UNITED NATIONS ESCAP
Economic and Social Commission for Asia and the Pacific

CSAM

Report and Analysis

Status of Straw Management in Asia-Pacific and Options for Integrated Straw Management

Status of Straw Management in Asia-Pacific and Options for Integrated Straw Management

Disclaimer

The views expressed in this report are those of the author and do not necessarily reflect the views of the Secretariat of the United Nations Economic and Social Commission for Asia and the Pacific. The description and classification of countries and territories used, and the arrangements of the material, do not imply the expression of any opinion whatsoever on the part of the Secretariat concerning the legal status of any country, territory, city or area, of its authorities, concerning the delineation of its frontiers or boundaries, or regarding its economic system or degree of development. Designations such as ñdevelopedò, ñindustrializedò and ñdevelopingò are intended for convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names, commercial products and/or technologies does not imply the endorsement of the United Nations Economic and Social Commission for Asia and the Pacific.

This publication has been issued without formal editing.

Contents

1

Background

1.1 Straw Burning Status in Asia and the Pacific and its Environmental Impacts

The crop straw yield has kept growing and maintained a high level with the agricultural productivity development in Asia-Pacific region in recent years. However, the high-efficient utilization of crop straw in Asia-Pacific region is mainly constrained by two factors, namely the high cost for collecting the straw, and immature technologies of integrated straw management.

In the past, straw was used as rural living energy materials and livestock feed; while nowadays, it can be used for more purposes such as fertilizer, base material, and raw material for papers and other products. However, surplus of straw always exists in specific regions and seasons and its unreasonable use still prevails in Asia-Pacific region. On the one hand, the amount of discarded straws is increasing year by year due to limited utilization ways and change of rural energy and animal feed; on the other hand, straw burning is hard to manage, which will not only result in ecological environment pollution, but also increasing security risks. These discarded crop straws were burnt by farmers after harvesting or before planting due to lack of appropriate methods and machines, shortage of rural labor, and weak environmental awareness, etc. In recent years, this problem has become more and more serious, particularly in multiple cropping areas of Asia-Pacific region. In India, a large portion of the residues, about 140 Mt was burnt in situ primarily to clear the straw and stubble of the preceding crop after harvest (Mehta et al., 2013). In Southeast Asia, it was estimated that only 20% of the rice straw was used for the production of ethanol, paper, fertilizers and fodders. The rest 80% of the total rice straws were either removed from the fields, piled up, spread out, burnt in the fields, incorporated into the soils, or used as mulching materials for the following crop (Hanafi et al., 2012). Several studies indicated that partial removal of rice straw from the fields does not significantly affect to the grain yield (Bijay-Singh et al., 2008; Thuy et al., 2008).

These days, straw burning in fields is a great challenge for sustainability as it exacerbates air quality and human respiratory ailments. One ton of paddy straw contains approximately 5.5 kg N, 2.3 kg P_2O_5, 25 kg K_2O, 1.2 kg S. Burning of the paddy straw would lose 50-70% of the micro-nutrients that rice absorbed from the soil and 400 kg of carbon (Anonymous, 2013). Apart from loss of nutrients, some of the soil properties like soil temperature, pH, moisture, available P and soil organic matter are greatly affected due to straw burning. Microbial population of soil is governed by the factors like soil temperature, pH, moisture content and organic matter content. Straw burning disturbs soil's natural environment and also has an adverse effect on microbial population of soil. Furthermore, straw burning poses threat to farmers' health and decreases air visibility, thereby threatens transportation security and causes negative effects on residents' lives.

1.2 Rationale of the Research Paper

Following up the outcomes of the *4th Regional Forum on Sustainable Agricultural Mechanization in Asia and the Pacific* of CSAM held in Nov. 2016 in Hanoi, Vietnam, and for strengthening CSAM's efforts to promote climate-smart agriculture/agricultural mechanization, a new initiative on Integrated Straw Management in Asia-Pacific is pursued to address the shared issue of straw burning faced by many member countries.

It is a demand-driven initiative responding to a pressing need of member countries and supporting their efforts to achieve the Sustainable Development Goals, in particularly, SDG 13 (combating climate change) and SDG 15 (life on land) through conservation of soil and restoration of degraded land.

Although as above mentioned, the technologies of integrated straw management are immature. There are sound and proven practices exist in different countries, which might include use of farm machinery to cut and mix the straw into soil, baling and transportation for industrial applications, briquetting for fuel and power generation, biomethanation of straw for biogas and compost preparation, etc.

As a first step of CSAM's efforts on integrated straw management, a team of experts was engaged to conduct research to understand the status of straw management in three sub-regions, namely, East Asia, South Asia and Southeast Asia, to collect the available and proven practices/technologies of straw management in member countries, and to make an action plan for pilot interventions of integrated straw management in selected member countries.

2

Objective

The Research Paper on Status of Straw Management in Asia-Pacific and Options for Integrated Straw Management will achieve the following objectives:

- Understand the current situation of crop straw resources in Asia-Pacific; and collect the available and proven practices/technologies of straw management in the region;
- Make an action plan for pilot interventions of integrated straw management in selected member countries; and
- Identify requirements, and recommend appropriate pilot sites and partners.

The Research Paper will contribute to both the renewed focus of ESCAP on the 2030 Agenda for Sustainable Development and Regional Economic Cooperation and Integration, the three Expected Accomplishments of Sub-programs of Trade, Investment and Innovation (2016-2017) and the Environment and Development (2018-2019) of ESCAP, and the priority thematic areas of climate change as well as management of natural resources of ESCAPôs óRegional Roadmap for Implementing the 2030 Agenda for Sustainable Development in Asia and the Pacificô including leveraging of opportunities to ódevelop and share best practices related to increasing agricultural productivity, sustainable agriculture, food security and rural welfare while reducing negative environmental impacts and degradation of the ecosystemô

3

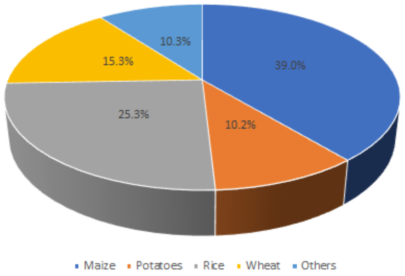
Report & Analysis

3.1 Status of Crop Straw Resources in Asia-Pacific Countries

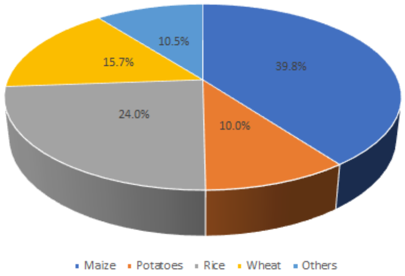
3.1.1 Types of crop straw

The crop straw in the Asia-Pacific region can be divided into four categories: grain crop straw, oil crop straw, fiber crop straw and other crop straws. Grain crop straw mainly includes maize straw, rice straw, wheat straw, barley straw, and oat straw; oil crop straw mainly includes bean straw, rape straw, sesame straw, peanut straw, and sunflower straw; fiber crop straw mainly includes cotton straw, linen straw, ramie straw, kenaf straw, and jute straw; other crop straws mainly include sugarcane straw, flue-cured tobacco straw, and sugar beet straw. Rice, wheat and maize are the top three main sources of crop straws. The straw production in the three targeted sub-regions are showed below.

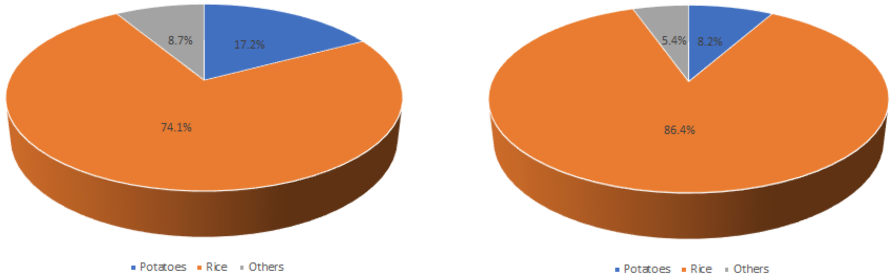
East Asia: This study covered three countries in East Asia, namely China, Japan and Republic of Korea. Straws in East Asia are mostly from maize (39.0%), rice (25.3%), wheat (15.3%) and potato (10.2%) (Fig.1). To be specific, the proportion of maize, rice and wheat straws in China was estimated to be 39.8%, 24.0% and 15.7%, respectively. In Japan and Republic of Korea, the main crop straw is rice straw, estimated to be 74.1% and 86.4% of the total, respectively.



(a) East Asia



(b) China

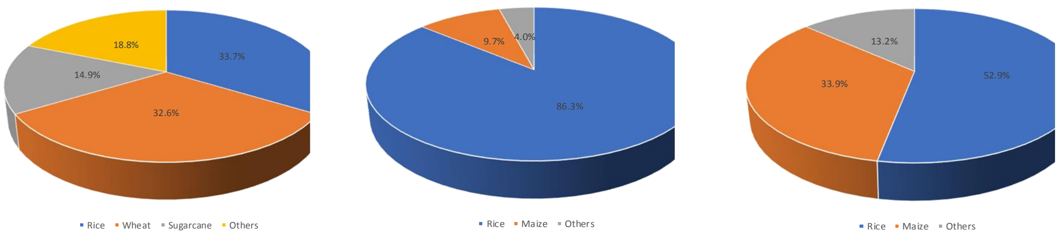


(c) Japan (d) Republic of Korea

Figure 1 Proportion of major straw types in East Asia, China, Japan and Republic of Korea (FAOSTAT, 2014)

Note: Straw yield was estimated from crop yield by straw-grain ratio (with the ration of about 3:1).

South Asia: There are various types of crop straw in South Asian countries that the Study covers: Bangladesh, India, Nepal, and Sri Lanka. Details of the straw proportion in some South Asian countries are presented in Fig.2. Main straw types include rice straw, wheat straw and maize straw. However, in India a large amount of straw is also from cotton, soybean, mustard and sugarcane crops.



(a) India (b) Bangladesh (c) Nepal

Figure 2 Proportion of major straw species in India, Bangladesh and Nepal (FAOSTAT, 2014)

Note: Straw yield was estimated from crop yield by straw-grain ratio.

Southeast Asia: Rice and maize straws are the main crop straws in the Southeast Asia (FAOSTAT, 2014). And other straws of great yield include sugarcane residues in Vietnam, soybean straw in Cambodia and bean straw in Myanmar. According to FAOSTAT (2014), total sugarcane output of Vietnam in 2014 was 19,822,851 tons which produced about 6.678 million tons of sugar residues (Nguyen Van Loc, TTC Group & Diep Huynh Nhu, 2014). For Cambodia, soybean and mung bean outputs in 2012 were 120,000 tons and 74,677 tons, respectively (Ministry of Agriculture, Forestry and Fishery, April 2013). These produced about 200,000 tons of the residues.

3.1.2 Distribution of crop straw

Due to the diversity of climate and geography in the Asia-Pacific region, crop types and planting systems are quite different. Natural farming systems generally fit into four major agroecological zones, namely, (a) the humid and sub-humid lowlands where the major systems are shifting cultivation (much less now) and plantations (tea, rubber, coconut), (b) irrigated and naturally-flooded areas where the major systems are based on lowland rice and irrigated farming of a variety of crops including aquaculture, (c) hill farming in the mountainous areas, and (d) dryland areas with uncertain rainfall which are usually devoted to sisal plantations, upland cereal based systems, and pastoral systems.

In Asia-Pacific region, rice straw is mainly distributed in China, India, Indonesia, Bangladesh, Vietnam and Thailand; maize straw is mainly distributed in China, India and Indonesia; wheat straw is mainly distributed in China, India and Pakistan; while, Potato straw is mainly distributed in China, India, and Bangladesh. The distributions of crop straw in the targeted Asia-Pacific countries are showed as follow:

1. East Asia

China: China covers a wide geographical area, and the crop species vary from different agricultural climate, cropping system and socio-economic conditions. Therefore, the distribution of crop straw in different regions is multifarious. According to the geographical and climatic division, main straws in northeast China are maize, rice and potato straw; maize and wheat straw in North China and Huanghuaihai region; maize, wheat and cotton straw in Northwest region; and rice, wheat and rape straw in Yangtze valley (Table 1).

Japan: According to geographical location, climate, soil conditions and production characteristics, agricultural areas in Japan can be divided into nine areas: Hokkaido, Tohoku, Hokuriku, Kanto, Higashiyama, Tokai, Kinki, Chugoku, Shikoku and Kyushu. Rice straw is mainly distributed in Hokkaido, Niigata and Akita; wheat straw is mainly in Hokkaido, Fukuoka and Saga; barley straw in Hokkaido, Saga and Tochigi; and potato straw is mainly in Kagoshima, Ibaraki and Chiba (Table 1).

Republic of Korea: Arable land in the Republic of Korea mainly situates in the western plain, southern plain, and hilly areas. Rice straw mainly distributes in Jeonnam, Chungnam and Jeonbuk; barley straw mainly distributes in Jeonnam, Jeonbuk and Gyeongnam (Table 1).

Table 1 Distribution of main crop straw in the targeted East Asia Countries

Country	Straw distribution
China [a]	Yangtze valley, South China; Southwest region, Huanghuaihai area, Northeast region, Yellow River valley
Japan [b]	Hokkaido, Niigata; Akita, Fukuoka, Saga, Kagoshima, Ibaraki, Chiba, Tochigi
Republic of Korea [c]	Jeonnam, Chungnam, Jeonbuk, Gyeongnam

a: Yuyun Bi etc., 2010;

b: http://www.maff.go.jp/e/

c: http://english.mafra.go.kr/main.jsp

2. South Asia

India: India has the most amount of arable land in this region; and crop straw distributes almost in all parts of the country. The major crops contributing straw include paddy, wheat, sugarcane, cotton, soybean, etc. Significant variations are observed among the states of India in terms of surplus residue fraction availability. Nationally 34% of the gross residue generated is available as surplus. However, at state level the availability varies from a minimum level of 21% in Arunachal Pradesh to a maximum value of 48% in Haryana and Punjab. Uttar Pradesh, which produces the highest amount of residue in country, has surplus availability of 33%, almost equals to national average value but less than many other states. The straw contributing states are: West Bengal, Uttar Pradesh, Andhra Pradesh, Punjab, Orissa, Bihar, Chhattisgarh, Tamil Nadu, Assam, Haryana, Madhya Pradesh, Bihar, Maharashtra, and Rajasthan (Table 2).

Bangladesh: Bangladesh consists of 30 agro-ecological zones and is divided into six divisions. The major crop residues are generated from rice, wheat and maize crops. It is available mainly in Barisal, Chittagong, Khulna, Rajshahi and Rangpur (Table 2).

Nepal: The major crop straws in Nepal are rice, wheat and maize. The crop straw is available in the Eastern, Western and Central regions of Nepal (Table 2).

Sri Lanka: Rice is the major straw-producing crop in Sri Lanka. Rice is cultivated during both Maha and Yala seasons. The Anuradhapura, Kurunegala, Polonnaruwa,Hambantota, Ampara, Monaragala, Badulla, Matale, Puttalam and Trincomalee are major paddy growing regions in Sri Lanka (Table 2).

Table 2 Distribution of main crop straw in the targeted South Asia Countries

Country	Straw distribution
India	West Bengal, Uttar Pradesh, Andhra Pradesh, Punjab, Orissa, Bihar, Chhattisgarh, Tamil Nadu, Assam, Haryana, Madhya Pradesh, Bihar, Maharashtra, Rajasthan states
Bangladesh	Barisal, Chittagong, Khulna, Rajshahi and Rangpur Divisions
Nepal	Eastern, Western and Central regions
Shri Lanka	Anuradhapura, Kurunegala, Polonnaruwa,Hambantota, Ampara, Monaragala, Badulla, Matale, Puttalam and Trincomalee districts

3. Southeast Asia

Indonesia: Indonesia is the largest rice producer in Southeast Asia. Rice straw is produced throughout the country. About 75% of rice producing areas is irrigated land; and less than 10% of rice producing areas are rain-fed lowland. Indonesia can be divided into five major rice producing regions. These are Kediri in East Java, Klaten in Central Java, Majalengka in West Java, Agam in West Sumatra, and Pinrang-Sidrap in South Sulawesi

(Table 3).

Vietnam: Vietnam is the second biggest rice producer in Southeast Asia. There are 6 major rice straw producing regions. These are Mekong river delta (MRD) in the South, Red river delta (RRD) in the North, Northern Central & Central Coast, Northern highland & mountain areas, South-East region and the Central highland region. Mekong river delta has the biggest rice straw yield in Vietnam (Table 3).

Thailand: Rice, planted throughout the country, is one of the main crops in Thailand. The Northeast, North and Central are the major rice straw producing regions, and occupy 49.1%, 25.4% and 22.3%, respectively, of the total rice producing area in the country (Table 3).

Myanmar: Rice is grown throughout the country by poor rural farmers with small farms of about 2.3 hectares in size. Therefore, rice straw was also distributed throughout the country (Table 3).

Cambodia: Rice is the principal crop in Cambodia. Main rice straw producing provinces of Cambodia are Battambang, Kampong Cham, Banteay Meanchey and Kampong Thom (Table 3).

Philippines: Major rice straw producing regions of the country are Central Luzon, Western Visayas, Cagayan Valley, Ilocos, and Soccsksargen. On average from 2006 to 2010, these regions contributed up to 60% of the total rice straw production (Table 3).

Table 3 Distribution of rice straw in the targeted Southeast Asia countries

Country	Straw distribution
Indonesia	75% in irrigated land and less than 10% in rain-fed lowland; Kediri in East Java, Klaten in Central Java, Majalengka, Agam and Pinrang-Sidrap
Vietnam	Mekong river delta, Red river delta, Northern Central & Central Coast, Northern highland & Mountain areas, Southeast region and the Central highland region
Thailand	Northeast, North and Central of the country occupying 49.1%, 25.4%, and 22.3%, respectively of the total rice straw producing area
Myanmar	Throughout the country
Cambodia	Battambang, Kampong Cham, Banteay Meanchey and Kampong Thom
Philippines	Central Luzon, Western Visayas, Cagayan Valley, Ilocos, and Soccsksargen

3.1.3 Yield of crop straw

East Asia: Straw production can be generally calculated by straw-grain ratio. There is a wealth of straw resources in China; maize, wheat and rice straws were estimated to be about 442, 174 and 266Mt/yr, respectively. Rice straw is the main straw in Japan and Republic of Korea, with annual yields estimated to be around 13.5 and 7.22 Mt, respectively. The main crop straw production in China, Japan and the Republic of Korea are shown in Table 4.

Table 4 Main crop straw production in the targeted East Asia countries (Mt/yr) (FAOSTAT, 2014)

Crop	Straw-grain ratio	China		Japan		Republic of Korea	
		Grain	Straw	Grain	Straw	Grain	Straw
Rice	1.28	208.24	266.55	10.55	13.50	5.64	7.22
Wheat	1.38	126.22	174.18	0.85	1.18	/	/
Maize	2.05	215.81	442.41	0.25	0.51	/	/
Potato	1.16	95.57	110.86	2.46	2.85	0.59	0.69

South Asia: India produces maximum straw among all the South Asian countries, and rice straw is the main straw in South Asia with 139.26, 44.25, 6.33 and 5.76 Mt/yr in India, Bangladesh, Nepal and Sri Lanka, respectively (Table 5). The amount of wheat straw produced in India is estimated to be 133.3 Mt/yr which was almost equal to rice straw.

Table 5 Major crop straw production in some South Asia countries (Mt/yr) (FAOSTAT, 2014)

Crop	straw-grain ratio	India		Bangladesh		Nepal		Sri Lanka	
		Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Rice	1.28	108.8	139.26	34.57	44.25	4.95	6.33	4.50	5.76
Wheat	1.38	96.6	133.30	1.30	1.79	1.57	2.16	/	/
Maize	2.05	26.15	53.60	2.75	5.63	2.20	4.50	0.24	0.48

Southeast Asia: Rice and maize straw are the two main crop residues in the Southeast Asia. According to Bakker et al (2013), the total amount of rice straw in the Southeast Asia was about 210.10 Mt/yr. Rice straw yield in Indonesia was 90.68 Mt/yr, which was much more than the other Southeast Asia countries (Table 6). Due to the tropical climate, wheat is grown only in the Northern parts of the region, being Myanmar and Northern of Thailand. Therefore, the straw amount is much less than the other two crops.

Table 6 Rice straw yield in the targeted Southeast Asia countries (Mt/yr)

Crop	Straw-grain ratio	Indonesia		Vietnam		Myanmar		Thailand	
		Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Rice	1.28	70.84	90.68	44.07[a]	49.59[b]	26.42	33.82	32.62	41.75
Wheat	1.38	-	-	-	-	0.186	0.256	0.0015	0.00028
Maize	2.05	18.51	37.94	5.19	10.64	1.60	3.28	4.87	9.98

(Source: FAOSTAT, 2014)

a: Statistical Yearbook of Vietnam 2013;

b: Diep Quynh Nhu, 2014

3.2 Investigation and Analysis of Crop Straw Management Patterns in Asia-Pacific countries

3.2.1 Crop straw management pattern

As the by-product of agricultural production, crop straw is valuable biological resource which is rich in organic matter (fiber, lignin, starch, protein, enzymes) and nutrients (N, P, K). There are abundant straw resources in the Asia-Pacific region. Hence, improving straw utilization efficiency, reducing straw burning and waste can not only improve the agricultural ecological environment, but also develop rural economy, increase farmersô income and promote sustainable development of agricultural production. Currently, crop straw is mainly used as fertilizer, fodder, new energy resource, base stock and industry material.

3.2.1.1 Straw used as fertilizer

Crop straw is a fertilizer resource with high nutrient value, which can be achieved by returning straw to field. Straw retention can supply and balance soil nutrients and increase soil organic matter content. Thus, the chemical fertilizer input can be reduced. Straw retention is considered as a potential effective measure to improve crop productivity. Straw used as fertilizer can be classified into: direct straw returning (soil cover, mix-buried with soil) and indirect straw returning (decomposed straw returning, carbonized straw returning).

(1) Technologies for straw used as fertilizer

A. Direct straw returning

In direct straw returning, the un-decomposed straw is chopped in-situ and incorporated into the soil using chopper and rotary tiller/disc plough. With the increasing yield and reduced application of fertilizer, farmersôincome increases and the burden to collect straw can be eased. Meanwhile, straw burning can be avoided and thereby improve the agricultural ecological environment. Direct straw returning can be subdivided into soil cover with straw and straw mix-buried with soil.

i. Soil cover with straw

Soil cover with straw refers to that the soil is covered with the chopped straw or standing stubble in the intercrop of next crop before harvest ; or after harvest, the seed of the next crop is directly planted in straw covered fields. Straw cover is beneficial to reduce soil and water erosion, slow down soil degradation, and can play a significant role in regulating ground temperature, reducing soil moisture evaporation, inhibiting weed growth and increasing soil organic matter.

Typical technological process includes: crop harvestŸ straws chopping and mulchingŸ no-till seeding.

ii. Straw mix-buried with soil

Straw mix-buried with soil refers to the management that mechanically chopping and spreading crops (maize, wheat, rice, etc.) straw on soil surface after harvest, and then use rotary tiller to mix and bury the straw into soils.

Typical technological process includes: crop harvestŸ straw chopping and spreadingŸ straw burying by roto-tillŸ crop planting.

B. Indirect straw returning

The key feature of indirect straw returning is that the straw was made into organic fertilizer before returning to field. Straw can be converted into organic carbon that is available to plants after indirect straw returning, which will significantly increase the soil fertility by improving the physical and chemical properties of the soil. Indirect straw returning can be subdivided into decomposed straw returning and carbonized straw returning.

i. Pre-decomposed straw returning

Pre-decomposed straw returning method means that crop straw would be decomposed into simple organic material, humus and mineralization by adding decomposition agent (accelerate the decomposition of wood fiber of straw) under conditions of suitable nutrition, temperature, humidity, ventilation and PH condition.

Typical technological process includes: crop harvestŸ fertilizingŸ adding decomposition agentŸ watering or steeping fieldŸ rotary tillageŸ planting crop.

ii. Carbonized straw returning

Carbonized straw returning method means that carbon-producing technology and equipment are used to carbonize straw, then return the slow-release fertilizer or soil ameliorant produced by biochar to the fields. The biochar has excellent performance in adsorption buffering, and fertilizer and water conserving, which can significantly improve soil structure, enhance fertility and solve soil degradation. It is effective to improve middle-and-low-yield farmlands and achieve high-efficiency utilization of agriculture and forestry waste.

Typical technological process includes: straw carbonizationŸ slow release fertilizer and soil ameliorant producingŸ low-release fertilizer and soil ameliorant returning to soils.

(2) Status for straw used as fertilizer in Asia Pacific region

East Asia: The use of straw as fertilizer in East Asia accounts for a large proportion of all straw utilization technologies (Table 7). In China, the straw used as fertilizer accounts for

43.2% of the total straw utilization (National Development and Reform Commission, 2016). The main management pattern of straw in two/more cropping system of China is directly returning straw to field followed by straw indirectly returning to field technology (decomposed straw returning and carbonized straw returning). In Japan, straw used as fertilizer accounts for about 55% of the total straw utilization. For the rice straw, 75.9% is mixed with soil and 6.4% is made into manure (MAFF, 2006). In Republic of Korea, straw used as fertilizer is one of the two main ways of straw utilization. Rice straw is directly returning to field after chopping. Of the 7.77 million farms consuming 24.39 million tons of straw, 3.94 million farms have adopted this technology.

Table 7 Status for straw used as fertilizer in the targeted East Asian countries

County	Major used crop straw	Usage Percentage	Technology
China	Maize, Wheat, Rice	43.2%	Straw directly returning to field, Straw indirectly returning to field
Japan	Rice, Wheat	55.0%	Straw directly returning to field, Decomposed straw returning
Republic of Korea	Rice	45.7%	Straw directly returning to field

South Asia: The straw is poorly utilized for fertilizer in South Asian countries. In India, crop straws left in the field (15-20%) after harvesting (by manual and with reaper) are directly incorporated into the field by ploughing. Only 5-10% of the straw recycled back to the field as compost manure or as decomposed material. In the case of the combine harvested paddy field, technology for in-situ incorporation of straw using chopper has been demonstrated in a few fields of thousand-hectare for 3-4 years. In other south Asian countries, the situation is almost the same.

Southeast Asia: Most of rice straw in the Southeast Asia is burnt after harvest. For examples, 47.81% of the rice straw in Thailand (Gadde et al., 2007), 62% in Indonesia, 42.0-57.5% in the Philippines, and 54.1% in Vietnam is burnt (Table 8) (Nguyen, 2012; Tran et al, 2014; Chiharu et al., 2017). Some areas, top rice straw is collected, the other stubble remaining in the fields is returned directly to the soil using plows or rotary machines. Besides, straw of rice or maize (corn stover) could be returned directly to the soil after being used as mulching materials for fruit trees or vegetables. After each mushroom growing cycle, the pre-decomposed rice straw is used as organic fertilizer for rice or other crops. This method is very popular in Vietnam, Thailand and the Philippines.

Table 8 Status for straw used as fertilizer in the targeted Southeast Asian countries (Gadde et al., 2007)

Country	Major used crop straw	Ratio	Technology
Thailand	Rice, Maize	35.3%	Straw directly returning to field
Vietnam	Rice, Maize	26.1%	Straw directly returning to field
Philippines	Rice	29.7-40.2%	Straw directly returning to field

Thailand, Vietnam, Philippines	Rice	1-5%	Straw indirectly returning to field

3.2.1.2 Straw used as fodder

Crop straw which stores half of the organic matter of the crop has a high nutritional value, and the nutritional value of 4 tons of straw is equivalent to 1 ton of grain (Li et al., 2017). In the cattle and sheep breeding area, there are many farms and straw feed processing enterprises to produce silage, biogas and other fodder. Straw used as fodder can be divided into: ensilage, silken straw fodder processing/rubbing processing, briquetting, extrusion, ammoniation treatment.

(1) Straw used as fodder

i. Ensilage

Ensilage is a roughage that can be produced by the fermenting of green straw (moisture content between 65% and 75%) with anaerobic lactic acid bacteria under confined hypoxia conditions. Silage is a good source of livestock fodder, which is conducive to long-term preservation. However, because of the high content of straw fiber, the use of ensilage is limited to cattle, sheep and other ruminants.

Typical technological process includes: harvestingŸ choppingŸ adding additiveŸ bagging.

ii. Silken straw fodder processing/rubbing processing

Silken straw fodder processing/rubbing processing technology refers to mechanically knead straws into soft filament. With the separation of cellulose, hemicellulose and lignin, the straw is softened and easy for livestock to chew, which can help to improve feed-intake and reduce straw waste. In addition, the long silken straw can delay the residence time staying in the rumen and is good for the digestion and absorption of livestock, and thus to enhance both the straw feeding rate and conversion rate.

Typical technological process includes: dry strawŸ kneadingŸ bundlingŸ dryingŸ storingŸ storageŸ feeding.

iii. Briquetting

Straw briquetting is a kind of straw physical treatment method, by which straw can be briquetted into a high-density cake. The compression ratio can reach 1:5 or even l:15. The briquetted straw has smaller size for transportation and storage.

Typical technological process includes: choppingŸ dryingŸ compression molding.

iv. Ammoniation treatment

Ammoniation treatment means that crop straw is treated by ammonium hydroxide. The principle of straw ammoniation is that the organic matter of straw reacts with ammonia to form ammonium when the low-quality roughage with low nitrogen content (Ò1%) meets ammonia and provides nitrogen source for rumen microbes in ruminants. Ammonia dissolved in water after the formation of ammonium hydroxide on the roughage of alkalization. Straw ammoniation will consume large amount of ammonia sources, and is likely to cause environmental pollution. Thus, this method is not widely used.

Typical technological process includes: straw choppingŸ mixing straw with ammonia sourcesŸ sealing treatment

(2) Status of the Straw used as fodder in Asia-Pacific region

East Asia: Using straw as fodder has been applied widely in East Asia, but still, with a need for potentiality application (Zhou, 2015). As shown in Table 9, in China, straw used as fodder accounts for 18.8% of the total utilization of straw. Straw suitable for processing accounted for 85.67%; while only about 15% of the straw is processed. The rests are cut into 3-5cm as coarse fodder (Li, 2017). In Japan and Republic of Korea, rice straw used as fodder accounts for 10.3% and 20.8% of each countryǿs total rice straws, respectively (MAFF, 2006).

Table 9 Status for straw used as fodder in the targeted East Asian countries

Country	Ratio	Major used crop straw	Technology
China	18.8%	Maize and rice	Ensilage and coarse fodder
Japan	10.3%	Rice	Coarse fodder
Republic of Korea	20.8%	Rice	Ensilage

South Asia: Wheat straw and chopped maize stalk are the most favored fodder for animal in many parts of India and Nepal. In southern & eastern parts of India and almost all the parts of Shri Lanka and Bangladesh, paddy straw and maize stalk are used as fodder for animals; while ground nut and sorghum stalk are also used as fodder in western and northwestern parts of India.

Southeast Asia: Rice straw, especially raw rice straw is popular for animal feed in most of the Southeast Asian countries (Table 10). Devendra and Thomas (2002) reported that about 90% of ruminant animals in the tropical Asian countries are fed with rice straw. This might be due to the abundance of rice straw in this region. In the Southeast Asia, rice straw is mainly utilized by swamp buffaloes and cattle with adult live weights of 350 and 200 kg, respectively (Devendra, 1997). According to Truc and Ni (2009), 23% of the total rice straw in Vietnam is used for animal feed. For sweet corn, it is harvested at the "milk stage", after pollination but before starch formation (FAO, 1997; VNFOREST, 2011). Because of the low rate of the poorly fermented rice straw passing through the rumen, the feed intake can be reduced (Conrad, 1966). Therefore, farmers and dairy farms from many regions in Thailand, Indonesia and Vietnam are applying different treatments to improve nutritive value of the rice straw for animal feed. By treating rice straw with urea or calcium hydroxide or by supplementing rice straw with protein; feed intake, degradability and milk yield of cows can be improved, compared with raw straw without any treatments (Fadel Elseed, 2005 & Wanapat et al., 2009).

Table 10 Status for straw used as fodder in the targeted Southeast Asian countries

Country	Ratio	Major used crops straws	Technology
Indonesia	31%	Rice	Ensilage and coarse fodder
Vietnam	23%[a]	Rice	Coarse fodder
Thailand	15%[b]	Rice	Ensilage and coarse fodder[c]
Philippines	2-4%	Rice	Coarse fodder

a: Truc and Ni, 2009 & Biomass Business Opportunities Vietnam, 2012

b: Gadde et al., 2007

c: Rosmiza et al., 2014

3.2.1.3 Straw used as new energy resources

Crop can store 50% of the energy in straw through photosynthesis. With high contents of carbon, hydrogen, oxygen and other nutrients and low nitrogen and sulfur, crop straw can generate high calorific value with less noxious gas. Currently, crop straw can be used as energy source by converting into briquetted fuel, generating producer gas in gasifiers, biogas generation and ethanol production, which can help reduce consumption of coal, oil and other non-renewable energy resource.

(1) Technologies for straw used as new energy resources

i. Briquette fuels

Straw briquetting is a modern technique to achieve straw solidification, which means to transform straw from loose, shapeless crop residues into high-density and shaped briquette fuels using briquette implement. Compared with traditional direct burning method, the thermal efficiency is improved by 50-70%, so that it can be used as the substitute of coal, lumber and fuel gas to save energy. Furthermore, briquette fuels have advantages in transportation, storage and usage, and are easy to be industrialized and produced in large scale.

Typical technological process includes: raw materialŸ smashingŸ briquettingŸ product packagingŸ meteringŸ warehousing

ii. Biogas production

Biogas is a commonly used energy in rural area. Excrement of human and animals are mixed with crop straw as backing material to produce biogas through anaerobic digestion.

This technique is low energy consumption, pollution-free and benefiting economy and agroecology.

Typical technological process includes: raw materialŸ smashingŸ steepingŸ stack rettingŸ fermentationŸ biogas producing.

iii. Carbonization fuel

Straw carbonization means to dry straw and smash it and transform the loose straw into charcoal through destructive distillation, and cooling in carbonizing implement.

Typical technological process includes: raw materialŸ smashing/packagingŸ shove chargeŸ carbonizationŸ pulverizationŸ carbon dustŸ packagingŸ warehousing

iv. Gasification fuel

Straw gasification refers to drying, gasifying, burning and reducing of chopped straw under oxygen deficit environment, so as to produce smokeless, dust-free, pollution-free mixed straw gas of carbon monoxide, hydrogen and methane. After purification, dust extraction, cooling and pressurized storage, straw gas is sent to farmers as gasholder or underground tub for cooking or heating. Burning rate could reach 35-45% after gasification, which was twice higher than direct-burning. In addition, it is clean, cheap and convenient, hence more welcomed in rural areas.

Typical technological process includes: straw and airŸ gasifierŸ water scrubberŸ water removal systemŸ separator Ÿ gas tankŸ consumer

v. Degradation and ethanol production

Biomass degradation technique has been considered as a high-efficient and integrated biomass utilization approach. It combines physical, chemical and biological methods to split macromolecular structure (such as lignin cellulose hemicellulose) into micromolecule liquid products (such as alcohol flammable oil), in order to transform crop straw into liquid fuel and chemical material. Through this method part of fossil fuel can be replaced by biomass fuel, thereby ensure reasonable energy allocation, and reduce air pollution and cost.

Typical technological process includes: pretreatment of raw materialŸ saccharificationŸ fermentationŸ distilling.

(2) Status for straw used as new energy resources in Asia-Pacific region

East Asia: Prospect of using straw as new energy resource is optimistic. For example, in China, it occupies 11.4% of total straw usage. Biogas and briquette fuel have been greatly developed in recent years. From 2009 to 2014, the amount of straw biogas and briquette companies increased from 178 and 259 to 458 (157% increased, the household increased to 77.6 thousand) and 1147 (343% increased, annual output increased to 6,000 thousand ton) (Fig. 3). In Japan, straw is mainly degraded into ethanol and used as energy. In 2008, the Ministry of Agriculture, Forestry and Fisheries of Japan conducted the experiment for ethanol production of biomass in three sites (Eniwa of Hokkaido, Akita Prefecture and Hyogo), and the highest annual output were 1040, 22500 and 800 L, respectively.

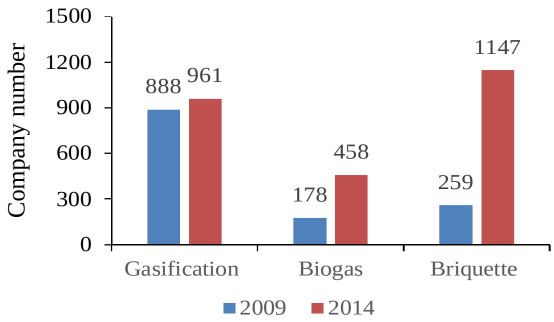


Figure 3 Number of straw gasification fuel, biogas and briquette companies in China

South Asia: Biomass power/co-generation projects are getting momentum in India. Table 11 shows the state wise capacity of the commissioned projects in India up to 2016. The table shows that the rate of growth during 2012 to 2016 is slightly in decreasing trend. This may be due to cheaper option of solar power generation projects. Briquetting of crop residues is slowly gaining in India due to shortage of saw dust. The biomass briquettes are generally used for thermal applications in boilers, kiln, hot air generation and ovens. In other south Asian countries, the biomass based power generation is slowly taking up. In Bangladesh, the biomass based power generation capacity is less than 1 MW (Ahmed and Tanin, 2013).

Table 11 State Wise/ Year Wise List of Commissioned Biomass Power/Co-generation Projects in India (MW) (Ministry of New and Renewable Energy, Govt. of India, 2016)

State	2012-03	2012-13	2013-14	2014-15	2015-16	Total
Andhra Pradesh	363.25	17.5				380.75
Bihar	15.5	27.92				43.42
Chattisgarh	249.9		15	15		279.9
Gujarat	20.5	10	13.4	12.4		56.3
Haryana	35.8	9.5				45.3
Karnataka	441.18	50	112	111	158	872.18
Madhya Pradesh	8.5	7.5	10	9		35
Maharashtra	603.7	151.2	185.5	184	96.38	1220.78
Odisha	20					20
Punjab	90.5	34	16	15		155.5
Rajasthan	83.3	10	8	7		108.3
Tamil Nadu	532.7	6	32.6	31.6	39	626.9
Uttarakhand	10		20	20	13	50
Uttar Pradesh	644.5	132			93.5	842
West Bengal	16	10				26
Total	**3135.33**	465.6	412.5	405	400	**4831.33**

Southeast Asia: According to Devendra (1997), advanced biofuel from residues in the Southeast Asia could displace all fuel used for transport in the Philippines, Thailand and Vietnam; and about half of all fuel used for transport in Indonesia. In spite of those, most of rice straw in the region is used for animal feed (Devendra and Thomas, 2002). Some countries in the region like Indonesia, Thailand, Vietnam have plants and plans using agricultural biomass including rice straw and rice husk rice for energy generation. Straw targeted for fuel production in Indonesia is about 25%; and for fuel production in Thailand is about 0.2% (Rosmiza et al., 2014).

3.2.1.4 Straw used as base stock

Crop straw can be used to produce organic solid materials which can provide favorable conditions for the growth of animals, plants and microorganisms. With a low investment and technical requirements, it can reduce waste and burning of crop straws, protect ecological environment and promote the recycling use of natural resources. The base stock produced by straw includes edible fungus culture substrate, plant cultivation substrate, bedding materials in animal feeding process, and adsorbent material used in solid microbial preparations production.

(1) Technologies for straw used as base material

i. Cultivating straw rotting fungus

Straw rotting fungus is a kind of fungus which absorbs the organic matter of the gymnosiphon as main source of nourishment. The suitable carbon sources for the straw rotting fungus are sucrose, glucose, sour straw, livestock wastes and mushroom cultivating residue. The mushroom cultivating residue are peptone, yeast powder, bran, corn flour and rice bran.

i. Cultivating wood-decay fungi

Wood-decay fungus is a kind of fungus which gets the nutrition mainly from wood, such as mushroom, agaric, oyster mushroom, lucid ganoderma and hericium erinaceus. However, there was no clear difference between the wood-decay fungi and straw rotting fungus. Some wood-decay fungi, such as mushroom and oyster mushroom, can be also cultivated by straw, while some straw rotting fungus, such as agaricus blazei murill and coprinus comatus, can get nutrition from bits of wood.

Typical technological process includes: determine time and scaleŸ house constructionŸ material reservingŸ compostingŸ pre-fermentationŸ post-fermentationŸ plantingŸ seedbed buildingŸ soil mulchingŸ mushroom managementŸ harvest

(2) Status for straw used as base material in Asia-Pacific region

East Asia: Straw used as base material in East Asia region only accounted for a small fraction of all the crop straw. In China, straw used as base material occupies 4.0% of total straw usage, and there are already 20 products which used straw as base material, such as pleurotus ostreatus, lentinus edodes, auricularia auricula and ganoderma lucidum. In 1996, Chinese Academy of Agricultural Sciences first proposed organic eco-hydroponics and proved the feasibility of using straw as a culture medium by mixing the organic waste (ripening corn stalks and disinfect chicken dung) with turf and slag. However, technology for straw base material utilization has yet to be further enhanced, and the production technology and process is not standardized (Wang, 2017).

South Asia: Wheat or paddy straw is usually used as a base material for growing mushroom in India and other south Asian Countries. However, the straw quantity used for this purpose is almost negligible as compared to its production.

Southeast Asia: Like other regions in the Asia, using the rice straw and corn stover as based stock is not much popular in the Southeast Asian countries. In some rural areas in Vietnam, Thailand and Indonesia, rice straw and corn stover are still used as bedding materials for cattle houses or used as building materials for animal houses. The residues can absorb urine and manure from the animals in order to keep the houses drier or make the animals more comfortable in cold seasons. However, technology as well as machinery for enhancing uses of the residues have not much developed. After using, the residues which were mixed with organic matters from the animals could be used as fertilizer for crops.

3.2.1.5 Straw used as industry materials

Other than fertilizer, fodder and energy resources, straw can also be used as agricultural implement, architectural, industrial and daily materials. Straw fiber is a natural cellulosic fiber with good biodegradability, and it can be used to produce paper, panel, artware and activated carbon in replace of lumber and make xylitol in replace of grain.

(1) Technologies for straw used as industry material

i. Papermaking

Straw fiber is a good material to make paper with abundant natural cellulosic. It means to extract straw pulp include blasting, solvent and screw pulping so to make paper.

Typical technological process includes: smashŸ infiltrationŸ calcify Ÿ continuous cookŸ straw pulpŸ decolorationŸ homogenateŸ compression Ÿ coatingŸ moldingŸ incisionŸ packageŸ products.

ii. Building materials

After mixture of fiber in crop straw with binder and consolidation material, straw can be used to make green straw building material, such as fiber sheet, composite board and low-density sheet and hollow brickwork, which is cheap, light and environment friendly. It has advantages of anti-flaming water-proof antiseptic and fungi-proofing. Straw has been widely used in light building material and has a great development prospect.

Typical technological process includes: smashŸ roller-compactionŸ maintenanceŸ packageŸ warehousing.

iii. Crafts production

Through handmade or machine processing, the straw is woven into straw curtain, straw rope or straw hat, and exquisite handicrafts such as murals, which can enrich agricultural market. Processing the straws into handiwork can not only avoid the environmental pollution caused by straw burning, but also increase the income of farmers.

Typical technological process includes: collecting high quality strawŸ manually flattening strawŸ making paste materialŸ pasting the materials on drawing board after cuttingŸ coloring the murals with a hot ironŸ framing

iv. Xylitol production

Xylitol is an important raw material in light industry and chemical industry for making beverages, candies, cans, papers, explosive and toothpaste. Xylitol plays an important role in the industries of food, medicine, chemistry, leather, tobacco and cosmetics. Xylitol produced from straw has both financial and social significance.

Typical technological process includes: raw materialŸ preprocessingŸ hydrolysisŸ decolorationŸ evaporationŸ hydrogenationŸ concentrateŸ crystallizeŸ centrifugeŸ crystalline xylitol

(2) Status for straw used as industry material in the Asia-Pacific region

East Asia: As an important raw industrial material, straw has been widely used to make paper, knit, sheet base materials and construction materials. Statistically, China is the largest country making straw pulp; and the straw pulp occupies 33.95% of total paper pulp in the country (Fig. 4). Rice, wheat and maize straws are also raw material in straw plaiting industry, and can be used to make bag sack mat and handiwork (Meng, 2008). In Japan, rice straw for industry utilization accounted for 0.7% (MAFF, 2006). Straw is thatched with wooden frames and use as construction materials. The number of straw bale buildings in Japan increases every year. The degradable material produced by crop straw, such as plastic wrap, disposable tableware are safe, light, non-poisonous and with good air permeability. These products could be treated easily.

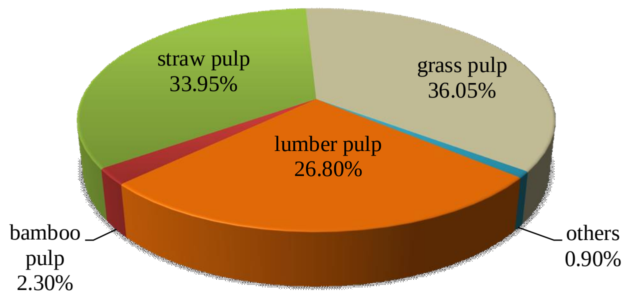


Figure 4 Raw material proportion for papermaking in China

South Asia: About 30% of Indiaꞌs paper is made from agricultural residue and/or non-wood fibers (Jain et al., 2005; Anonymous, 2017). There are many mills-modern, commercial scale facilities ï that produce pulp that is used pure or is mixed with other fibers such as recycled or virgin wood pulp to make paper and packaging. In Sri lanka, 2% - 3% of the total paddy straw produced in the northern, central, and southern parts of the island is used in the paper industry (Jayasuriya, 1983). In Bangladesh, the paper industry uses mostly bamboo and mixed hardwood. As documented by FAO (2002), Bangladeshꞌs capacity to produce paper and paperboard has remained constantly at 121,000 tons during 1997-2001.

Southeast Asia: Agricultural residues, especially rice straw could be still used as building materials in some rural areas in Indonesia, Vietnam or Thailand. Rice straw is usually mixed with clay soil to produce brick or build house walls. Besides, rice straw could be used to make handicraft products for tourists. Most of Southeast Asian countries have rain-forests with plentiful wood sources. Therefore, the paper industries usually use wood or other non-wood plants for paper making rather than agricultural residues like rice straw or corn stalk. Despite that, some studies are carrying out in some countries like Thailand, Vietnam on the usage of rice straw as building materials such as sheets and panels, etc.. Rice straw used as raw material for industry in Indonesia is about 7%.

3.2.2 Options for integrated straw management

3.2.2.1 Selection principles of straw management

Integrated straw management means to utilize crop straw as resources including using as fertilizer, fodder, new energy resources, base stock and industry material fully considering the specific social, economic and environmental aspects of the local context and through extensive consultation of all the key stakeholders. Integrated straw management may be an option for reducing/stopping burning of the agro-residues in the field. Straw used as fertilizer could enhance the resource utilization rate and soil fertility, save cost and effectively avoid the environment pollution caused by straw waste and incineration; as base material promoting the development of rural edible fungus industry, it could provide fresh vegetable food for the rural population. Straw used as fodder could contribute the growth and weight gain for livestock due to its high crude fiber; for straw used as energy, it could reduce energy cost and meet the requirement of gas and heating. There are a range of options for integrated straw management in Asia-Pacific. However, each country has different straw management patterns because of its own characteristics. The selection principles for straw management could be concluded as follows.

(1) Availabilities of the practices/technologies

Technologies for the selected straw management should be mature and reliable, which means that the technology model, equipment and effects of the technologies have been sufficiently studied and proved. The technology should be suitable in the applied regions, and could reduce straw burning and improve labor productivity after being applied.

(2) Meet the specific conditions of the pilot areas

The related practices, facilities, equipment, machines, land condition, climate and farming system, should be all put into consideration while choosing the straw management technologies. The selection of the technology should take into full consideration of the current situation, characteristics and development requirement of agriculture in the region. Besides, the economic base, relative professional technician and cultural quality could provide support for the technology. Farmersô willingness and understanding of the technology is also important to the technology application.

(3) In-situ Utilization of the Straw

To avoid cost of long-distance transportation and the emission of such transportation, the technologies for local and in-situ straw utilization are encouraged, such as covering straw on soil and mix-burying straw with soil.

(4) Benefits of the practices/technologies

The chosen technology should reduce cost but increase income of the users, which means to obtain maximize economic benefit by improving the agriculture output. It also should be environmental friendly by improving regional ecological environment and function.

3.2.2.2 Recommended straw utilization technologies

As describe above, crop straw can be used for fodder, in-situ mixing in the soil/composting, energy generation, and raw material for industrial use. Against the principles of Integrated Straw Management and selection criterions, it is suggested the following practices and technologies for East Asia, South Asia and Southeast Asia according to the selection principles:

(1) East Asia

1) Straw used as fertilizer

According to the selections principles above, three available technologies for straw used as fertilizer are recommended: soil covering with straw, mixing straw with soil and burying straw into soil. Covering soil with straw implies that straw is chopped and spread evenly on the soil surface. Mixing straw with soil is that straw is mixed with soil by rotary cultivator after straw being chopped and spread. Burying straw into soil is that the straw is buried into soil with moldboard plow after straw being chopped and spread. These technologies help the straw to decompose above or in the soil as fertilizer. According to the availability of the existing technologies, it is suggested to establish demonstration areas applied different methods in line with the local climate, crop types, soil condition and cropping system, and to promote in a larger scale through the training, workshops and other ways.

2) Straw used as fodder

Straw can also be used as fodder to feed livestock, the specific use patterns are as follows: (1) timely harvesting of crops; (2) managing the straw moisture content; (3) chopping or cutting the harvested straw to smaller pieces; (4) filling and compacting the chopped straw; (5) packing the straw in the airtight container, and the sugar contained in the raw materials is converted into organic acids via anaerobic fermentation of microorganisms. If the forage silage could be stored under airtight conditions with no microbial activities, it can be stored for as long as a year. According to the characteristics of the straw and local conditions, as well as building upon the existing research basis and, establishing high-quality demonstration areas can promote larger scale adoption of straw used as fodder in East

Asia.

(2) South Asia

1) Straw used as fertilizer

In-situ management is one of the best and most effective options for utilization of combine harvested crop residues left over in the fields particularly for paddy straw. The straw can be incorporated into the soil by choppers, mulchers and mowers; and seed can be sown with the help of Happy Seeders, zero-till-drills, etc. This will help in reducing air pollution; improving soil health and soil fertility. It would also reduce dependence on chemical fertilizers. All this will result into economic benefits to the farmers in terms of reduced input costs of fertilizers and low irrigation requirements etc. Yadvinder-Singh et al., (2004b) suggested for successful rice straw in-situ management by allowing sufficient time (10-20 days) between its incorporation and sowing of the wheat crop to avoid nitrogen deficiency due to nitrogen immobilization.

2) Straw used as new energy resources

Crop straw such as paddy, wheat, maize, etc. can be utilized as energy source for biogas generation by installing biogas plants for anaerobic digestion. The dry fermentation can be achieved by loading the crop residue along with little amount of biogas spent slurry or animal dung in the biogas plant. The biogas digester is completely air tight unlike conventional biogas plant. Biogas produced in the digester is stored in a steel gas holder connected to the digester through HDPE / rubber pipe gas outlet. At present the major bottleneck is the availability of costly cellulase enzyme required for hydrolysis of lignocellulosic straw (in the process of producing ethanol). The straw can be used for power generation in direct fired grate boilers followed by steam Cycles. The steam cycle is favorable compared to other technologies for using straw-fuels, mainly, because this is proven, simple, cheaper, flexible to the moisture content and particle size, and less sensitive to slagging / fouling.

3) Straw used as base material

The paddy straw can be very well utilized as base material for mushroom cultivation in rural areas. It will create employment opportunities in the villages and improve the income of farmers. Paddy straw mushroom (*Volvariella volvacea*) is a world famous edible mushroom variety that has high demand due to its deliciousness and nutritive value. Indoor/polyhouse cultivation system is usually more successful and profitable.

(3) Southeast Asia:

1) Straw used as fodder

Rice straw is usually used as an important part of nutritional requirements for ruminant animals like buffaloes, cattle beef, cows, sheep and goats in most of rice producing countries. Traditionally, ruminant animals can eat rice straw directly in the fields after harvesting seasons or within the farms. After each harvesting seasons, rice straw is usually collected, transported and stored inside or outside warehouses of the farms to be used gradually throughout the year. In order to save animal feed costs for farmers or dairy farms, some studies showed that about 20-25% of cattle rations should be rice straw or top parts of corn stalk at maturity stage. Furthermore, to improve the feed intake and degradability of cattle or milk yield of cows, the straw could be chopped and treated with urea or calcium hydroxide or by supplementing the straw with protein (Fadel Elseed, 2005 & Wanapat et al., 2009).

2) Straw used as base materials

Mushroom can be grown anywhere with conditions suitable to its growing. Mushroom could be grown traditionally in open fields, semi-open fields, in-door spaces or under automatic controlled conditions. Vietnam is one of the five world leading countries in mushroom production due to abundance of agricultural residues for mushroom production such as rice straw, sugarcane residues, etc. Mushroom production in the Philippines is still less developed, but an abundant amount of rice straw in the country together with new technologies can open up promising opportunities for development of mushroom production at commercial scale in the Philippines. Traditional method, growing mushroom in the open fields, is still the most popular method in straw mushroom growing in Southeast Asia countries. As a replacement, straw mushroom could be also grown on the ground while fields are still in rice production or still wet. It could be also inter-grown with other fruit trees like bananas. Consumption need of mushroom in the Southeast Asia market is very high. Practical production of mushroom in Vietnam indicated clearly that rice farmers can increase considerably their incomes by growing mushroom during off-seasons. Besides, in-door mushroom growing methods can also improve significantly quality as well as market prices of the mushroom compared with the traditional mushroom growing in the open fields. Their selling prices are US$0.75/kg mushroom compared with only US$ 0.35-0.5/kg mushroom from the traditional method. In addition, owing to much better controls of growing conditions (temperature and relative humidity) of the mushroom and diseases, compared with the traditional growing method; in-door mushroom growing method can increase mushroom yields as well as growing cycle per year; from only one growing cycle/year up to 9-10 growing cycles/year. These increased considerably the income of the mushroom growers up to more than 10 times.

3) Straw used as fertilizer

For the Mekong river delta in Vietnam, there are three rice crops per year. Moisture content of the rice straw after harvest is much different from season to season. The dried rice straw in the dried seasons could be collected conveniently using straw balers or manual methods for long term storage. Reversely, most of rice stubble and wet rice straw in the wet seasons were usually incorporated into the soil several days before direct seeding or transplanting, using tractors with rotary machines or cage wheels. Results withdrawn from many studies revealed that incorporation of straw into the soil improved remarkably soil organic matter, soil porosity, availability of N, Zn, Fe, Mn, and enzymes. As a result, rate of fertilizer N application could be reduced for the crops. In order to reduce collection cost, rice straw in wet seasons should be incorporated into the soil. Moreover, to reduce the de-composing time, the straw could be treated with Trichoderma fungi during operation of rice combine harvesters. Besides, de-composed rice straw from mushroom growing processes should be also used as fertilizer for rice itself or other fruit trees and vegetables.

3.3 Beneficial Impacts on Sustainable Development

Crop straw, the main by-product of crops, is an important resource in industrial and agricultural production, whose utilization can significantly improve the agricultural ecological environment and production efficiency. Crop straw used as fertilizer enhanced the resource utilization rate and soil fertility, saved cost and effectively avoided the environment pollution caused by straw waste and incineration. In recent years, with the development of technology and society progress, many Asia-Pacific countries have further development on the integrated utilization of crop straw, as fodder, energy, base material and raw material. In all, the integrated and efficient utilization of crop straw is an important way to realize the agricultural sustainable development and bring good social, ecological and economic benefits.

3.3.1 Social benefits of straw integrated utilization

The integrated straw management can broaden the channel of straw resource utilization. Straw used as base material, which promotes the development of rural edible fungus industry and can provide fresh vegetable food for the rural population. Straw used as fodder, which has a good effect on the growth and weight gain for livestock due to its high crude fiber; meanwhile the development of rural animal husbandry can provide high quality meat and dairy products, etc. Straw used as energy, such as bio-energy power generation, biogas production, bio-ethanol, etc., which can reduce energy cost and meet the requirement of gas and heating. For example, the large-scale biogas projects and natural gas projects implemented in China can significantly improve the treatment of livestock manure, crop straw, and the gas supply capacity. Directly using crop straw as biogas, farmers can build rural marsh gas for the usage in kitchen, toilets and farms, contributing to the environment improvement in rural areas.

3.3.2 Ecological benefits of straw integrated utilization

Straw utilization technology is a necessary step to improve the ecological environment of farmland and develop sustainable agriculture, and is an important link in the production efficiency and the development of sustainable agriculture. It is an effective means to promote the healthy development of agroecosystem in the Asia-Pacific region in various aspects.

(1) Reduce soil erosion and improve soil nutrition

Ammoniated straw can promote the development of soil pore structure, increase the total amount of soil water stable aggregates and field water-holding capacity, improve water use efficiency, and enhance farmland drought resistance capacity. Burying a straw layer and applying flue gas desulfurization gypsum are effective practices to ameliorate soil salinization or alkalization and to increase crop yield. The effectiveness of the straw layer lies in its ability to provide an appropriate environment with a higher water content to promote the reaction of flue gas desulfurization gypsum with the soil during water infiltration and redistribution.

Returning straw to field can adjust soil nitrogen supply and reduce fertilizer consumption. Straw contains rich nutrient resources such as N, P and K. The complete return of straw to the field could compensate for all of the K_2O, the majority of the P_2O_5 and some of the N in fertilizers. Promoting the return of straw to field has a great potential to reduce the use of chemical fertilizer and environmental burden.

In addition, returning straw to field can effectively promote the microbial activity and nutrient decomposition in soil, which is beneficial to the improvement of soil organic matter. It also can reduce soil compaction, enhance soil permeability and promote crop root growth. In the dry and dust area, straw returning can hold stable water moisture, and effectively inhibit sandstorms and protect the ecological environment.

(2) Protect environment and reduce greenhouse gas emissions

Straw incorporation plays important roles in reducing greenhouse gas emissions and increasing soil carbon sequestration. It was estimated that the annual CH_4 and N_2O emissions from rice paddy were as high as 20-100 Tg and 82 Gg in the globe (Wang et al., 2017). Straw incorporation significantly enhanced N_2O efflux, and tended to reduce the CH_4 emissions. Straw used for generating electricity can decrease the greenhouse gas emissions compared to coal-fired power because of its lower carbon and sulfur nature, while avoiding resource waste and environmental damage.

(3) Protect forest resource

Straw fiber is a natural cellulose and has good biodegradable performance. It can be used for paper pulp, light building materials, packaging materials, biodegradable agricultural production materials and other products. This can not only reduce the consumption of wood, reduce deforestation and protect forest resource, but also reduce the straw burning and effectively improve the agricultural ecological environment, and enhance the sustainable development of agriculture.

(4) Replace non-renewable resources

Partial crop straw, like maize, wheat, cotton, peanut shells and other waste in rural area, which can be processed as fuel after chopping, compression molding and carbonization. The volume of the molded product can increase the bulk density and calorific value and it is easy to store and transport. Compression straw fuel can replace coal, wood, liquefied gas and so on; and it can be widely used in various types of household heating furnace, small hot water boiler or small power generation facilities. This new environment-friendly and clean energy, is an important way to make full use of straw and other biomass resources in the rural areas.

3.3.3 Economic benefits of straw integrated utilization

The comprehensive utilization of straw can reduce the investment of the government and farmers, increase the farmer income and promote the development of agriculture and rural economy. Straw contains a lot of crude fiber and nitrogen, phosphorus, potassium, calcium, magnesium and other nutrients. Reasonable use of straw can enrich the production of raw materials in Asia-Pacific countries, bring good economic benefits. Straw used as fertilizer and fodder can efficiently save agricultural cost and invest. At the same time, the comprehensive utilization of straw can prolong the relevant industries (food processing, transportation, sales, leather, clothing, etc.) chain, and achieve multiple value-added income.

Table 12 Economic benefits of straw utilization in targeted Asia-Pacific countries

No.	Sites	Straw type	Straw management pattern	Economic benefits	Reference
1	Shouyang, China	Maize	Straw directly returning to field	In 19 years, the cumulative yield increased by 13.43-24.28t/ha, the net income increased by US$ 1,950-2,762/ha.	Zhou H. P. (2013)
2	Heilongjiang, China	Rice	Straw directly returning to field	Wheat yield increased by 2.46t/ha through applying the N, cellulose decomposition bacteria and earthworm breeding.	Bian H.S. (2016)
3	Japan	Rice	Straw directly returning to field	In 2006, 75.9%, 10.3% and 4.0% of 9Mt rice straw was used for directly returning to field, fodder and corral, respectively.	International Herald Leader (2016)
4	Northern India	Rice	Used as mulch	Rice straw mulch Increased wheat grain yield, reduced crop water use by 3-11% and improved water utilization efficiency by 25% compared with no mulch.	Chakraborty *et al.* (2008, 2010)
5	Haikou, China	Banana	Solidification molding	The profit of 600t banana straw fuel was about US$ 3,190.	Zhang X.R. (2012)

6	Hokkaido University, Japan	Rice	Solidification molding	When straw solidification molding output reaches over 1,500t/yr, which could bring higher economic benefits; Small-scale production need to rely on >50% subsidy to solve high cost problem.	Kazuei Ishii (2016)
7	Japan	Rice	Extract ethanol	One tone straw can extract 250L ethanol, and if half of the total amount of straw was used for bioethanol production, which can substitute for 2% petrol consumption.	METI (2008)
8	Gyeongsang National University, Korea	Rice	Extract ethanol	Rice straw used for ethanol can reduce the production cost compared to grain.	Sheikh M.M. (2013)
9	Vietnam	Rice	Bioethanol	Rice-straw bioethanol production could reduce annual gasoline consumption by >20%, and plant construction costs accounted for 8-22% of the total investment	Yoji Kunimitsu, (2013)
10	Thailand	Rice	Energy source	Using rice straw as energy source could result in considerable annual savings on primary energy imports of around 7-9%.	Mitra Kami Delivand (2011)
11	Chaoyang, China	Rice, Green hay	Used as fodder	Feeding rubbing maize straw could save about US$ 18 per sheep per year.	Shang G.R. (2006)
12	Anyang, China	Rice	Used as fodder	Feeding maize silage fodder could gain >4.0kg/d milk per dairy cow, namely increased US$ 1/d.	Xu R.J. (2006)
13	Hokkaido University, Japan	Pod	Used as fodder	Pod used as fodder can promote the digestion of rice straw for ruminant, raise the rate of straw intake, and save production cost.	Ryosuke FUMA (2012)

(1) Save cost and reduce consumption, increase income and enrich farmer

Straw returning to field is an effective measure to increase crop yield and bring subsequent benefits shown in Table 12 (No.1-4). Besides the maize and rice straw returning with ploughing in China, the yield can increase by 5-10% and the use of fertilizer can decrease by 10%.

In recent years, with the continuously rising of the prices of the crude oil and coal and increasing requirement for resources, many countries in East Asia is developing bio-energy to replace fossil fuels. Especially in China, Japan and Republic of Korea (No. 5-8, Table 12), crop straw was used for modeling fuel and extracting ethanol, which can increase fuel sources and save cost in industrial production and resident living. Rice-straw bioethanol production could reduce annual gasoline consumption by >20%, and plant construction costs account for 8-22% of the total investment in Vietnam (No. 9, Table 12). Using rice straw as energy source in Thailand could result in considerable annual savings on primary energy imports of around 7-9% (No. 10, Table 12).

(2) Reduce requirement for fodder and promote the development of animal husbandry

Straw fodder has the characteristics of wide sources, large quantities, and low prices. Studies from Table 12 (No. 11-13) have shown that the fodder conversion technology, such as silage, alkalization and rubbing processing, can degrade crop straw into biological protein fodder containing plenty of bacterial protein and cellulose. Feeding cattle with this type of fodder can improve the intake of livestock digestion. The processing and utilization of straw fodder can effectively alleviate the supply and demand constrain of feedstock in Asia-Pacific countries, promote the development of herbivorous livestock production and optimization of animal husbandry structure, which is an important way to increase farmers' income.

3.4 Requirements and Recommendations of Pilot Sites and Partners

3.4.1 Selection principle of cooperative partners and pilot sites

Choosing appropriate cooperative partners and pilot sites is crucial for the application of integrated straw management technology in the Asia-Pacific region. Cooperation partners for pilots will apply and trial the selected practices and technologies for future larger scale application and promotion. The selection of relevant cooperative partners and pilot sites should represent the typical farming conditions in the pilot country in terms of geographical conditions, climate status, planting systems, research basis, supporting facilities and government support. The following principles should be observed.

(1) Selection principles of cooperation partners

i. Research Capacity

First of all, the partners should have the capacity to conduct related research and pilots on integrated straw management in terms of having available facilities, human resources and experiences for such pilot activities. The research capacity of researchers is the key to the pilots. The researchers shall have both theoretical and practical expertise in the areas of integrated straw management practices and technologies.

ii. National/local policy support

National and local policy support provides impetus to research and demonstration of integrated straw management technology. It is optimal that the selected partners were supported by national/local policies. The partners are expected to have close collaboration and linkages with the policy makers, which is conducive to the implementation for the pilot activities and future larger scale promotion of the sound practices.

(2) Selection principles of pilot sites

Selection of pilot sites must adhere to the principal “from a point to an area”. The selected pilot site shall have high representability. The selected area is expected to have prominent characteristics in straw yield, climate, geographical conditions, planting system and so on. The pilot will be conducted through demonstration, training, workshop and other appropriate activities.

i. Good facilities

The related facilities are the important guarantee of the pilots of the integrated straw management practices/technologies. The relevant pilot sites should have a certain scale, good infrastructure, machine, a long-term test demonstration base for integrated straw management. In addition, some test instruments used to determine and analyses mechanical performance, soil properties, straw sampling and chemical composition are also requested.

ii. Good conditions for organizing training and demonstration

How to make the farmers in the Asia-Pacific region master the new technology as soon as possible is the key to technical extension. We can train the farmers, change the behavior of farmers and improve the capacity of farmers. There are many ways for capacity building: training courses, opening evening school, itinerant instruction, field teaching and practical operation; establishing technical information market and publicize and introduce integrated straw management technology by means of radio, telephone, TV and movies. Through these methods, the farmers will gradually understand and master the integrated straw management technology. Thus, it is beneficial to promote the application of the integrated straw management technology in the Asia-Pacific countries. Regular visits and study tours to expose farmers to the advanced integrated straw management pilot sites is an important way to extend the application of integrated straw management technology. Farmers will not only increase knowledge, but also provoke greater interest through on-site seeing and hearing of the technical information and successful experiences.

3.4.2 Recommended Pilot Sites and Partners

(1) Pilot sites and partners in East Asia

Countries: China is an agricultural country with vast territory. Its total output of straw ranks the first in the world. China's straw is not only large in quantity, but also rich in variety and wide in distribution. With the increasing growth of straw, high-efficient and environment friendly use of straw in China is of high significance.

Partners: As the most famous agricultural university in China, China Agricultural University (CAU) has strong scientific research strength and conditions. It has rich research experiences on integrated straw management. In recent years, CAU undertakes various projects for national and ministerial programme on straw management. A number of academic papers have been published and national patents have been applied and granted in the field of integrated straw management. CAU obtained a number of national and provincial awards for its achievements in this regard. It has several national and provincial level key laboratories for agricultural research, which can provide sound and concrete support for the pilot. Therefore, CAU is strongly recommended as the East Asia partners for integrated straw management pilots in the Asia-Pacific region.

Pilot Sites: In line with the selection principles for pilot sites and after on-the-spot investigation, it is recommended to conducting pilot in Qingdao City, Shandong Province in China. Qingdao City is typical with two crops a year in North China. The maize or wheat seed is sown directly after harvesting, and the straw should be treated quickly after harvesting so as not to affect the subsequent sowing operation. Straw treatment is urgent and necessary in this area. Local farming system has been linked with animal husbandry. There are practices of straw directly returning to field after harvesting in Qingdao. There is biogas equipment for straw energy utilization, also rich technical experience and comprehensive facilities for straw returning and biogas production. Furthermore, some cooperatives in this region have established conservation tillage demonstration sites in collaboration with China Agricultural University. All these good conditions ensure the sound implementation of the pilot.

(2) Pilot sites and partners in South Asia

Countries: India is a major agricultural country in the south Asia region, with vast territory and with large amount of straw yield. Particularly in India, the surplus crop straw must be utilized for useful purposes by adopting integrated straw management techniques. Therefore, the choice of suitable cooperation partners and pilot site in India to study and trial the integrated straw management technology aimed at South Asia has important guiding role for applying the approach in south Asia region.

Partners: The Central Institute of Agricultural Engineering (CIAE) of the Indian Council of Agricultural Research (ICAR), located in Bhopal is recommended to be the co-partner. It is a leading and national level institute in the area of Agricultural

Engineering in India. The institute has rich experienced scientists and technical staffs to complete the design and implementation of the pilots and other related tasks.

Pilot Sites: The Punjab Agricultural University has strong scientific research strength and laboratory facilities. It has rich experiences related to straw management. In recent years, they have undertaken related projects at national and ministerial level in management of straw. They published academic papers, presented reports and prepared videos. It is also situated in the Punjab province which is worst affected by straw burning. Hence, Punjab Agricultural University, Ludhiana (Punjab) would be ideal choice for establishment of straw management technology in India. The Punjab Agricultural University agreed for pilot study for straw management in India.

(3) Pilot sites and partners in Southeast Asia

Countries: Vietnam is one of the biggest rice producers in the South-East Asia. Besides, compared with the other countries in the region, Vietnam is a leading country in using of rice straw for different purposes with various technologies and equipment. Recent years, collection, storage as well as using of rice straw for animal feed and mushroom growing became popular in Vietnam, especially in the Mekong river delta (MRD). Mekong river delta, which is located in the South of the country, is the biggest rice granary of the country. Annually, it produces up to 50% of the total rice output and occupies more than 95% of the total milled rice export of Vietnam. In the Mekong river delta, there are proven technologies, machines/equipment and good models of rice straw collection and storage for cattle feed processing and mushroom growing, which are proved economically efficient in the practical production as well as conducive to income growth for different partners in the value chain including the rice farmers.

Partners: Post-harvest Technology (SIAEP) in Ho Chi Minh City and Than Nong Mushroom Enterprise located in Can Tho City of the MRD are two recommended partners. Can Tho City is about 200 km from Ho Chi Minh City. There is a national airport in Can Tho City. SIAEP has researchers specialized in mushroom growing and processing who joined with CORIGAP project co-ordinated by IRRI from 2013 until 2015. SIAEP also organized many training courses on mushroom growing and storage for mushroom growers in the MRD 3 years ago. Than Nong Mushroom Enterprise is the biggest supplier of spawn for mushroom growing in the MRD. The enterprise has facilities and mushroom growing farms using in-door mushroom growing method as well as industrial mushroom growing method (automatic control of the growing environment). It also helps the local authorities organize training courses for mushroom growers in the last 5 years. Main partners for the second pilot site are SIAEP in Ho Chi Minh City; and Binh Minh Feed Cooperative located in Tien Giang province of the MRD. Tien Giang province is 70 km from Ho Chi Minh City. Binh Minh Co-operative owns an animal feed processing factory, 15 rice straw balers, 10 vertical hydraulic compressing systems and a warehouse for rice straw storage. The cooperative collects rice straw and does business on rice straw. The cooperative has a contract of supplying thousand tons of rice straw monthly to TH True Milk Corporation. TH True Milk Corporation is one of the two biggest milk producing companies in Vietnam. It has a herd of thousands of cows and several milk processing plants in the central Vietnam.

Pilot Sites: The two pilot sites are located in Can Tho City and Tien Giang province in the MRD where are not far from Ho Chi Minh City, very convenient for travels, pilot site demonstrations and organizing training courses. These is a pilot site using rice straw for in-door mushroom growing; and another one using straw for cattle feeding.

4

Summary

The continuous growth of agricultural productivity produces a great amount of crop straw in Asia-Pacific region every year. According to the source, these straws can be divided into four types: grain crop straw, oil crop straw, fiber crop straw and other crop straws. Grain crop straw manly includes maize straw, rice straw, wheat straw and barley straw. Oil crop straw covers bean straw, rape straw and peanut straw. Fiber crop straw mainly includes cotton straw, linen straw and ramie straw. Other crop straws generally include sugarcane straw, flue-cured tobacco straw and sugar beet straw. Rice straw is mainly produced in China, India, Indonesia, Bangladesh, Vietnam and Thailand; maize straw in China, India and Indonesia; wheat straw in China, India and Pakistan; and potato straw in China, India and Bangladesh.

It is usually difficult and costly to collect all straw and the technologies of integrated straw management are immature so that many of straw were discarded or burned. Uncontrolled field burning of straw is harmful for human health, decreases air visibility, threatens transportation security, and causes negative effects on residentsôlives. To help address these issues, integrated management of crops straws in Asia-Pacific region is initiated by CSAM to eliminate straw burning, which has significant ecological, economic and social benefits. Integrated straw management means to utilize crop straw as resources including using as fertilizer, fodder, new energy resources, base stock and industry material fully considering the specific social, economic and environmental aspects of the local context and through extensive consultation with all the key stakeholders. For using as fertilizer, main technologies include straw directly returning to field (covered on soil, mix-buried with soil) and straw indirectly returning to field (decomposed straw returning, carbonized straw returning). For fodder use, main technologies include ensilage, silken straw fodder processing/rubbing processing, briquetting, extrusion, ammoniation treatment. For energy use, main technologies include briquette fuels, biogas production, carbonization fuel, gasification fuel, degradation and ethanol production. For base stock use, main technologies include grass saprophytic bacteria and wood saprophytic bacteria cultivation. For industry material use, main technologies include make paper, panel, artware and activated carbon in replace of lumber and make xylitol in replace of grain.

Crop straw is an important resource in industrial and agricultural production. And the integrated and efficient utilization of crop straw is an important way to achieve the agricultural sustainable development and bring good social, ecological and economic benefits. The ecological benefits include reducing soil erosion and greenhouse gas emissions, improving soil structure, protecting environment and forest resource, and replacing non-renewable resources.

In order to promote the integrated straw management technologies, some suitable options for East Asia, South Asia and Southeast Asia were selected, considering demonstration, training, study tour and visit, and regional seminar and workshop. Thus, three pilot sites and partners respectively in China (East Asia), India (South Asia) and Vietnam (Southeast Asia) were chosen. The selected partners should have research basis, qualified researchers and national policy support, while the pilots should have well-equipped facilities and convenient for organizing training and exhibitions.

5

Reference

Anonymous, 2017. Web site of Indian Agro & Recycled Paper Mills Association, http://www.iarpma.org/indian-paper-industry.asp.

Anonymous, 2013. Draft of policy for management and utilization of paddy straw in Punjab. Department of Science, Technology and Environment, Govt. of Punjab, India.

Ahamad M, Tanin F., 2013. Next power generation-mix in Bangladesh: outlook and policy priorities. Energy Policy 60:272ï 83.

Bakker Rob, Wolter Elbersen, Ronald Poppens, Jan Peter Lesschen, 2013. Rice straw and Wheat straw. Potential feed stocks for the Biobased Economy. Wageningen UR, Food & Biobased Research. 1-31.

Bi Yuyun, Wang Yajing, Gao Chunyu. 2010. Straw resource quantity and its regional distribution in China. Journal of Agricultural Mechanization Research 3, 1-7. (in Chinese).

Bian Haisheng. 2016. Technical benefit analysis of rice straw returned to field. Farm Machinery Using & Maintenance 5, 75-76. (in Chinese).

Bijay-Singh, S.Y.H., Johnson-Beebout, S.E., Yadvinder, S.Z., Buresh, R.J., 2008. Crop residue management for lowland rice-based cropping systems in Asia. advances in agronomy. 98, 117-199.

Biomass Business Opportunities Vietnam (2012) available from URLhttp://www.agentschapnl.nl/sites/default/files/Biomass%20opportunities%20in%20Vietnam.pdf.

Chakraborty D, Garg R N, Tomar R K, Singh R, Sharma S K., Singh R K, Trivedi S M, Mittal R B, Sharma P K, Kamble K H. 2010. Synthetic and organic mulching and nitrogen effect on winter wheat (Triticum aestivum L.) in a semi-arid environment. Agric Water Manage 97: 738-748.

Chakraborty D, Nagarajan S, Aggarwal P, Gupta V K, Tomar R K, Garg. R N, Sahoo R N, Sarkar A, Chopra U K, Sarma K S S and Kalra N. 2008. Effect of mulching on soil and plant water status, and the growth and yield of wheat (Triticum aestivum L.) in a semi-arid environment. Agric Water Manage 95: 1323-1334.

Chiharu H., Eisaku T., I. G. A. A. Ambarawati, I. Made Anom Wijaya , A. A. A. Mirah Adi., 2017. Evaluation of potential for ethanol production from rice straw using satellite data. Journal of Agricultural Science 9(6):22-36.

Conrad, H. R. 1966. Physiological and physical factors limiting feed intake. Symposium on factors influencing the voluntary intake of herbage by ruminants. J. Anim. Sci. 25:227-235.

Department of Agriculture Hokkaido Government. Agriculture in Hokkaido Japan. January 2017.

Devendra, C. 1997. Crop residues for feeding animals in Asia: Technology development and adoption in crop/livestock systems. In: Crop residuals in sustainable mixed crop/livestock farming system (Ed. C. Renard). CAB International; Wallingford, UK. pp. 241-267.

Devendra, C. and Thomas, D. 2002. Crop-animal interactions in mixed farming systems in Asia. Agricultural Systems, vol. 71, no. 1-2, pp. 27ï 40.

DIEP QUYNH NHU, 2014. Evaluation of the potentials for development of ethanol production from rice straw in Vietnam. Doctoral Dissertation. Graduate School for International Development and Cooperation. Hiroshima University, March 2014.

Ding Dianyuan, Feng Hao, Zhao Ying, Du Xuan. 2016. Effect of ammoniated straw returning on soil pore structure. Journal of Plant Nutrition and Fertilizer 22, 650-658. (in Chinese).

Eui Soo Chung, Jong Geun Kim, Meing Joong Kim, Sung Seo. 2009. Survey of the Fresh Rice Straw Silage in Mid-Western Costal Area in Korea. August 10, 2009.

Fadel Elseed, A. M. A. 2005. Effect of supplemental protein feeding frequency on ruminant characteristics and microbial N production in sheep fed treated rice straw. Small Rumin. Res. 57:11-17.

FAOSTAT, 2014. http://www.fao.org/faostat/en/#data/QC.

Fuma R, Oyaizu S, Nukui Y, Shinkai T, Koike S, Kobayashi Y. 2012. Use of bean husk as an easily digestible fiber source for activating the fibrolytic rumen bacterium Fibrobacter succinogenes and rice straw digestion. Animal Science Journal 83, 696-703.

Gadde,B. et al., 2007. Technologies for energy use of rice straw: A review. International Rice Research Notes. 32 (2) 5.

Gadde, B.; Menke, C.; Wassmann & R. GMSARN, 2007. Possible energy utilization of rice straw in Thailand. International Conference on Sustainable Development: Challenges and Opportunities for GMS.

Gadde B., Menke C., Wassmann R., 2009. Rice straw as a renewable energy source in India, Thailand and the Philippines: Overall potential and limitations for energy contribution and greenhouse gas mitigation. Biomass and Bioenergy 33, 1532-1546.

Gadde, B., Bonnet, S., Menke, C. and Garivait, S., 2009. Air pollutant emissions from rice straw open field burning in India, Thailand and the Philippines. Environ. Pollut. 157 (5), 1554ï 1558.

Hanafi, E. M, El Khadrawy, H. H., Ahmed, W. M. and Zaaba, M. M. 2012. World Applied Sciences Journal.16 (3): 354-36.

Ishii K, Furuichi T, Fujiyama A, Watanabe. 2016. Logistics cost analysis of rice straw pellets for feasible production capacity and spatial scale in heat utilization systems: A case study in Nanporo town, Hokkaido, Japan. Biomass & Bioenergy 94, 155-166.

Jain, R.K., Singh K. and Kulkarni A.G., 2005, Pulp & Paper International, Country Outlook (https://legacy.risiinfo.com/db_area/archive/ppi_mag/2005/03/04.html).

Jayasuriya M C N. 1983. The Use of Organic Residues in Rural Communities, UNU, 177 p. (www.nzdl.org/gsdlmod).

Jiang C M, Yu W T, Ma Q, Xu Y G, Zou H. 2017. Alleviating global warming potential by soil carbon sequestration: A multi-level straw incorporation experiment from a maize cropping system in Northeast China. Soil & Tillage Research 170, 77-84.

Kim Y J, Choo B K, Cho J Y. 2017. Effect of gypsum and rice straw compost application on improvements of soil quality during desalination of reclaimed coastal tideland soils: Ten years of long-term experiments. Catena 156, 131-138.

Kurokochi Y, Sato M. 2015. Properties of binderless board made from rice straw: The morphological effect of particles. Industrial Crops & Products 69, 55-59.

Li Hailiang, Wang Chun, Sun Haitian, Yan Xiaoli, Liang Qi. 2017. Comprehensive Utilization and Sustainable Development of Agriculture Straw. Journal of Agricultural Mechanization Research 8, 256-262. (in Chinese).

Mao Yixin. 1981. Utilization of Biogas in Japan. World Agriculture 1, 36-36. (in Chinese).

Mehta, C.R., Sharma, Shefali, Nair, Reena, Singh, K.P. 2013. Impact of crop residue burning on environment and human health. Indian Farming, 63(4), 24-25.

Meng Haibing, Xu Feiming. 2008. Straw Returning and Comprehensive Utilization Technology. China agricultural science and technology press. (in Chinese).

METI (Minister of Economy, Trade and Industry), Japan. 2008. The Demonstration Project for an Area System of Ecofuel Utilization.

Ministry of Agriculture, Forestry and Fisheries (MAFF). 2006. Japan.

Ministry of Environment Protection of the peopleŝ Republic of China. 2016. Number 71 letter response to environmental proposal. 2016-08-16. (in Chinese).

Mitra Kami Delivand, Mirko Barz, Savitri Garivait. 2011. Overall Analyses of Using Rice Straw Residues for Power Generation in Thailand- Project Feasibility and Environmental GHG Impacts Assessment. Journal of Sustainable Energy & Environment, Special Issue, 39-46.

Mirko B. Energy from agricultural biomass sources - Experiences and success factors. Vietnamese-German Forum on Bioenergy in Vietnamese Industries. September 16th 2013. Intercontinental Asiana Saigon, Ho Chi Minh City, Vietnam.

National Development and Reform Commission. 2016. Number 2504 letter of development and reform commission. http://www.ndrc.gov.cn/zcfb/zcfbtz/201612/t20161207_829417.html. (in Chinese).

Nguyen M.D., 2012. An estimation of air pollutant emission from open rice straw burning in Red river delta. Science and Development Journal (Vietnamese).

OECD. Evaluation of Agricultural Policy Reforms in Japan. 2009. www.oecd.org/publishing/corrigenda.

Rosmiza, M.Z., Davies, W.P., Rosniza, Aznie C.R., Mazdi, M., and Jabil, M.J. 2014. Farmersô knowledge on potential uses of rice straw: An assessment in MADA and Sekinchan, Malaysia. Malaysian Journal of Society and Space. 10 issue 5 (30-43).

Shang Gurong, Wang Zhongliang. 2006. Experiment on Maize Straw Crushing and Filtration by Fattening Sheep. Modern Journal of Animal Husbandry and Veterinary Medicine 7, 17. (in Chinese).

Sheikh M M, Kim C H, Park H J, Kim SH, Kim GC, Lee JY, Sim SW, Kim JW. 2013. Effect of torrefaction for the pretreatment of rice straw for ethanol production. Journal of the Science of Food & Agriculture 93, 3198.

Shi Zuliang, Liu Lulu, Wang Fei, Li Xiang, Chang Zhizhou. 2016. Development Model and Policy Proposal for Comprehensive Utilization of Crop Straw in China. Journal of Agricultural Science and Technology 18, 16-22. (in Chinese).

Tae Jin Won, Chang Sung Kang, Kwang Rae Cho. 2014. Optimum Application Rates of Oil Cake, Rice Bran and Rice Straw for Effective Soil Management in Korea Lettuce Field. Korea Institute of Soil and Fertilizer, 2014.

Thuy, N.H., Shan, Y., Bijay-Singh, S.Y.H., Wang, K., Cai, Z., Yadvinder, S.Z., Buresh,R.J., 2008. Nitrogen supply in rice-based cropping systems as affected by crop residue management. Soil Sci. Soc. Am. J. 72, 514-523.

Tran S.N, Nguyen T.Q.N, Nguyen H.C, Nguyen V.C.N, Le H.V and Ingvorsen K., 2014. To quantify the seasonal rice straw and its use in different provinces in the Vietnamese Mekong Delta. Can Tho University Science Journal.

Truc N.T.T. and Ni D.V., 2009. An environmental assessment of rice straw burning practice in the Mekong Delta. In: MEKARN Workshop 2009: Livestock, Climate Change and the Environment.

Wang Cong, Shen Jianlin, Tang Hong, Inubushi Kazuyuki, Guggenberger Georg, Li Yong, Wu Jinshui. Greenhouse gas emissions in response to straw incorporation, water management and their interaction in a paddy field in subtropical central China. ARCHIVES OF AGRONOMY AND SOIL SCIENCE, 2017, 63(2):171-184.

Wang J, Zhang Y, Gong S, Xu D, Juan S, Zhao Y. 2017. Evapotranspiration, crop coefficient and yield for drip-irrigated winter wheat with straw mulching in North China Plain. Field Crops Research, 2017.

Wang Jinwu, Tang Han, Wang Jinfeng. 2017. Comprehensive Utilization Status and Development Analysis of Crop Straw Resource in Northeast China. Transactions of the Chinese Society for Agricultural Machinery 48, 1-21. (in Chinese).

Wang Ye, Zheng Hui, Wei Mingyue, Xu Liping, Li Haohao, Guo Han. 2017. The influence of straw on rural economy and its rational utilization in Gaobeidian city of Hebei province. Economic research guide 6, 11-12. (in Chinese).

Wanapat, M., S. Polyrach, K. Boonnop, C. Mapato and A. Cherdthong. 2009. Effect of treating rice straw with urea and calcium hydroxide upon intake, digestibility, rumen fermentation and milk yield of dairy cows. Livest. Sci. 125:238-243.

Xu Rongjun, Zhang Mingxiu, Zhang Hongyan. 2006. Comparison test of dry corn stalk and silage corn stalk for Feeding Dairy Cattle. Sichuan Animal and veterinary sciences 4, 27. (in Chinese).

Xu Yan, Wang Qizheng, Zhang Xuejing, Wang Shuhe. 2010. Application of Stalk Bio-reactor to The Tomato Planting in Winter and Spring. Tianjin Agricultural Sciences 1, 105-107. (in Chinese).

Yadvinder Singh, Bijay Singh, Ladha J K, Khind C S, Khera T S and Bueno C S. 2004. Effects of residue decomposition on productivity and soil fertility in riceï wheat rotation. Soil Sci Soc Am J 68: 854-864.

Yan Lei. Refuse to burn, Japan use straw efficiently. 2015. International Herald Leader, December 25, 2015. (in Chinses).

Yonggan ZHAO, Yan LI, Shujuan WANG, Jing WANG, Lizhen XU. 2017. Combined application of a straw layer and flue gas desulfurization gypsum to reduce soil salinity and alkalinity. Pedosphere, Available online 5 August 2017.

Yoji Kunimitsu, Tatsuki Ueda. 2013. Economic and environmental effects of rice-straw bioethanol production in Vietnam. Paddy and Water Environment, 11:411-421.

Zhang Xirui, Wang Junlin, Li Yue, Wang Tao, Qiu Qianqian. 2012. Design and experiment on biomass pellet densifying machine for banana stem. Transactions of the Chinese Society of Agricultural Engineering 28, 22-26. (in Chinese).

Zhao Chun. 2015. Utilization Status of Crop Straws and Sustainable Development in Beijing. Journal of Agriculture 5, 42-46. (in Chinese).

Zhao Guiyu, Lv Yang. 2017. Analysis on Economic Benefits of Straw Power Generation in Jilin Province. Resource Development & Market 33, 86-90. (in Chinese).

Zhou Huaiping, Xie Wenyan, Guan Chunlin, Yang Zhenxing, Li Hongmei. 2013. Effects of long-term straw-returning on corn yield, economic benefit and water use in arid farming areas. Plant Nutrition and Fertilizer Science 2, 321-330. (in Chinese).

Zhou Yingheng, Zhang Xiaoheng, Yan Binjian. 2015. A Study on the Problem of Straw Burn and Beef Shortage in Korea. World Agriculture 23, 152-154. (in Chinese).

END