stored soil water at (C) 0-40 cm, and (D) 0-10 cm. The dates in Figure4-3A indicate those of irrigation with VWC peak

Figure 4-4: Surface features in minimum tillage with mulch residue and full tillage with residue incorporated (April 3, 2013)

3.2. Change in soil temperature during cropping period

Interestingly, minimum soil temperature for the inter-row at the 5 cm depth under MT_m conventional irrigation remained slightly higher than that of the FT_i conventional irrigation treatments during winter from late November to early January in 2012-2013 (Figure 4-5A). However, during winter from late November to early January in 2013-2014, minimum soil temperature between MT_m conventional irrigation and FT_i conventional irrigation treatments decreased with the same trend (Figure 5B). This may indicate that higher soil temperature in the MT_m during winter in 2012-2013 occurred especially approximately 2°C lower compared with in 2013-2014, providing a relatively warm environment for the seedlings to survive the winter. This likely occurred because residue cover in the MT_m treatment insulated the soil. Residues normally form a protective cover between the air and soil, reflecting solar radiation and preventing heat loss (Shinners et al., 1994). We observed a similar trend for the in-row 5cm depths, but minimum soil temperature of other soil depths showed no major differences between MT_m and FT_i conventional irrigation systems (no data shown).

Comparison of cumulative soil temperature at 5 cm (average of inter-row and in-row) between 2012-2013 and 2013-2014 reflected lower air temperature in 2012-2013 than 2013-2014 as described above (Figure 5C and 5D). There was little difference under FT_i and MT_m with conventional irrigation during the winter wheat growth period. This suggests that minimum tillage with mulch residue should not be considered a negative factor for winter wheat growth. At harvesting time, however, cumulative soil temperature at FT_i was higher (6.6% and 3.0%) than MT_m in 2012-2013 and 2013-2014, respectively.



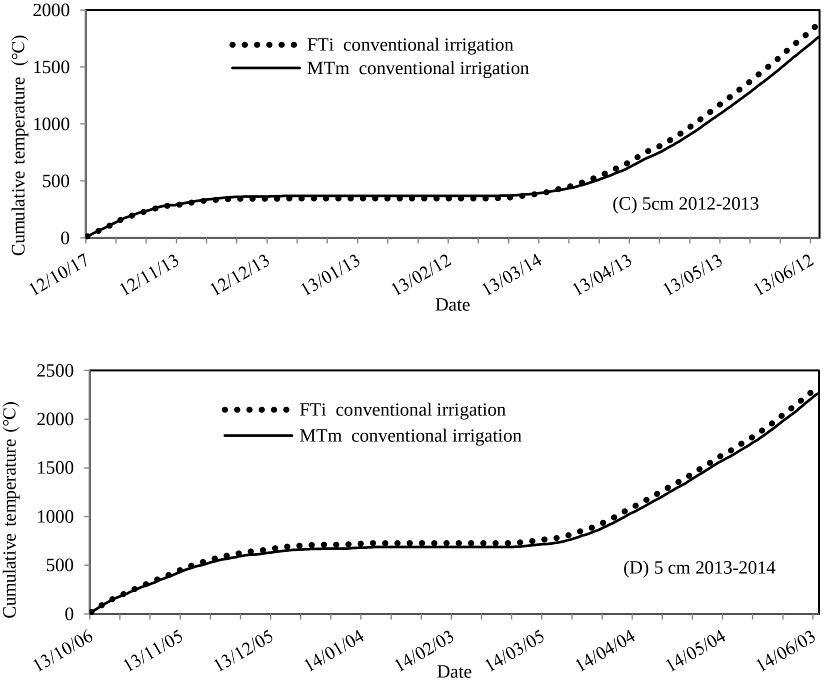


Figure 4-5: Changes in soil temperature under different tillage systems. (A)Inter-row temperature at a depth of 5 cm in 2012-2013, (B) Inter-row temperature at a depth of 5 cm from late November to early January in 2013-2014, (C) Cumulative soil temperature at a depth of 5 cm (average of inter-row and in-row) in 2012-2013, and (D) that of in 2013-2014

3.3. Tiller number during cropping period

Figure 4-6 shows the tiller number under the tillage/residue treatments in 2013-2014 that included the seedling emergence, wintering period, and green up stage, as well as the harvest-ready stage. There was no significant difference found among treatments during the four growth period of winter wheat. Hence, in our study, tiller number was not reduced by MT_m. However, different results about the wheat tiller number affected by CT were found. Li et al. (2008) found that the number of wheat tillers produced with NT was significantly lower than that of conventional tillage. But they believed that the lower rate of emergence of NT was mainly due to low performance of non-till planter in Luan Cheng, Hebei Province, China and the lower temperature in NT soil than in conventional tillage during seedling period and returning-green period may be less important. Negative effects were also reported from Luan Cheng, Hebei Province, China, where the practice of NT and MT resulted in low soil temperature during the green up stage of winter wheat growth and thus, negatively affected the emergence rate and wheat yields (Dong et al.2007). In contrast, NT with mulch residue was found effectively increased tiller number with sufficient soil moisture and topsoil nutrient content in the Henan Province, China (Huang et al., 2009). Under CT, the emergence of winter wheat in Xiang He County, Hebei Province was delayed for only one or two days, which had no effect on crop growth (Zhou et al., 2001). Moreover, CT with residue retention conserved soil heat, allowing soil warming at times with low soil temperatures and moderation of soil temperatures when the temperature was high; this allowed for the maintenance of a relatively constant temperature in Inner Mongolia for Avenasativa growth, but had no effect on the seedling emergence rate (Liu et al., 2014).

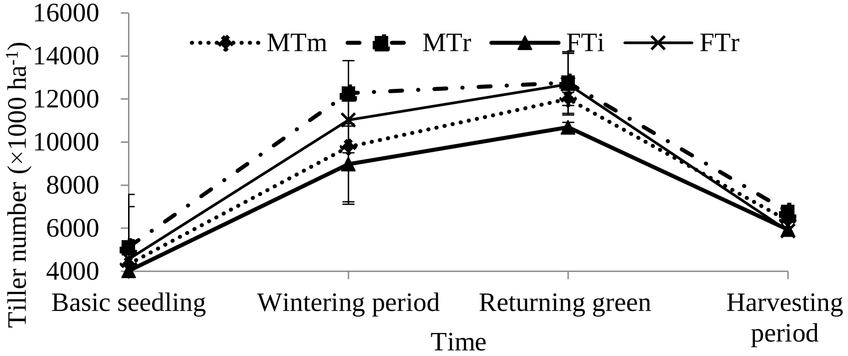


Figure 4-6: Tiller number per hectare during the cropping period of 2013–2014.Error bars show the standard deviation

3.4. *Effects of tillage and irrigation management on grain yield*

Table 4-2 shows the yield and yield components for the two consecutive years. Wheat yield using the MT_m reduced irrigation treatment during 2012-2013 was not statistically different among the four treatments with modest reductions of 25% for the irrigation water applied during the head development stage of plant growth. While wheat yield using the MT_m reduced irrigation treatment during 2013-2014 was statistically significantly higher than that using the FT_i reduced irrigation treatment (by 10.2%) and not significantly different from FT_i conventional irrigation treatment with reductions of 29% of the irrigation water. This showed that irrigation could be reduced by one irrigation practice under MT with mulch residue management, in agreement with the results of research conducted in Beijing, China (Peng, 2010). In addition, Cui et al. (2014) reported applying 25% less irrigation water would improve crop yield for winter wheat.

Comparison of yield and yield component between 2012-2014 and 2013-2014 showed some differences. Averaged one thousand grain weight and grain yields in 2013-2014 were significantly higher than in 2012-2013. This may have occurred because the climatic conditions for winter wheat growth during the 2013-2014 season were the best of the past five years, with several rains from October 9, 2013 to November 24, 2013, and relatively warm temperatures in December 2013 (Liu and Guo, 2014). The effects of weather can be seen in the variance of temperatures between 2012-2013 and 2013-2014 (Figures 4-5B and 4-5C). In particular, decreased rainfall in the spring and frost damage during the jointing and boot stages affected grain weight and number in 2012-2013 (Shen, 2013).

Table 4-2: Grain yield of wheat in a wheat-corn double cropping systems under MT_m and FT_i with different types of irrigation management (2012-2013 and 2013-2014)

Year	Treatment	Panicle number (× 1000) /ha	Grain number /panicle	Thousand grain weight (g)	Panicle weight (g)	Yield kg/ha
2012-2013	MT_m reduced irrigation	7402 ± 273	22.6 ± 1.6	35.2 ± 0.8a	0.80 ± 0.05	5886 ± 181
	MT_m conventional irrigation	7152 ± 504	24.4 ± 0.7	33.2 ± 1.2ab	0.81 ± 0.02	5784 ± 366
	FT_i reduced irrigation	7144 ± 35	24.9 ± 0.9	31.6 ± 0.7b	0.79 ± 0.04	5605 ± 53
	FT_i conventional irrigation	6631 ± 573	25.6 ± 2.6	32.7 ± 0.8b	0.84 ± 0.10	5520 ± 176
2013-2014	MT_m reduced irrigation	6569 ± 518	26.4 ± 2.9	40.3 ± 1.9	1.06 ± 0.10	6931 ± 165b
	MT_m conventional irrigation	6839 ± 758	28.3 ± 1.6	39.5 ± 2.4	1.12 ± 0.11	7608± 347a
	FT_i reduced irrigation	6119 ± 266	25.5 ± 1.1	40.3 ± 2.6	1.03 ± 0.04	6289 ± 162c
	FT_i conventional irrigation	6133 ± 570	29.1 ± 3.0	42.0 ± 0.9	1.22 ± 0.11	7460 ± 149ab

Values with different letters are significantly different among treatments each year ($P<0.05$) and those without letters are not ($P<0.05$).

3.5. Effects of tillage and residue management on grain yield

The MT_m treatment produced the greatest number of wheat panicles number in 2013-2014 (Table 4-3). Panicle number per hectare, grain number per panicle, thousand grain weight, and panicle weight did not respond uniformly to the four tillage treatments in both years; however, the differences were not significant between all treatments in 2012-2013 ($P<0.05$). Grain yield (7,608 kg/ha) under MT_m treatment in 2013-2014 was slightly but not significantly higher than yield under the FT_i treatment. Similarly, wheat grain yield was slightly, but not significantly higher under CT than under traditional tillage in a wheat-sunflower crop rotation system in southern Spain (Moreno et al., 1997). Likewise, Arshad and Gill (1997) reported that reduced tillage produced a greater wheat yield than conventional or NT based on 3 years of experiments in northwestern Alberta. The beneficial effects of the mulch may be associated with increased soil moisture (Triplett et al., 1968) and Raper et al. (2000) observed positive effects of mulch on crop yield. López and Arrúe (1997) believed that adverse environmental conditions could easily influence seed growth, whereas Unger (1984) found tillage management using the greatest amount of residue had little effect on surface conditions.

The beneficial effect of minimum tillage and mulch residue on wheat grain yield could be attributed to improved soil properties and infiltration rates, as well as improved conservation of soil moisture (Sharma et al., 2011). Sow et al. (1997) also concluded that soil strength would decrease with increased soil water content. Increased soil water content is closely associated with greater root length and densities under NT with mulch residue when compared with conventional tillage, which results in higher crop yield. López and Arrúe (1997) reported that a similar crop response between conventional and reduced tillage treatments and poor grain yield with no-tillage, which depended more on seasonal rainfall and, hence, on the effective soil water content. One hypothesis states that seedling growth and grain yield with high soil strength under CT would not be adversely affected when there is enough soil water content. The findings of Fernandez-Ugalde et al. (2009) supported this hypothesis, and showed that NT resulted in an improvement of soil structural properties. This appears to be consistent with the results of our experiment in that the MT_m treatment was higher stored soil water (0-10 cm) during the growing season.

Table 4-3: Grain yield of wheat in wheat-corn double cropping systems under MT and FT with different types of residue management (2012-2013 and 2013-2014)

Year	Treatment	Panicle number (× 1000)/ ha	Grain number /panicle	Thousand grain weight (g)	Panicle weight (g)	Yield kg/ha
2012-2013	MT_m	7152 ± 504	24.4 ± 0.7	33.2 ± 1.2	0.81 ± 0.02	5784 ± 366
	MT_r	7263 ± 519	25.4 ± 2.0	30.8 ± 1.1	0.78 ± 0.08	5658± 228
	FT_i	6631 ± 573	25.6 ± 2.6	32.7 ± 0.8	0.84 ± 0.10	5520 ± 176
	FT_r	6615 ± 433	24.7 ± 2.1	33.2 ± 0.6	0.82 ± 0.06	5395 ± 44
2013-2014	MT_m	6839 ± 758a	28.3 ± 1.6	39.5 ± 2.4	1.12 ± 0.11	7608 ± 347a
	MT_r	6772± 1115ab	26.1 ± 2.4	39.6 ± 2.0	1.04 ± 0.14	6920 ± 176ab
	FT_i	6133 ± 570ab	29.1 ± 3.0	42.0 ± 0.9	1.22 ± 0.11	7460 ± 149a
	FT_r	5375 ± 879b	28.3 ± 2.8	42.3 ± 0.9	1.20 ± 0.09	6369 ± 584b

Values with different letters are significantly different among treatments each year (P<0.05) and those without letters are not (P<0.05).

4. Conclusion

Results from our two-year experiment indicated that MT could be recommended as a viable alternative to FT for North China. In particular, the practice of MT_m allowed a saving of 25-29% of the amount of irrigation water during the growth cycle of winter wheat. In 2012-2013, the MT_m with reduced irrigation produced the same wheat yield with conventional irrigation. In 2013-2014, wheat yield under MT_m with reduced irrigation was also as same as that under FT_i with conventional irrigation and higher than FT_i with reduced irrigation. This same yield of MT with reduced irrigation gives us confidence to promote MT_m in farmers' fields, which should decrease water consumption used for agriculture.

5

CHAPTER 5. CONCLUSION AND FUTURE PROSPECTS

1. Research background, objective and methodology

1.1. Research background

The severe smog and haze that has blanketed many Chinese cities over the past ten years has drawn the public's attention to the increasingly prominent air pollution in China. One of the reasons for smog and haze around harvest time is open burning of crop residues in the field. Although crop residue burning is a long-standing agricultural practice used to remove agricultural waste and excess crop residue from fields, increasing populations and demands on agricultural land and food has had a profound effect on the extent of field burning. Its most serious consequence is increasing environmental pollution, especially air pollution, which now threatens human health.

Since 1999, the Chinese government has implemented a series regulations and laws to forbid outdoor burning of straw to reduce air pollution. Although more and more laws have been issued to control the burning of straw, they have not achieved the desired results. Traditionally, cost-benefit analyses have been used as a tool to inform and guide government agencies involved in regulatory and policy development. For instance, since the early 1980s, U.S. federal government regulatory agencies have been required to conduct cost-benefit analyses on all major regulatory initiatives. A cost-benefit of the crop straw management scenario in China would be essential to understand what the Chinese public thinks about the benefits of ban open burning. In this way, better policy development could be achieved.

In addition to fully acknowledging such control benefits, we need to consider how to make sustainable use of straw as a top priority. Straw recycling is fundamental to solving ongoing open burning of straw. In China, straw utilization as soil fertilizer is the most widely used among all the recycling methods and is a government-supported method. However, operational standards for the harvest machinery that require returning straw as a fertilizer to the fields are lacking and farmers are not satisfied with the current operational process of straw return, increasing the possibility of farmers burning straw in their fields. Furthermore, farmers are skeptical as to the effects of straw return, especially in combination with CT, on subsequent crop yields.

1.2. Research objective and methodology

The dissertations aims at exploring the willingness to pay of a sample of residents of Henan Province, China, for straw burning ban that controls open burning and improves air quality. A Contingent valuation method (CVM) was applied in a face to face survey to assess the individual WTP for straw burning ban. Prohibition of open burning is a prerequisites, recycling is the outlet of the large amounts of straw. Hence, the thesis also aims to contribute the sustainable development of returning straw to the field by exploring factors influencing straw return with a survey study. A questionnaire survey and face-to-face interview method on respondents. The survey applied stratified random technique for selecting farmers respondents. In addition to investigation for evidence collection, we also conducted field experiments to verify the effectiveness of straw return.

2. Summary of the main findings

This dissertation follows a thesis by paper format, incorporating three papers as chapters. The main findings of these three papers (Chapters 2, 3, and 4) are summarized in the Table 5-1, with reference to the research questions raised in the General Introduction (Chapter 1).

Table 5-1: Summary of research questions and main findings of Chapter 2, 3 and 4 of this thesis

Chapter	Research questions	Main findings
Chapter 2 *Straw burning ban and willingness to pay (WTP)*	How do urban residents value environmental benefits through a WTP for the "corn straw burning ban"?	Huge potential benefits of the corn straw burning ban were demonstrated using the Tobit model. Aggregate values were between 3.4 and 3.9 billion RMB (giving WTP values of 77 and 143 RMB per person per year for the total respondents and respondents with positive WTP bids, respectively). This indicates that the corn straw burning ban has considerable economic weight in Henan and there is a strong public demand for a burning ban. The difference between the limited level of government investment and the strong demand for banning of straw burning reveals high expectations from the government. Clearly, it is beneficial for policy makers to know the public's support of the importance and urgency of forbidding straw burning. The government should allocate more appropriate levels of funds to compensate for recycling of straw, as well as introduce consequences of open burning.
	What are the factors influencing urban residents' WTP?	In an econometric analysis, the signs of most parameters were predictable. The following respondents were more willing to pay for the straw burning ban: urban residents that spend money to protect their family members' health from air pollution, residents that support sustainable environmental practices in their life styles; respondents that perceived the poor air quality during harvest time; respondents whose health was negatively affected by air pollution related to straw burning; and respondents whose life and work has been affected by air pollution related to straw burning. Age, gender, education, income, and family size all showed positive relationships with the probability of WTP, although job type had a highly negative relationship with WTP.

Chapter	Research questions	Main findings
Chapter 3 *Straw return and willingness to participate / willingness to accept (WTA)*	What are the critical factors affecting farmers' willingness to participate in straw return?	A farmers' adoption of this practice was significantly negatively influenced by the high machinery cost, amount of straw to return, its slow decomposing rate, and the poor quality of crushed straw. These results indicated that not only the direct monetary costs involved in returning straw, but also the indirect processes involved in straw return play a role in their willingness to participate. Governments should attach greater importance to the specifications and technical requirements for recycling straw. In contrast, having large crop areas and benefits to the soil of crop straw as a fertilizer were positive factors influencing their adoption of this practice. Gender also significantly influenced a farmers' willingness to return corn straw. Women farmers were more likely to return corn straw.
	What are the determinants affecting farmers' willingness to accept financial compensation for straw return?	Nine variables were found to be significantly affecting farmers' WTA compensation amounts. Aside from complications of dealing with crushed straw, in the farmers' willingness to participate model, factors, such as machinery costs, return amounts, and decomposition rates all increased the amount that farmers' were expecting as compensation. Meanwhile, the larger the area sown with corn, the lower the WTA compensation amount proposed by farmers'. Soil fertilizer and growth of the subsequent wheat crops were categorized as benefit variables; both variables were negatively correlated with farmers' WTA amounts. Moreover, aged farmers, more educated farmers, and wealthier farmers had lower expectations of compensation than other respondents.
	How much are farmers' willing to accept as compensation for implementing straw return?	This research found that almost all (98%) farmers thought that the government should compensate them for returning straw to the field. The mean WTA value for the total respondent sample was 47 RMB per

Chapter	Research questions	Main findings
		mu. In the reality, the existing government subsidy for corn straw return in Henan is just 5-15 RMB per mu per year, which is far less than this mean WTA value, indicating that the existing level of compensation for corn straw return is too low to encourage farmers to carry out his practice.
Chapter 4 *Corn straw return, minimum tillage, and winter wheat yield*	What is the effect of minimum tillage with corn straw return on winter wheat yields?	A three-year field experiment was conducted to test whether there were significant effects on the wheat yield caused by minimum tillage and straw return practices. Minimum tillage with residue mulch treatment in the third year (2013-2014) resulted in the highest wheat grain yield (7,608 kg/ha) in the experiment. This yield was slightly but not significantly higher than the yield under full tillage with incorporation of crop residue. The yield under minimum tillage with residue removal was also slightly but not significantly higher than the yield under full tillage with residue removal.
	What are the differences in soil water contents under various tillage practices?	Soil water content under minimum tillage with residue mulch was much higher than under full tillage with incorporation of residue at an inter-row depth of 5 cm. There was no clear difference in water contents at an in-row depth of 5 cm. No major differences among treatments were observed at 15, 30, or 60 cm soil depths. Neither was there any significant difference among treatments in stored soil water within the 0-40 cm soil layer during the cropping period. However, the surface layer (0-10 cm) under minimum tillage with residue mulch had much higher soil water than that under full tillage with residue incorporation.
	If conservation tillage can conserve soil water, what are the effects of straw	Minimum tillage with residue mulch and reduced irrigation treatment maintained high yields, despite eliminating one cycle of irrigation.

Chapter	Research questions	Main findings
	return with minimum tillage on yields, while reducing irrigation in North China?	Wheat yields under minimum tillage with residue mulch and reduced irrigation treatment for 2013-2014 were statistically significantly higher than those for full tillage with incorporated residue and reduced irrigation (by10.2%) but not significantly different from full tillage with residue incorporated and conventional irrigation treatment (with reductions of 29% of the irrigation water).

2.1. Air quality improvements related to the straw open burning ban: the benefits of multi-faceted cooperation

In many developing countries, like China, economic and industrial developments have resulted in tremendous increases in energy consumption, emissions of air pollutants, and the number of poor air quality days in mega cities and their immediate vicinities. Air pollution has become one of the top environmental concerns in China (Chan and Yao, 2008). Specifically, there has been increasing concern about air pollution related to open burning of crop straw in the field. These concerns have galvanized policy makers into action. The benefits of air pollution control have driven policy makers to formulate better policies for environmental regulation. However, there are many factors that undermine this ban, although it is intended to improve air quality. Most of these factors are not related to its benefits, but concern technology, and active participation levels of farmers.

Scientific benefit evaluation: Benefit evaluations are carried out in many instances, for example, when resources are scarce, or to evaluate various health care interventions. In various contexts, different methods have been developed for economic evaluation to guide decisions and policymaking in various policy areas (Slothuus, 2000). Economic analysis has been championed and used for efficient decision-making especially in the areas of environmental policy, transportation planning, and health care by many worldwide government agencies and organizations. Aggregating benefits across different social groups or nations involves summing WTP for benefits, or WTA compensation for losses, regardless of the circumstances of the beneficiaries or losers. Of course, the assessments and policy outcomes assume that, income effects aside, WTP and compensation-demanded valuations are equivalent. Generally, however, the level of WTA (compensation) is commonly far larger than that of the WTP (payment) (Zhao and Kling, 2001). In the case of overestimating the economic impacts of the straw burning ban, the WTP measure was considered herein as a means for assessing the benefits based on urban residents' response to open burning. It is still likely that such benefits are understated by these groups, yielding standards that are set at inappropriate levels, or to biased policy, with too few mitigation efforts (Knetsch, 1990). In reality, the total economic value of the corn straw burning ban is far larger than the Henan government's investment in the ban. Its larger value reflects the strong demand by all Chinese citizens for a ban on straw burning.

The results of this survey suggest that many people in Henan show WTP for a ban on open burning, which goes some way towards addressing the question regarding whose preferences the legislation claims to reflect. The remaining question relates to whether these preferences should constrain the consumption of people, who do not support the legislation. The answer to this question depends on the nature of the goods involved, the groups considered, and their preferences. Where public goods are involved or where significant externalities exist, there may be a case for government intervention in the form of legislation to constrain consumption choices (Bennett, 1997). In this case, farmers' rights/consumption choices (e.g., to openly burn crop straw) are constrained by urban residents, who experience a negative externality caused by straw burning, i.e., involuntary exposure to polluted air.

Technology progress: The progress in technology is key to recycling large amounts of crop residue. At present, technical issues prevent its increased use in many other sectors. Development of straw reuse is associated with technological progress (including direct combustion, thermochemical conversion, biochemical conversion, direct liquefaction, physical/mechanical extraction, and electrochemical conversion) (Suramaythangkoor and Gheewala, 2010). For instance, a significant amount of bioethanol and biodiesel are produced as biofuels which partially replace gasoline and diesel within the transportation sector worldwide. However, it is not feasible to massively increase biofuel production using current technologies. Biofuels represent a tiny portion (<4%) of the total fuels consumed (Cheng and Timilsina, 2011). In China, one of the aspects restricting the effective use of crop straw in biofuel production is the technological barriers in the production process. Technological innovation to increase production efficiency and reduce costs is essential to ensure the biofuel's economic competitiveness (Hao et al., 2018).

Participation of members of society: Without open burning, farmers face difficulties as to how to treat their agricultural straw residue. Generally, farmers continue to burn it in their fields, while rural residents are harmed by its ensuing air pollution. As social interests become increasingly diverse, many traditional practices face these dilemmas. The government's responsibility is to optimize the allocation of resources to maximize social benefits. To solve the problem of ongoing open burning of straw, the goal pursued by the government cannot be only the prohibition of straw burning, but must also promote comprehensive reuse of this straw. A ban is only a temporary solution to this problem, while the restructuring involved in reusing this straw would be a permanent one. Thus, the government's action/support is crucial to ensure the compliant behavior of farmers and agricultural enterprises.

The current government attaches great importance to developing the straw market, allowing enterprises to play a leading role in promoting straw as a resource, and developing large-scale industrialization around it. However, to select the most appropriate social arrangement to restructure this industry, an analysis should be carried out to determine whether farmers, agricultural enterprises or governments should be driving the solution to this problem. Although direct government regulation likely will not result in a better solution to the problem than the market- or enterprise-driven concerns, it is unlikely that government control will lead to an increase in economic efficiency. The key to restructuring the agricultural straw market is to determine the largest total output value and minimize its transaction costs, based on the specific circumstances.

2.2. Returning straw to the field: the sustainable development of this technology

Unlike commercial goods, crop straw is a by-product or waste from crop production and its reuse is being promoted to solve ongoing air pollution problems (Suramaythangkoor and Gheewala, 2010). Promoting straw return to the field is consistent with the aims of Chapter 2, the national advocacy on banning straw burning, and any endeavor to minimize its transaction costs.

Subsidy policy: The subsidy policy is a form of financial support extended to an economic sector (or institution, business, or individual) with the aim of promoting a specific economic or social policy (Myers, 2001). Actions that mitigate environmental problems related to crop cultivation practices are eligible for subsidy payments, such as those related to degradation of water quality by sediments, nutrients, and pesticides; hydrologic modifications contributing to flooding and groundwater depletion; disruption of terrestrial and aquatic wildlife habitats; emissions of greenhouse gases; degradation of air quality with odors, pesticides, and particulates; and land-use changes (Lubowski et al., 2006). Given the payoff uncertainties combined with risk aversion and/or real options, farmers may demand a premium to adopt CT practices, over and above their compensation for expected profit losses (if any). Kurkalova et al. (2006) found that such a premium may play a significant role in farmers' decisions to adopt a given practice. In this context, we explored how much farmers wanted the government to compensate for corn straw return, the factors influencing farmers' willingness to participate in returning corn straw to the field, and their WTA compensation amounts. Generally, there is no or little money compensated to farmers who return corn straw to the field or who collect and package straw for reuse. Policy interventions in the straw markets for bioenergy/feedstock may be required to provide an incentive to farmers to engage with these markets (Glithero et al., 2013). A combination of legislation and subsidies may be the appropriate measure to motivate farmers to engage in recycling rather than burning of straw.

Machinery reform: Returning straw directly to the field requires reliable agricultural technology. Such practices rely on large and medium-sized agricultural machinery to crush straw and carry out rotary tillage. Mixing straw with soil and carrying out deep tillage would achieve the best results. However, the current yield of corn straw is about 440 million tonnes (Table 1-3). This large amount of straw demands relatively high technical requirements for its recycling. At present, the machinery for returning straw is not satisfactory for such amounts, and technology for returning it to farmland is not readily available. Culms are particularly difficult to completely bury in farmland, causing straw to resurface during subsequent sowing of wheat. Straw returned to the field, to some extent, has caused more trouble than it was worth, leading farmers to refuse to use it. Among the issues caused by straw return, we explored which determinants influence a farmers' adoption of this technology. Consistent with our assumptions, machinery cost, return amounts, quality of the crushed straw, and decomposition rates all significantly negatively affected farmers' adoption of the practice. This indicates that not only direct money costs, but also indirect concerns related to the process of straw return influence their decisions to comply with the ban. The configuration and selection for adequate technology to support the practice of straw return is clearly lacking in China (Du, 2009). At present, straw return mainly uses single-operation machinery. There are not many joint-operation machines used in the field, suggesting that this needs to be further developed and studied.

2.3. Conservation tillage combined with straw return management: obstacles and benefits

Improvement of grain production is an important aspect of ensuring global food security. However, like much of the world's prime farmland, intensive cropping and tillage in China have led to substantial decreases in organic matter levels of soils related to increased microbial decomposition, along with wind and water erosion of inadequately protected soils. Moreover, the water table has continued to decrease under excessive use of ground waters by large-scale agricultural irrigation projects designed to produce high grain yields. Crop straw return is of vital importance to preserve soils, but some farmers still struggle to adopt CT with straw return as a practice, fearing that reduced soil temperatures following planting will affect crop yields (Shen et al., 2018). Unlike the scope of Chapter 3 which focused on determining the factors influencing farmers' adoption of straw return (full tillage with straw incorporation) as a practice, Chapter 4 shows the practical benefits of minimum tillage combined with straw mulch in field experiments.

Possible disadvantages of conservation tillage: Some studies show that CT hampers soil warming during the early growing season, producing soil temperatures within surface soils (5- and 10-cm depths) under CT that are less than under FT treatments (Johnson and Lowery, 1985; Nyborg and Malhi, 1989;). Higher straw residue coverage caused lower soil temperatures in surface soils, with soil temperature under corn being lower than under soybean residue (Shen et al., 2018). The lower soil temperature within the seed zone may inhibit crop emergence under CT compared with FT (Gupta et al., 1988). However, our results suggest that MT_m provides a warm enough environment for seedlings to survive winter. Residues normally form a protective cover between the air and soil, reflecting solar radiation and preventing heat loss (Shinners et al., 1994). Furthermore, the net mineralization rate was greater under FT than under CT. Hence, CT produced significantly lower yields, than fields under FT, without addition of N fertilizer.

Benefits associated with using crop straw as a fertilizer under conservation tillage: Suitable CT practices may be appropriate in certain farm settings to address soil and climatic constraints. Use of CT in the process of straw return avoids the adverse effects of excessive crop residues on the growth of subsequent crops (Carter, 1994). Wheat growth after NT of a post-rice harvest field uses residual soil moisture and reduces the crop periods in intensive rotation cropping systems. Some of the major constraints in NT wheat production are high weed infestation, poor stand establishment related to rapid drying of the topsoil and low nitrogen use efficiency (Rahman et al., 2005). However, NT or MT coupled with straw mulch were highly effective measures for increasing moisture content in the soil by providing maximum surface cover. In a three-year field experiment, soils under MT mulched by corn residue maintained higher soil water content in surface soils (inter-row at 5 cm depth) than under a FT with no mulch treatment. Irrigation experiments showed that MT_m practices could maintain grain production, even when irrigation was reduced by one irrigation cycle. These results indicate that MT with straw mulch is a promising agricultural practice for farmlands in North China.

Practices of NT or MT coupled with straw mulch were highly effective at reducing soil erosion losses and reducing weed growth (Rahman et al., 2005; Bhatt and Khera, 2006). Straw mulch can further enhance microbial biomass, activity, and potential N availability, relative to non-mulched soils, likely via improving carbon and water availability for soil microbes (Tu et al., 2006). Sharma et al. (2011) revealed that MT can have a pronounced effect not only on soil physical properties (improved infiltration rate and conserve soil water), but also on energy requirements, economics, and the growth of corn and wheat, when combined with mulch and compared with no mulch treatments. In the agricultural environment, depletion of soil carbon is accentuated by soil degradation and exacerbated by land misuse and soil mismanagement. CT in combination with cover crops and crop residue mulch can restore a considerable part of the depleted soil organic carbon pool and reduce the rate of enrichment of atmospheric CO_2 (Lal, 2004). In any case, straw return (as straw mulch) is a productive practice.

3. Solutions to open burning of crop straw

The poor funding, poor collection rates, and poor disposal methods, and lack of awareness, result in farmers burning crop straw in the field. Environmental protection to reduce the open burning of crop straw should adopt a systematic approach to managing large amounts of crop straw and environmental affairs. In addition to strive to raise awareness of environmental impacts, however, measures must be taken to prevent open burning where possible such as build collection system, accelerated disposal, improved utilization and general awareness of the dangers of straw open burning.

The development of control measures requires coordination and construction of the linkage mechanism between the government, enterprises and farmers to achieve a win-win situation for the three parties. The government fulfills its duties to supervise and supply financial investment. Farmers and enterprise reuse crop straw and acquire benefits. The straw collection system should be established to ensure the smooth connection between farmers' straws and utilization enterprises. Therefore, farmers can get rid of the cumbersome task of straw disposal, and enterprises can reduce costs and obtain a stable source of crop straw. Straw market prices should be established so that crop straws have market value like food and will not be burned or discarded as waste (Figure 5-1).

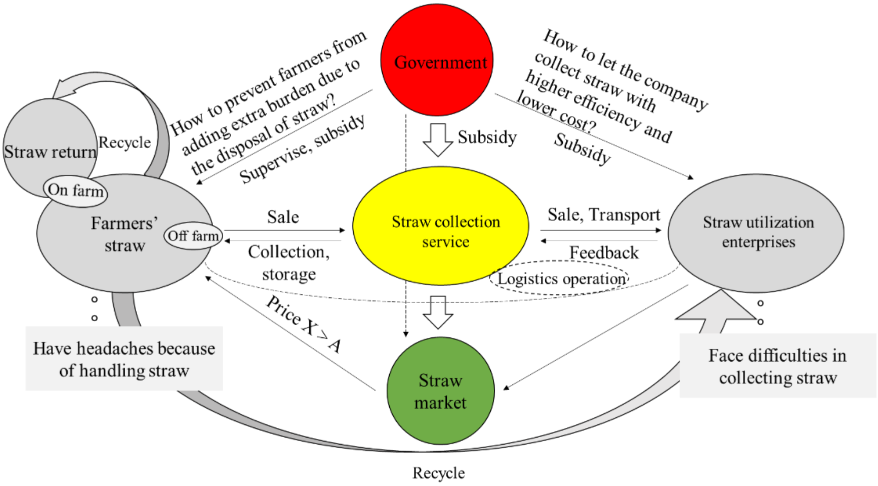


Figure 5-1: Links and chains to promote comprehensive utilization of crop straw

3.1 Comprehensive utilization

The key issue to reduce open burning of crop straw is finding suitable solutions to deal with large quantities of agricultural straw in local area. Comprehensive utilization of crop straw is reusing crop straw as recycled resources, has become a significant policy and practical objective for the Chinese government (MOA, 2017). The strategies of crop straw reuse include on-farm and off-farm utilization. The option to utilization should be adjusted measures to local conditions.

3.1.1 On farm: Straw return-farmers' participation

Strong technical support is needed to return straw to the field. The practical technologies and equipment for chopping straw and ploughing it into soil need to be developed and distributed more widely. Non-compliance with standards of straw return will not receive the desired results and may even cause a reduction in crop production. To apply the appropriate technology for straw return, the appropriate time to plough, the amount of straw returned, the amount of nitrogen supplemented, and the appropriate machinery need to be determined for various climates (temperature, precipitation), soil conditions (soil type, texture, fertility), and production levels.

Suggestion for the amount of corn straw return

With ongoing and increasing high yields of corn production, crop straw production continues to increase. Whether or not it is feasible or appropriate to fully return this straw to the field remains to be determined. How to control the amount of straw returned, how to handle any excess straw, and the appropriate amount of straw to be returned under different settings are questions that still need to be addressed. The amount of straw returned cannot be regulated without considering climate and soil conditions. In relatively infertile soils, where soil fertilizer is insufficient, the amount of straw returned must be reduced to an amount of around 3000-4500 kg/ha. However, in fertile soils, the amount of straw returned can be as much as 6000-7500 kg/ha.

Suggestion for mechanical operations

Production practice has shown that long straw is not easy to mulch and is not conducive to decomposition. Similarly, poor quality of straw crushing and distribution will affect ploughing and sowing, lowering the emergence rate and yield of subsequent crops. Typically, the finer the shredded straw, the better the outcomes of straw return. The appropriate length of shredded straw is 5 to 8 cm. To meet these length requirements, the machinery must be operated under low-gear to increase the grinding time and cutting frequency of straw to be returned to the field.

After crop straw return, the crushed straw should be ploughed (to at least 18 to 20 cm depth) in time and to disperse the residual straw evenly into the soil before sowing. Afterwards, soil surfaces should be furrowed to avoid aerial exposure of wheat seedlings.

Suggestion for amount of N fertilizer should be applied

The C:N ratio has a huge effect on the initial decomposition of straw in the field. The lower the C:N ratio, the faster the decomposition rate in its early stages. Straw return to the field must be accompanied by nitrogen fertilization. If the C:N ratio of the crop residue returned to the field is greater than 25:1, then soil microbes must scavenge the soil to obtain enough nitrogen. The C:N ratio of corn straw is 53:1, which is far higher than 25:1, indicating that corn straw is rich in carbon but deficient in nitrogen. Thus, returning corn straw to the field results in slow straw decomposition. Moreover, soil microbes and crops compete for the available nitrogen in the soil, producing a nitrogen deficiency, and affecting crop growth and production.

It is generally believed that to decompose 100 g straw (dry weight), soil microbes need about 0.8 g of nitrogen; this means that per 1,000 kg of straw returned to the field, at least 8 kg of nitrogen should be added to ensure timely decomposition of straw in the field. As per China’s current production practices, phosphate and sulfur fertilizers should also be supplemented in the case of phosphorus and sulfur-deficient soils.

3.1.2 Off farm: Straw processing enterprises’ participation

Crop straw utilization measures should be adapt to local conditions. According to the difficulty level of local straw collection system and the amount of straw resources, the chosen of on-farm and off- farm utilization will be decided. Under off-farm utilization, according to the conditions and level of animal farm, mushroom cultivation, bio-energy and straw material utilization, a number of key enterprises and demonstration projects should be established in the local area to support and accelerate the development of comprehensive utilization of crop straw.

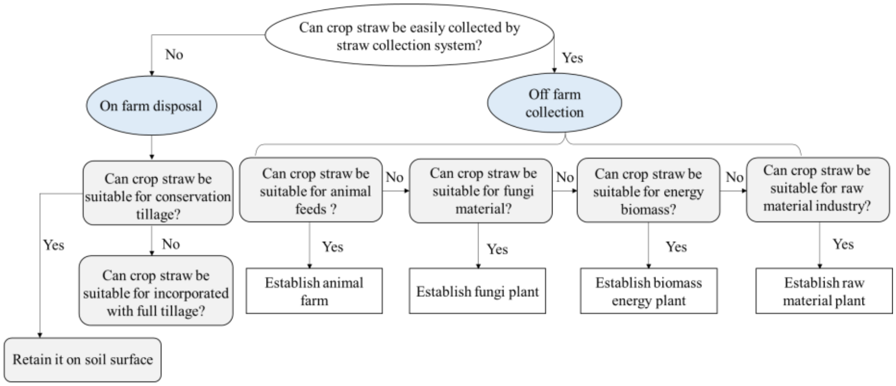


Figure 5-2: Suggestions for comprehensive utilization of crop straw according to local conditions

3.1.3 Integration of crop and livestock

Economic development and increased productivity have led to the separation of Chinese crop cultivation and livestock farming which results in the obstacle of agricultural recycling and brings about agricultural pollution. The integration of crop and livestock makes straw and animal linked in which crop straw can be reused by animal, animal manure can also be reused by crop, and hence, the environmental pollution can be reduced.

Such kind of integration can build an internal circulation chain of agriculture, promote the rational development and effective protection of agricultural resources and environment, and help the green development of Chinses agriculture. Developing the integration of crop and livestock should consider the quantity and type of crop and animal based on the resources and environmental conditions.

3.2 Construction of local straw collection service

Creating a well-executed crop straw collection system, or disposal mechanism is difficult in developing countries. The biggest constraint for Chinese recycling of crop straw is the lack of collection, storage and transportation system. The question is who cuts and collect crops straw, and then who take responsibility transporting? Given the scattered distribution of straw and its seasonal harvest, straw collection, storage, and transportation have become major bottlenecks to large-scale utilization of straw. To ensure ongoing and sustainable straw recycling, a system for collection, storage, and transportation must be established. The system is the basis for the comprehensive use of straw, linking agricultural and industrial sectors. Moreover, building an information sharing platform is key to identifying the areas of straw supply and demand.

At present, the system for straw collection, storage, and transportation in China is mainly based on straw brokers who supply straw for companies consuming straw. In some cases, the brokers collect straw themselves with transport vehicles and store it in simple storage yards; in other cases, retail farmers are paid by brokers to collect straw. Some collection companies also collect straw. Limited amounts of straw are collected by retail farmers for various companies that consume straw. Although there are some small-scale collection systems operating in China, many problems impede development of a large-scale collection system. First, there is no efficient straw harvesting or packaging machinery, which increases the difficulty of straw collection. Second, straw acquisition in China is from individual farmers having small planted areas of many types of straw; this results in difficulties in collection, storage, and transportation of this resource. Thus, straw cannot compete with equivalent energies, such as coal, in price. Third, straw supply is overly dependent on brokers, resulting in impacts on demand and supply, because to gain higher profits, straw brokers often hoard goods. Last, although the government attaches importance to a straw burning ban, it has not yet issued any relevant policies to support straw collection, storage, or transportation systems. The lack of support policies to encourage farmers to actively collect and sell straw creates an anecdote that “farmers burn straw and enterprises rush straw”.

Hence, key questions need to be addressed in this area. What constitutes a good packing machine? What methods should be employed when plots are small and scattered? What to do when large amounts of straw are collected and stored, while there is no buyer’s market? What type and size of storage space is required for storing straw without risk of getting it wet? What steps should be undertaken, if the cost of packaging is high, but the profit is low? What should the price of straw be? The existence of these specific problems clearly has restricted the establishment of the systems.

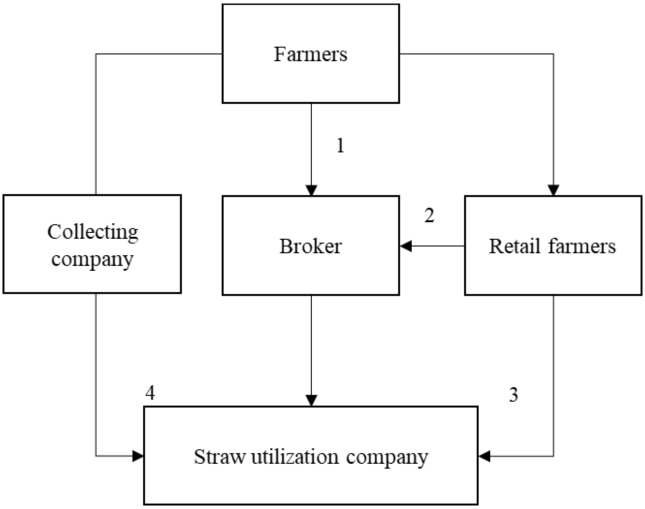


Figure 5-3: Current straw storage and transportation modes

3.3 Government subsidy incentive

Reasons for inadequate waste collection and utilization vary from country to country. Insufficient funding is a common reason if there is no shortage of technology, manpower and infrastructure. Government officials should work out proper incentive schemes to encourage the utilization and recycling of crop waste. The straw burning ban is of considerable economic value. Therefore, straw recycling is key to offset the costs related to the burning ban policy. Similarly, regardless of whether it costs farmers or enterprises, the cost of making full use of straw is very high. Although straw acquisition companies or brokers have certain benefits, straw acquisition still involves many logistic difficulties. Thus, the straw burning ban requires more financial support in the form of subsidies and infrastructure to compensate farmers and to develop straw as a resource. Most of government's investments in this area are issued in the form of subsidies. However, who should receive these subsidies, what are their standards, and how to supervise them, are all aspects that still need to be standardized.

Subsidy on farmers

Farmers' attitude and behavior directly affects the straw recycling. However, farmers gain the minimum profit in the straw supply chain that directly affects farmers' attitude towards straw disposal (Xue, 2017). Directly subsidizing farmers who return crop straw to the field and who supply straw off-farm use according to the commodity value and the cost of machinery operations. This policy can reflect the governmental guidance and encouragement of straw return behavior. Based on our research analysis, about 47 RMB per mu is suggested to compensate farmers who return corn straw to the field in Henan Province.

Subsidy support on straw processing factories

The government gives appropriate subsidies to straw processing factories. The factories will increase the purchasing price to straw collection system. As a result, the collection system will gain more profits and increase straw purchasing price to farmers. With the increase in government investment, the straw purchasing price of straw processing factories and straw collection systems will be higher, and the supply quantity of straw will become more.

Subsidy on collection system

The government give appropriate subsidies to straw collection system to guarantee their profits, in order to encourage them to collection crop straw. The collection system will, hence, raise straw purchasing price to encourage farmers to sell straw to them.

3.4 Render crop straw a market price

If crop straw is seen as the general commodity with a market price, then crop straw may not be burned by the farmers. Under price incentives, farmers are more willing to collect or sell straw. The formation of the straw market takes a certain amount of time. If the purchasing price of crop straw to farmers is low, the price can be improved by governmental subsidy through compensating the collection system and straw processing factories. A minimum market price that satisfies the farmers' no-burning attitude should also be established.

4. Prescribed burning

The current ban on open burning in China is that the burning is completely banned. This may be a little different with that in Europe. To maintain the soil organic matter level, burning crop stubble is banned. However, the ban policy of EU has an exception for plant health reasons (The European Parliament and the Council of the European Union, 2013). If the plant remains are much overrun with pests in organic production, in situ burning may be used after a thorough investigation of the burning opportunity, enrolling this matter in the farm register and promulgating the local organization of environmental protection (EU 889/2008).

In future, prescribed burning may be also used as a tool in agriculture of China, in compliance with the law. Appropriate time and atmospheric conditions should be considered, such as wind direction, wind speed, relative humidity, temperature and precipitation. Differences in climatic and soil conditions are among countries, and hence differences in specific control conditions for prescribed burning. However, general conditions are available for reference (Department of Agriculture, Food and the Marine (DAFM) of Ireland, 2012).

Wind

Wind direction and wind speed are critical to fire behavior. Wind direction specific to the burn field should be determined in advance to properly locate the fire breaks and control lines. Light, steady winds are ideal to maintain a steady rate of burn and to disperse smoke from operators. The actual wind speed at the burn field should be determined by the on site observations. It is better not exceeding 20km/h.

Relative Humidity

Relative humidity, a percentage value, the amount of water vapour in the air (at a specific temperature) compared to the maximum amount of water vapour air could hold at that temperature. When relative humidity values are lower than 50%, prescribed burning should not be attempted. It is usually best done early in the day before vegetation has a chance to dry completely.

Precipitation

Precipitation levels in the preceding days before burning is commonly used to determine general fire risk and is useful in determining safe conditions for prescribed burning. When rain is forecast coming, it is traditional in many areas to carry out burning that sufficient moisture is retained on the soil surface to protect soil and roots from damage.

Time

Time of day affects fire behavior. Compared to periods later in the day, morning is cooler, the humidity is higher, and the wind conditions are more stable. Hence, morning is better than afternoon. Burning should not start late in the evening and should never be tried at night.

5. Further work

5.1. Environmental impacts of crop straw management scenarios: open burning, incorporation into the soil, and collection

This research was initiated to assess the environmental impacts of various crop straw options (open burning, incorporation into soil, and collection) at the 'farmgate' to enhance the environmental sustainability of various crop straw treatments. Other related environmental burdens have been considered in several previous studies, including its impact on eutrophication, global warming, and aquatic eco-toxicity (Brentrup et al., 2004; Wang et al., 2013; Nguyen et al., 2013). Its total environmental impact can be assessed through implementation of an Attributional Life Cycle Assessment.

5.2. Cost and benefits for farmers for various crop straw management scenarios: open burning, incorporation into the soil, and collection

This research assessed the economic consequences of various straw management options. The agricultural production process is very complicated, resulting in straw treatments that are not only focused on yields, but also on other aspects of the production process. Hence, an economic analysis of crop production may be influenced by straw management options with varying grain yields, sowing amounts, application of fertilizers, pesticides and herbicides, irrigation frequencies, labor hours and machinery costs. To support this research objective, field surveys were carried out to retrieve field data. Considering the associated costs and benefits, both farmers and policy makers need a comprehensive understanding of straw management scenarios from both practical and theoretical bases.

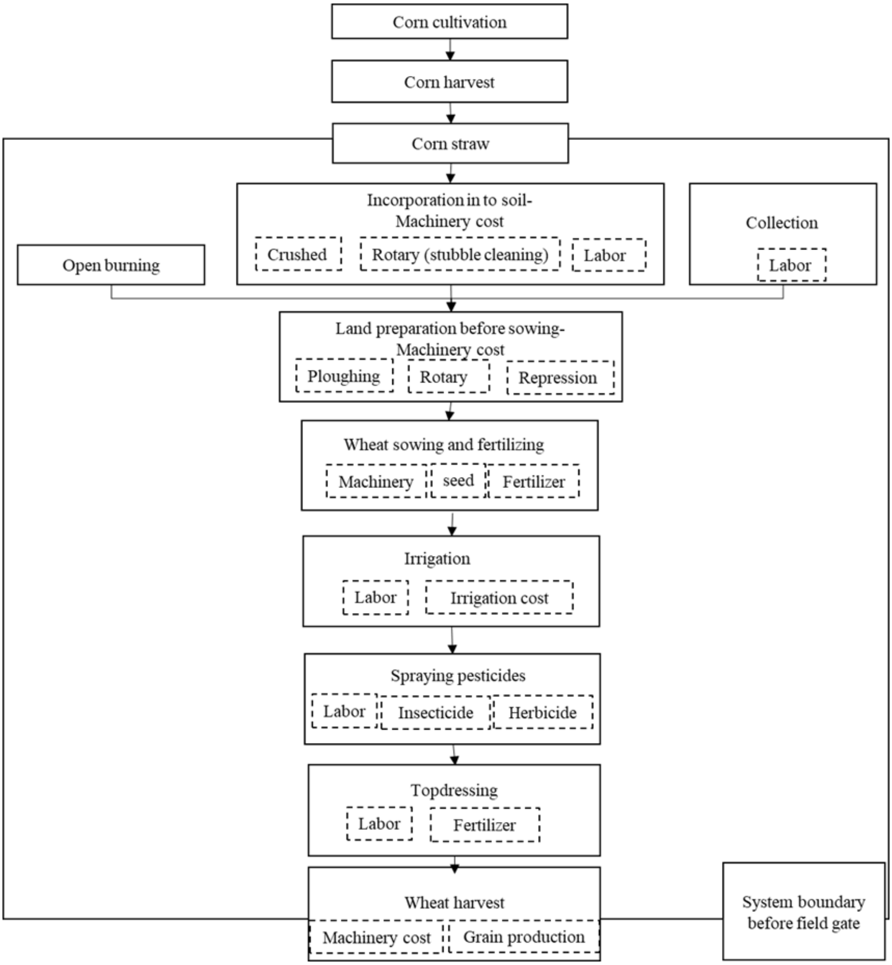


Figure 5-4: Boundaries of cost and benefit analyses for farmers for various straw management scenarios

5.3. Exploring the farmers' attitude towards straw commercialization

This thesis assesses the crop straw supply for enterprises, producing bioenergy or using straw, examining the barriers that exist at the farm-level to supply straw for recycling, as well as the incentives required to establish a sustainable feedstock supply base. The mindset and attitude of farmers has a great impact on straw commercialization, because straw commercialization involves various obstacles that need to be overcome to support farmers, such as its collection from small and scattered farm plots, and issues involved in its transport and storage. Straw is easily burned by farmers because straw has no further value to them. If straw is a commodity having monetary value like grain, then open burning and discarding of straw may not occur so readily. If straw was commercialized, then a method of pricing this resource needs to be proposed and established as soon as possible.

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ANNEX

1. Questionnaire for urban residents

Dear Respondent:

We are students from the Chinese Academy of Agricultural Sciences. This survey will helps us establish the effects of crop straw field burning during harvest periods of winter wheat and summer corn on citizens'. Moreover, we want to know whether citizens are willing to financially support efforts to reduce farmers' straw burning and to protect the environment. If citizens agree to some monetary support, then how much would they be willing to pay for the ensuing environmental benefits?

Questionnaire number: Investigator:

Date: dd mm yy

Survey site: City Province

Remarks:

1. The survey is completely anonymous, and the results will only to be used for academic research. Please do not have any concerns regarding your answers, just answer truthfully.

2. The survey only refers to the personal situation of the respondents. There is no a right/wrong answer.

3. Please answer each question according to what the questionnaire requests. Any blanks will lead to an invalid statistical analysis.

1. Basic activities regarding environmental protection of respondents

(1) Have you ever participated in environmental protection activities? A. Yes; B. No

(2) How much have your family spent on air pollution prevention annually in recent years RMB/Year. Mainly spent on

A. Masks; B. Air purifier; C. Isolated spray; D. Anti-fog haze screens; E. If there are other ways, please list

2. Effects of field straw burning during the summer and autumn harvests

(1) Air quality change

Did you feel that the air quality became worse during the winter wheat harvest period?

A. Significantly worse; B. No difference from before harvest

Did you feel that the air quality became worse during the summer corn harvest period?

A. Significantly worse; B. No difference from before harvest

If significant changes occurred in the two-harvest seasons, which season was worse?

A. Summer harvest; B. fall harvest

(2) Has your health been negatively affected because of straw burning during the harvest periods?

A. Yes; B. No

(3) Has your life or work been affected because of straw burning during the harvest periods?

A. Yes; B. No

3. Citizens' willingness to pay for "straw burning ban" to improve the air quality in Henan

The Government needs to invest to control farmers' field straw burning and support recycling of crop straw to prevent serious episodes of air pollution every year. Assuming we build "straw burning ban" funds to support this policy in Henan, please answer the following questions:

(1) Would you like to provide financial aid to support the "straw burning ban"?

A. Yes; B. No

(2) If you would not like to provide financial aid, what are your reasons.

A. I have no ability to pay because of low income.

B. "Straw burning ban" is government' responsibility.

C. I have adapted to the air pollution during harvest period, so I do not want to participate.

D. Air pollution is not so serious during harvest time because of the strict straw burning ban of the government.

E. Other reason.

(3) If you support the "straw burning ban" and recycling utilization of crop straw. What's the maximum amount of money you would pay for wheat straw per year, according to your family economic conditions?

A. 1–50	B. 51–100	C. 101–150	D. 151–200	E. 201–400
F. 401–600	G. 601–800	H. 801–1000	I. 1001–	

If greater than 1001 RMB, then please write in the exact amount.

If you support the "straw burning ban" and recycling of crop straw. What's the maximum amount of money you would to pay for corn straw per year, according to your family economic conditions?

A. 1–50	B. 51–100	C. 101–150	D. 151–200	E. 201–400
F. 401–600	G. 601–800	H. 801–1000	I. 1001–	

If greater than 1001 RMB, then please write in the exact amount.

4. Socio-economic characteristics of respondents

(1) Gender.

A. Male; B. Female

(2) Age.

(3) Education years.

A. Uneducated (0); B. Junior high school or below (9); C. Senior high school (12); D. Bachelor’s degree or higher (16+);

(4) Permanent residents or temporary residents A. Permanent B. Temporary

Remark: Permanent residents refer to people who have lived in a certain area for six months or more.

(5) Job (If retired, then list the job undertaken before retiring)________.

A. Indoor workers; B. Outdoor workers

(6) In 2015, per capita annual disposable income of urban households___RMB. Family's annual spending; the specific value is__RMB. Family’s annual savings; the specific value is__RMB.

A.<1; B. 1–2 (“2” is not included); C. 2–4; D. 4–6; E. 6–8; F. 8–10; G. 10–15; H. 15–20; J. >20 (10^4 RMB)

(7) The family size________.

2. Questionnaire for farmers

Dear Respondent:

We are students from the Chinese Academy of Agricultural Sciences. This survey will help us establish the effects of returning corn straw to the field. Moreover, we want to know whether farmers are willing to adopt corn straw return to the field to protect the atmosphere. If farmers agree to participate, then how much compensation would they be willing to accept for corn straw returned to the field?

Questionnaire number: Investigator:

Date: dd mm yy

Survey site: Survey site: Village town County City Province

Remarks:

1. The survey is completely anonymous and our results will only be used for academic research. Please do not have any concerns regarding your answers, just answer truthfully.

2. The survey only refers to the personal situation of the respondents. There is no a right/wrong answer.

3. Please answer each question according to what the questionnaire requests. Any blanks will lead to an invalid statistical analysis.

1. Corn straw disposal

(1) In 2015, did you return corn straw to the field? A. Yes; B. No

If you returned corn straw to field, then using what method________.

A. Shred straw and rotary; B. Shred straw and deep ploughing; C. Other________.

If you did not return corn straw to field, what disposal method was used________.

A. Freely collected by others; B. Sold; C. For cooking; D. Livestock feed; E. Other________.

(2) Corn sown areamu (1 mu=1/15 mu).

2. Farmers' attitude to corn straw returned to the field

(1) Are you willing to adopt corn straw return to the field to protect the atmosphere?

A. Yes; B. No

If you are not willing to do so, then the reason why is________.

A. Affects wheat sowing; B. High machinery cost; C. Affects seedling emergence of wheat; D. Other reason____.____

If you are willing to do so, then the reason why is________.

A. To improve soil fertility; B. More time-saving compared to other disposal methods under the strict straw burning ban policy; C. No straw collection system; D. Cost-saving in fertilizer input; E. other reason

(2) Do you think machinery costs of returning corn straw to the field is too high for you?

A. Yes; B. No

(3) Do you think the quality of corn straw crushed is poor?

A. Yes; B. No

(4) Do you think there are some problems with or it is not good to return whole corn straw to the soil?

A. Yes; B. No

(5) Do you think the decomposing rate of corn straw in the soil is too slow?

A. Yes; B. No

(6) Do you think straw return does not protect the atmosphere?

A. Yes; B. No

(7) Do you think corn straw return improves soil fertility?

A. Yes; B. No difference

(8) Do you think corn straw return is beneficial to the growth of wheat?

A. Yes; B. No influence

(9) Did you get any subsidies for corn straw returned to field?

A. Yes; B. No

If you got one, then the subsidy wasRMB / mu.

How do you feel about the subsidies?

A. too low B. just right C. too high

(10) Do you think the government should subsidize farmers who return corn straw to the field?

A. Yes; B. No

3. Farmers' willingness to accept compensation for corn straw returned to the field

Straw returned to field is a clean production technique which can reduce environmental pollution caused by straw burning. However, straw returned to field will increase the burden on farmers. We propose that the government promote corn straw returned to the field by paying farmers who practice this technique. What is the minimum amount of money would you like to accept to carry out the practice of corn straw return to the field RMB / mu (1 mu = 1/15 hectare).

Which aspects of returning corn straw to the field do you think the government most needs to support/pay?

A. Machinery costs; B. Wheat seeds; C. Pesticides; D. Irrigation; E. Labor

4. Socio-economic characteristics of the respondents

(1) Gender A. Male; B. Female

(2) Age

(3) Education years.

A. Primary school or below (5); B. Junior high school (9); C. Senior high school (12); D. Bachelor's degree or higher (16+)

(4) Per capita annual disposable income of the rural household 10^4 RMB.