Economic and Eco-friendly Use of Rice Straw

P Bhattacharyya, H Pathak, AK Nayak, P Panneerselvam, MJ Baig, S Munda, D Bhaduri, S Satapathy, M Chakraborti, NT Borkar and N Basak

SUMMARY

There are about 731 million tons of lignocellulosic rice straw generated in the world every year. Every kilogram of harvested rice is accompanied by production of about 1.0-1.5 kg of the straw. Assuming that 50% of crop residues are utilized as cattle feed and fuel, the nutrient potential of the remaining residue is 6.5 million tonnes of NPK per annum. In India about 16% of generated crop residues are burnt on farms. Out of this 60% is paddy straw. Recent estimate showed that during November-December, around 70% cause of air pollution in New Delhi and its surrounding cities was straw burning. Not only Punjab and Haryana, straw burning is spreading over other states, very rapidly. Primarily burning causes emission of CO_2, CO, SOx, NOx, particulate matter and CH_4 which increases air pollution and GHGs/ Carbon footprint tremendously.

It is a paradox that on one hand we have a shortage of animal feed, biofuel and manures, and on the other hand considerable amount of crop residues are either wasted or burnt. This is not only a big loss of natural renewable resources but at the same time it is a source of greenhouse gas (GHG) emissions and environmental pollution. However, these residues can effectively be used as mulch, for production of manure, ethanol, bio-diesel, biochar, etc., and in conservation agriculture. In a rough estimate, if 20% of world's rice straw is used for production of ethanol annually, about 40 billion litres could be generated, which is able to replace 25 billion litres of fossil fuel based gasoline.

There are knowledge gaps on the economic technologies for *in-situ* and *ex-situ* composting of straw, characterization of rice straw of available varieties for fodder quality, cost effective small scale technologies for bio-energy production, technologies for value addition of paddy straw in view of present day mechanized agriculture and authentic database on contribution of straw burning in air pollution and GHGs/ carbon footprint.

However, a huge potential to use paddy-straw in bio-energy production, composting, as fodder and so on, can establish it as an important bio-resource. Microbial composting, is an up-coming technology for agricultural wastes disposal in which biodegradation of lignocellullosic matter like paddy straw is carried out exploiting ligninolytic and cellulolytic microorganisms. Breeding of new varieties of rice which not only provides good quality grains for human consumption but also superior quality straw for feeding ruminant animals and producing biofuels with increased efficiency is another innovative approach. At the same time there is an

urgent need for popularizing the array of available technology such as use for power/ electricity generation, ethanol production, biochar production, composting and raw material for paper mill/ board making industry.

1. INTRODUCTION

Rice straw is one of the most abundant lignocellulosic materials being produced in the world (Total, 731 million tons; Africa, 20.9 million tons; Asia, 667.6 million tons; Europe, 3.9 million tons; and America, 37.2 million tons) (Sarkar and Aikat 2013). Every kilogram of harvested rice is accompanied by production of about 1.0-1.5 kg of the straw. The major agro-residues in terms of volumes generated in India (in million metric tons–MMT) are rice straw (112), rice husk (22.4), wheat straw (109.9), sugarcane tops (97.8) and bagasse (101.3), which cumulatively amounts to approximately 620 million tons (Pandey et al. 2009). On an average these residues contain about 0.5% N, 0.2% P_2O_5 and 1.5% K_2O. Assuming that 50% of crop residues are utilized as cattle feed and fuel, the nutrient potential of the remaining residue is 6.5 million tonnes of NPK per annum.

In India about 620 million tonnes of crop residue is generated every year. About 16% of them are burnt on farms. Out of this 60%, paddy straw and wheat straw accounted for 22%. Recent estimate showed that during November-December, around 70% cause of air pollution in New Delhi and its surrounding cities was straw burning. Not only Punjab and Haryana, straw burning is spreading over other states, very rapidly. Primarily burning causes emission of CO_2, CO, SOx, NOx, particulate matter and CH_4 which increases air pollution and GHGs/ Carbon footprint tremendously.

2. RICE STRAW BURNING

The rice and wheat system (RWS) is one of the widely practiced cropping systems in India. This cropping system is dominant in India where almost 90-95% of paddy area in Punjab, Haryana and Western UP is under intensive Rice-Wheat-System (RWS) (Ladha 2000). Widespread adoption of green revolution technologies and high yielding varieties increased both crop yield as well as crop residue. In the RWS, a short period of time is available between rice harvesting and wheat plantation and any delay in planting adversely affects the wheat crop. This coupled with use of combined harvester compels the farmers to burn the residue to get rid of it.

After harvesting, open burning of rice residues (both straw and husks) is a standard practice in Asia. Open burning of rice straw residues has harmful environmental effects. It causes greenhouse gas emissions (GHGE), including 0.7–4.1 g of CH_4 and 0.019–0.057 g of N_2O per kg of dry rice straw, and emission of other gaseous pollutants such as CO_2, SO_2, NOx, HCl and, to some extent, volatile organic compounds (VOC) and carcinogenic polycyclic aromatic hydrocarbons (PAH), dioxins and furans (Oanh et al. 2011). It also affects the radiation budget of the earth. Intensive burning contributes to the formation of Atmospheric Brown Cloud (ABC) that affects the air quality and visibility (Kanokkanjana et al. 2011). Rice straw burning is also an important source of aerosol particles such as coarse dust particles (PM_{10}) and fine particles ($PM_{2.5}$) (Chang et al. 2013), affecting regional air quality and reducing visibility as a result of the gas and particle emissions. In November 2016, in an event known as the "*Great smog of Delhi",* air pollution spiked far beyond acceptable levels. Levels of fine particle and sand-coarse dust particles hit 999 micrograms per cubic meter, where as the safety limits for those pollutants are 60 and 100 micrograms, respectively, and this event is chiefly attributed to the practice of open burning of rice straw in the neighboring states of Punjab and Haryana.

Open burning of rice residues also results in loss of major nutrients. About 40% nitrogen (N), 30 to 35 % of potassium (K) and 40 to 50 % of sulphur (S) are lost. This is a critical and widespread issue in India, Bangladesh, and Nepal which is causing depletion of soil K and Si reserves at many places (Dobermann and Fairhurst 2002). Besides, the heating of the soil, kills the useful microorganisms of the soil causing soil degradation including nutrient loss, depletion of soil organic matter (SOM), and reduction in the presence of beneficial soil biota. Incorporation of rice straw into soil without proper decomposition is creating another problem of decrease in production efficiency and an increase in greenhouse gas emissions.

It is estimated that 22,289 Gg of paddy straw surplus is produced in India each year out of which 13,915 Gg is estimated to be burnt in the field. Punjab and Haryana alone contribute 48% of the total open field burning (Gadde et al. 2009). One year of crop residue in Punjab contains about 6 million tonnes of carbon that on burning could produce about 22 million ton of CO_2 in just 15-20 days, says a study published in Springer Briefs in Environmental Science (2014). The study also showed that CO levels become critical in the area surrounding a burning field: concentrations of 114.5 mg m^{-3} or more were observed at 30 m from burning fields and 20.6 mgm^{-3}at 150 m away. The permissible limit of CO in ambient air is 4.0 mg m^{-3}. Significant amounts (40–50 µgm^{-3}) of nitrogen oxide (NO_2) and ammonia (NH_3) were also recorded during burning.

Open burning in the field affects life of human, animals, birds and other insects below and above the earth. Burning at times also causes poor visibility and increases the incidents of road accidents. Apart from humans and animals, residue burning also adversely impacts the soil health. According to a presentation made by GV Ramanjeneyulu, agriculture scientist and executive director of Hyderabad-based non-profit Centre for Sustainable Agriculture, before the Punjab government, heat from burning straw penetrates 1 cm into the soil, elevating the temperature to as high as 33.8-42.2°C. This kills the bacterial and fungal populations critical for a fertile soil. The presentation also showed that the monetary cost of burning to Punjab farmers is around Rs. 800-2,000 crore every year in terms of nutritional loss and Rs. 500-1,500 crore in the form of government subsidies on nitrogen, phosphorus and potash fertilizers.

Recent environmental pollution caused by straw burning open up a challenge to agricultural scientist as to how the crop residue may be better managed. What other alternative economic avenues may be exploited that will enable environment friendly usages of straw/crop residues. Integrated research approach should be addressed to use straw/crop residues in all possible options like, biochar conversion, bio-ethanol production, better feedstock preparation for animals, as raw materials for paper industries etc. In this chapter we discuss the international and national status of rice straw management along with some alternative management strategies for *in-situ* utilization of paddy straw, value addition in the light of fodder quality improvement and substrate for mushroom production and few alternative avenues for utilization of rice straw towards bio-energy production and *ex-situ* composting.

3. TECHNOLOGIES FOR STRAW UTILIZATION

China: China being a leading rice producer, has ample generation of rice straw, contributing 62% of country's total crop residues. Few technologies are already available for utilizing the straw in the forms of fuel, feedstuff, manure and industrial raw material. For a part of the country rice straw plays as the major energy source. Since 1981, China had started a drive for better crop biomass resource and energy conversion technology, encompassing rice straw which plays an important role (Liu et al. 2011).

Pakistan: Farmers in Punjab, Pakistan adopt three main residue management practices, including: i) the burning of rice residue after the rice harvest or 'full burn', including the top part (pural) and the lower parts; ii) the removal of rice straw; and iii) the partial or complete incorporation of rice residue into the soil using farm machinery (rotavators and disc harrows).Though a negligible percentage of farmers followed the incorporation of rice residue into the soil, and if assessed by area, the 'full burn' method ranks first. Around 58% of the area under rice cultivation was fully burned, while the full removal of rice residue covered only 25% of the rice area in Pakistan. The remaining area was either partially burnt or had rice residue incorporated into the field.

Sri Lanka: In contrast, in Sri Lanka, straw is used for a number of purposes. Rice straw is widely used as fodder, for the manufacturing of paper and paper boards and for thatching the roofs of houses. Its use as mulches is also practiced in cultivation of ginger and turmeric crops. A small amount of the straw is also used as a packaging material. Only a handful of farmers add the straw back to the fields whereas a large number burn the straw at the threshing site. Majority of farmers are unaware of the value of rice straw as a fertilizer material and a sizable quantity of rice straw is wasted in Sri Lanka primarily owing to this unawareness.

Bangladesh: Bangladesh produces around 43.85 million MT of rice residue (EPA, 2011). For residue management in Bangladesh, several practices are followed: (a) burning in the field, (b) incorporating in the field and (c) removing from the field either for burning along with cow dung or for feeding cattle. Report says complete (100%) field burning of the residue is observed only in 3% of surveyed area, prevalent in Narail, Khulna and Faridpur districts (Haider 2011). The farmers also remove or do not burn residue instead keeping it for selling purpose. The main reason behind burning the lower part of residue in the field is to use it as fertilizer thereby eliminating expensive operations like removal and cleaning of the land. Many farmers think that residue burning in the field provides fertilizer to the field for the successive seasons. However, higher removal cost is the main reason behind not removing the residue from the field.

Vietnam: In Vietnam, to chalk out the alternative rice straw management for future, a study reported that deploying rice straw for biochar production and soil amendment led to a lower climate change impact showing negative carbon footprint than open burning of biomass in both spring and summer seasons' rice cultivation (Mohammadi et al. 2016). The Mekong Delta region has appeared to be potential hotspot for bioethanol production from rice straw, producing 26 Mt rice straw yearly with an estimated cost of 1.19 $ L^{-1}. However, to lower down the production cost in terms of energy cost, Diep et al. (2015) suggested few modifications in bioethanol plants, like using residues for power generation and improving solid concentration of material in the hydrothermal pre-treatment step.

Thailand: In order to discourage open burning of rice straw and to promote the possibility of rice straw utilization for industrial applications, researchers of Thailand proposed the use of rice straw based stoker boiler, a promising technology for heat and power generation and an alternative to coal based power, with less emission of NOx and chlorinated organic compounds (Suramaythangkoor and Gheewala 2010).

Japan: The Japanese cabinet launched "*Biomass Nippon Strategy*" for efficient biomass utilization in Japan, though the amount of biomass resource is not very large and limited production scale (Matsumura and Yokoyama 2005). In that scenario, power generation from rice straw biomass (with a production potential of 12 Mt-dry $year^{-1}$) had a potential to supply 3.8 billion (kW) h of electricity per year, sharing only 0.47% of the total electricity demand in Japan (Matsumura et al. 2005). In Japan, a long-term trial has been successfully conducted using crop residue management in Fukuoka, where soil quality showed beneficial impact under treatment of rice straw compost in terms of greater accumulation of total C and N in the soil from rice straw compost, with a declined value of metabolic quotient (qCO_2) indicating better C utilization efficiency by soil microbes (Tirol-Padre et al. 2005).

Korea: In Korea, rice straw (lingo-cellulosic fiber) is used along with waste tire particle for manufacturing composite boards using as insulation boards, which showed good acoustical insulation, electrical insulation, anti-caustic and anti-rot properties over wood particle board (Yang et al. 2004). In another instance, regenerated cellulose fibers (with a diameter of 10 to 25 ìm) were prepared by wet spinning in rice straw/*N*-methylmorpholine-*N*-oxide solution (Lim et al. 2001).

India: India, the second largest rice producer in the world, produces nearly 130 million tons of rice straw annually. Rice straw is fed to cattle and buffaloes in India since ages. Rice straw is fed to cattle at home as basal diet in most areas where green fodder is scarce. It is also used as feed for ruminants and has many other uses like manure, thatching, purpose paper pulp, alcohol, mats, poultry litter and mushroom production. Farmers are yet to realize the importance of rice straw as a form of manure and as a profitable raw material for various industries. In the major rice growing states of

Punjab and Haryana, farmers have tried various means of disposing the rice straw while earning some income. Brick manufacturing companies, power companies, and paper and packaging industries use rice straw as a raw material.

Punjab Agriculture University recommended various new technologies for straw management. One of the promising one is to cut the straw in to small pieces and scatter over the ground mechanically after harvesting by combined harvester followed by direct sowing of the wheat with happy seeder in that field. In one day, up to 15-20 acres can be sown. The scattered straw helps not only in conserving the soil moisture but also helps to operate happy seeder for direct drilling of wheat into the rice residue in a single pass without burning the straw.

Applications of microorganisms as accelerators of biodegradation have shown promising results. A consortium of *Candida tropicalis* (Y6), *Phanerochaete chrysosporium* (VV18), *Streptomyces globisporous* (C3), *Lactobacillus* sp. and enriched photosynthetic bacterial inoculum hasten the composting process of rice straw by bringing C:N ratio down to 15:1 and achieving a total humus content of 4.82% within 60 days as reported by Sharma et al. 2014.

A combination of cow dung slurry @ 5% + *Trichoderma harazianum* @ 5 kg/ha + *Pleurotus sajorcaju* @ 5 kg/ha had significant influence in degrading rice straw as evidenced through the activity of N- fixing and P- solubilizing microorganisms in the soil. It was reported that nutrient enriched compost can be prepared by using the consortium of fungal (*Aspergillus nidulans, A.awamori, Trichoderma viride and Phanerochaete chrysosporium*) inoculants within 70-90 days by pit and windrow methods.

Some existing microbial culture available in India for composting of rice straw are listed in tabular form (Table 1).

On short-term basis, rice residue addition stimulates CH_4 emission in next crop, immobilizes available N, and may accumulate toxic material in soil. In general, no consistent /significant effect of either incorporation or mulching of rice straw on N_2O emission was found, however, an increase in emission of N_2O from field with mulch compared to the incorporation was observed in subtropical rice-based cropping system. Bhattacharyya et al. (2012) reported that the application of inorganic fertilizers in combination with rice straw in tropical rice resulted in C build up, increase in productivity and sequestration capacity of soil, although, it also resulted in higher GHGs emissions. They recommended combination of inorganic fertilizer (urea) with rice straw (1:1 N basis) for building of soil C (1.39 Mg ha^{-1}), sustaining crop yield and lower GHGs emission as compared to addition of rice straw/green manure alone.

4. ALTERNATIVE USE OF RICE STRAW

4.1. Conservation agriculture (CA)

Zero and/or reduced tillage is an important component of CA. It helps in increasing soil organic matter by leaving the previous crop residues on the soil surface to decay, which leads to increased soil nitrogen while conserving soil moisture and structure.

Table 1. Existing composting technologies of rice straw available in India

Name of decomposing microbial inoculants	Type of microbes used	Recommended dosage	Source
TNAU Biomineralizer	Consortium of decomposing microbes	2.0 kg inoculum per tonne of wastes	TNAU, Coimbatore
Effective micro-organisms (EM)	photosynthetic bacteria, *Lactobacillus*, *Streptomyces*, actinomycetes, yeast	EM solution accelerators @33.3 lit per pit (6'x4'x3' LBH) *i.e* to produce 0.9 t compost	Indian Institute of Soil Science, Bhopal
Institute of Biological Sciences (IBS) rapid composting technology	*Trichoderma harzianum* (compost activators should be prepared by mixing *T.harzianum* with carbonaceous plus nitrogenous materials)	1.0 kg per 100 kg substrate	Indian Institute of Soil Science, Bhopal
Poultry waste compost	*Pleurotus sajar-caju*	1.25 kg inoculum per tonne of waste (1:1.25 ratio of paddy straw and poultry dropping)	Indian Institute of Soil Science, Bhopal
Phospho compost	Fungal consortium (*Aspergillus niger*, *A. flavus* and *Trichoderma harazianum*)		IARI, Delhi
EM consortium	*Phanerochaete chrysosporium* VV18, *Streptomyces sp.*C3, *Rhodotorula glutinis*Y6, *Lactobacillus plantarum*		IARI, Delhi
Biological delignification of paddy straw	*Myrothecium roridum* LG 7, *Trametes hirsuta* and *Streptomyces griseorubens*		IARI, Delhi
Coimbatore/ Indore/ Bangalore method	Cow dung slurry and bone meal or cow dung slurry is applied layer by layer	5-10 kg cow dung in 2.5 to 5.0 I of water and 0.5 to 1.0 kg fine bone meal sprinkled over it uniformly per layer	TNAU, Coimbatore

Leaving the residues on the field protect the soil surface from direct impact of wind and rain drops hence reducing wind and water erosion and conserving soil moisture. It also prevents germination of weeds. However, some disadvantages like, greater risks of crop yield reductions or failure in initial year, increased possibility of pests and diseases and difficulty in incorporating fertilizers may remain. But, with the advent of second generation farm machineries like "Happy Seeder", management of rice straw in field became easy. The Happy Seeder is a machine that cuts and lifts rice

Fig. 1. Happy seeder

Fig. 2. Straw chopper and baler

(Source: www.mikeprycemachinery.com)

straw, sows seeds into the bare soil, and deposits the straw over the sown area as mulch (Fig. 1).

Combine harvesters are gaining popularity day by day in India for timely harvesting of paddy. By the combine harvested fields leave high stubbles and straw in the field. For timely sowing of next crop without burning of these loose straw, chopping machine is used to pick them up and conveyed to serrated blade for chopping cylinder, and the chopped straw are then spread over the field.

Straw baling in the combine harvested paddy field is considered as technically and economically beneficial for animal feed, biofuel and other industrial uses. Straw baling technology is very useful for mechanized collection of straw and can be done in less time. It is convenient and economical for handing, transportation and storage of straw (Fig. 2) by straw bales.

4.2. Mulch

Rice straw could be used as mulch for other crops like wheat, maize, sugarcane, sunflower, soybean, potato, chilli etc. In one side, it would improve crop yield in dry land and water stress condition by conserving soil moisture and on the other hand, could save irrigation water of about 7 to 40 cm. In light of reduction of GHG emission, sowing of wheat with rice straw mulching in residual moisture (without pre-sowing irrigation) could save about 20% irrigation water, which could save 80 KWh of electricity and reduce emission of 160 kg of CO_2 equivalent (Singh and Sidhu 2014).

4.3. Biochar

Controlled pyrolysis of crop residues (CRs) could produce biochar which not only reduces GHGs emission but at the same time sequester C in soil for long time. Biochar is a heterogeneous substance rich in aromatic carbon and minerals. It is produced by pyrolysis of sustainably obtained biomass under controlled conditions with clean technology and is used for any purpose that does not involve its rapid mineralization to CO_2 and may eventually become a soil amendment (Fig. 3).

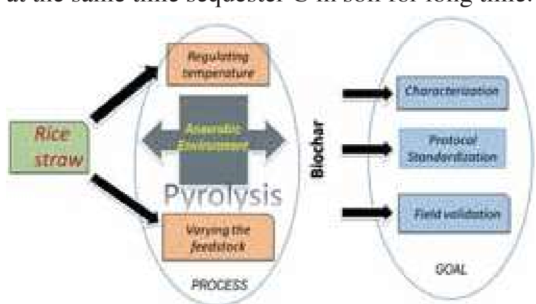

Fig. 3. Conceptual flowchart of rice straw recycling through biochar.

However, technological options and spatial field level data are required to fully utilize or recognize its GHGs mitigation/adaptation potential. Biochar serves as a sink for atmospheric CO_2 because of its reactive surfaces and recalcitrant aromatic structure. Further, during pyrolysis about 50% of C in rice straw is immediately released, which could be effectively used as energy sources and the remaining recalcitrant is biochar which sequester C in soil. So it is a win-win situation. On the other hand, 80-90% of C of rice straw in original form is emitted as CO_2 within 10 years, depending on soil and environmental constraints. Therefore, recalcitrant biochar offers a prospect of sequestering 40-50% of original rice straw-C having a huge greenhouse mitigation benefit. However, India produces only about India 1.7 million tons of biochar/year (Srinivasarao et al. 2013).

4.4. Rice straw as animal feed

In India, rice straw is used as fodder since time immemorial. In eastern part of the country, it is the traditionally the most popular form of dry biomass which is given to animals after they are chaffed and then mixed with green fodder or as basal diet in animal sheds. In Punjab, Haryana and western Uttar Pradesh, rice straw is used mostly as basal diet. However, the fact remain that it is the scarcity of good quality feed and fodder in the country which forces the farmers to use paddy straw as fodder. It is a poor quality feed in terms of protein and mineral content which are the two important components of a fodder crop. On an average the crude protein content in rice straw is as low as 4%. Although the crude fibre content is approximately 37% and the total ash content is nearly 18%, the major fraction of them is lignocellulose and insoluble ash. Due to these reasons, paddy straw is poorly palatable and thus its intake by animals is low.

Rice straw-based animal feed block making machine: It is useful for making animal feed blocks of size 20 cm x 20 cm by mixing rice straw with essential nutritional elements. The machine is powered by 25 hp electric motor and has the capacity of 250 kg h^{-1}. It is also available in 125 kg h^{-1} capacity with block size of 10 cm x 10 cm operated by 10 hp electric motor. The self-life of the feed blocks is more than one year, very economical to transport to distant places.

Feed block making procedure: The rice straws collected from farmers field are passed through chaff cutter machine (15 hp capacity) and are made into pieces of about 1 to 2-inch size. The essential mineral mixtures (i.e. splitted maize grain, green gram, black gram, horse gram and jiggery) for increasing its nutritional quality and chopped rice straw are placed in the mixing machine (5 hp size) (Fig. 4). The output from the mixing machine is then passed through the feed block making unit (25 hp size)

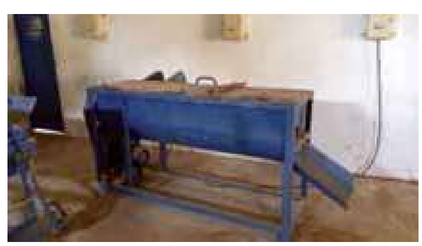

Fig. 4. Mixing unit (Rice Straw + Other ingredients) (Source: IARI, New Delhi)

Fig. 5. Feed block making machine (after mixing with ingredients) (Source: IARI, New Delhi)

Fig. 6. Feed block ready to use

(Fig. 5) which then makes feed blocks of 3.5 kg each (Fig. 6), which are ready for selling and are used for animal feeding (cow/buffalo).

4.5. Mushroom industry

Cultivation of edible mushroom is one of the cheapest and economically viable processes for the bioconversion of lingo-cellulosic wastes. Mushrooms have capacity to convert nutritionally less valued substances like rice straw in to valuable and nutritious human food and animal feed. Various studies recommends the use of paddy straw for cultivation of different types of mushrooms viz. Button mushroom *(Agaricus bisporus)*, Oyster mushrooms *(Pleurotus* spp.) and paddy-straw mushroom *(Volvariella volvacea, V.diplasia)* in India.

Mondal et al. (2010) revealed that, highest biological and economic yield of Oyster mushroom was obtained from rice straw as compared to other substrate materials tested. The highest yield from rice straw appeared, due to comparatively better availability of nitrogen, carbon and minerals from this substrate. The rice straw could be used as substrate at a concentration of 15%: 60% in planted media of Oyster mushroom production without any reduction in productivity of white Oyster mushrooms (Utami and Susilawati 2017). It is one of the best substrate for cultivation of milky white mushroom.

Paddy straw mushroom is the third most important mushroom cultivated in the world and this mushroom can use wide range of cellulosic materials and prefers C: N ratio of 40 to 60. North Eastern region and eastern India comprising of West Bengal, part of Bihar, Jharkhand and Odisha has tremendous potential and scope for paddy straw mushroom cultivation due to the easy availability of basic substrate (paddy straw). Use of rice straw for cultivation of *Volvariella* spp. will decrease the environmental problem and provide sustainable means of adding value to rice farmers (Tripathy et al. 2011).

Cultivation of *Pleurotus florida* on rice straw has beneficial effect on digestibility, degradability and increases the nutritional values for animal feed (Hadizadeh et al. 2015). Even the leftover of paddy straw after harvesting mushroom can be re-used as manure (after composting) for other crops which would save expenses on chemical fertilizers. The proteinaceous, low lignin content of the spent rice straw from mushroom production is a potential feed quality for ruminants (Kathrina et al. 2016). Edible mushroom treated rice straw shows promise as feed resources for ruminant animals either solely or in combination with other feedstuffs.

The physical and chemical properties of rice straw varies with variety, harvest time, method of threshing and season of cultivation of rice crop which influences the quality and productivity of mushrooms. There is consistent variation in the nutrient value of rice straw associated with location and season for rice cultivars. Hand threshed rigid and tall rice straw was found to be more appropriate than dwarf cattle threshed and flexible straw against *V. esculenta.* Cellulose/lignin ratios in rice straw were positively correlated to mycelial growth rates and mushroom yields.The physical properties (moisture content, particle size, bulk density and porosity of rice straw varies with rice varieties even though they were grown under same climatic conditions using similar soil type and cultivation methods. Earlier findings revealed that paddy straw derived from variety CR 1014, 1242, 141, T90 is good for preparing mushroom beds. The role of extracellular enzymes like cellulases, hemicellulases and lignases is pivotal to the production of any mushroom fruiting body which is affected by the various nutrients and physical factors of the used substrates. There is a great scope to evaluate the predominant rice varieties and available rice germplasms to establish the rice varieties most suitable for economic and environment-friendly utilization of rice straw for value addition.

4.6. Composting

Composting is a microbiological process carried out by succession of mixed microbial populations with specific functions. High lignin content restricts the enzymatic and microbial access to the cellulose in paddy straw. Many composting technologies are available which requires nearly 60-75 days for complete decomposition of paddy straw, but there is an absence of viable rice straw decomposing methods within short period of time (45-60 days). At present, there is a dearth of viable *in-situ* decomposition of rice straw residues at field levels. Hence, it is essential to develop efficient microbial consortium to solve the aforesaid problems.

The composting of agricultural residues rich in lignocellulose like paddy straw generally takes five to six months to obtain good and mature compost. Cellulose degrading microorganisms hasten the biodegradation of crop residues such as straw, leaves, trash etc. and such cultures have been used for composting of plant residues but the time taken for composting is still too long. In nature, during decomposition of lignocellulosic material many mesophilic, thermophilic and thermo-tolerant microorganisms like fungi, bacteria and actinomycetes play a significant role at various stages. Cellulose is the main polysaccharide in terrestrial ecosystems. Rice straw has a cellulose content of 37-49%. It represents a huge source of energy for microorganisms. In nature, most cellulose is degraded aerobically with the final product being CO_2. Cellulose is insoluble in water and therefore requires enzymatic degradation. The ability of bacterial and fungal communities to degrade cellulose aerobically is widespread among some soil microbial groups. Cellulose degrading bacteria are found in both filamentous (e.g. *Streptomyces, Micromonospora*) and non-filamentous (e.g. *Bacillus, Cellulomonas, Cytophaga*) genera.

Cytophaga and *Sporocytophaga* are dominant cellulolytic microorganisms in most of the composting processes; these are the aerobic mesophilic bacteria able to degrade cellulose. Some mesophilic aerobic forms of *Bacillus,* like *B. subtilis, B. polymyxa, B. licheniformis, B. pumilus, B. brevis, B. firmus, B. circulans, B. megaterium* and *B. cereus* are also reported to behave as cellulose and hemicellulose degraders. Similarly, actinobacteria (*Streptomyces* sp) has strong biodegradative activity, secreting a range of extracellular enzymes and exhibiting the capacity to metabolize cellulose, hemicellulose and lignin (Saritha et al. 2012).

Cellulose degradation is a common trait among fungi within both Ascomycota and Basidiomycota. Aerobic cellulolytic fungi produce freely diffusible extracellular cellulase enzyme systems consisting of endoglucanases, exoglucanases and â-glucosidases that act synergistically in the conversion of cellulose to glucose (Lynd et al. 2002). Hundreds of species of fungi are able to degrade lignocellulose. There are mainly three types of fungi living on dead wood that preferentially degrade one or more wood components viz. soft rot fungi, brown rot fungi and white rot fungi. In majority of soils, 80 per cent of the fungal population belongs to the genera *Aspergillus* and *Penicillium*. However, the most extensively studied lignocellulolytic fungi are *Trichoderma, Phanerochaete* sp. and *Pleurotus sp.*

4.7. Biogenic silica from rice straw

Biogenic silica from rice straw has amorphous silica. It is having at least 3% of silica and preferably more than 20% by weight of silica for use as an anti-caking agent, excipient or flavor carrier. The straw is ground and the silica may be concentrated by carbon reduction through enzymatic treatment or burning. In some instances an antimicrobial treatment of the silica may be beneficial.

4.8. Alternate source of energy: Biofuel/biogas/bioethanol production

Rice straw being a ligro-cellulosic material is considered to be a potential source of renewable energy. In this context synthesis of biofuel from rice straw, and mixing of biofuels with convectional fuels could save the exploitation of fossil fuel thereby reducing GHGs emission while helping to mitigate climate change. According to IPCC data inventory (2014) about 25 billion tons of CO_2 are generated by anthropogenic activity every year, which could be reduced by lowering emission, enhancing sink or removals and avoiding emission (through fossils fuels). All these three could be effectively done, partially by suitable/effective management of rice straw. An increasing trend has already been observed through 4th (2007) and 5th assessment (2014) report of IPCC on the use of CRs as sources of feed stock for energy to displace fossil fuel. CRs could be burnt directly or be processed further to generate liquid fuels like ethanol or bio-diesel (IPCC 2007; IPCC 2014).

There is a huge potential to offsets fossil fuel by generating ethanol from bulk CRs in general and rice straw in particular, with efficient commercial technologies.

Potentially, 250-350 litre ethanol could be produced from each metric ton of dry CRs. Considering only 20% of world's rice straw is being utilized for this purpose, lead to an annual ethanol production of 40 billion litres, which would be able to replace about 25 billion litre of fossil fuel based gasoline (Jeffery et al. 2011). As a result net GHGs emission could be reduced to a tune of 70 million tonnes CO_2 equivalent per year. But large scale and small scale commercial machineries/technologies need to be developed for harnessing this potential. However, for bio-energy perspective, residue would be removed rather than returned to the soil (opposite to concept of conservation agriculture). For that harvesting, threshing and transportation mechanism need to be streamlined. Along with that, varieties having desirable straw characteristics should be grown for biofuel production. Presently only 10% of the total rice residues in India are used for bioenergy production (NAAS 2012).

4.9. Biogas

Biogas from rice residue in combination with animal excreta is an age old technology in rice growing tropical world. But its use and efficiency has been declining over the years, although, it has various benefits including plant nutrient addition to soil. Further, fermented/composted biogas when used as manure in rice-paddy, generate less CH_4 as compared to addition of fresh organic manure. However, escalating fuel price and climate change/environmental issue may re-stimulate its future (Singh and Sidhu 2014).

5. KNOWLEDGE GAPS

- Lack of economic technologies for *in situ* composting.
- Absence of viable microbial inoculants for rapid *in-situ*/*ex-situ* decomposition of paddy straw.
- Paddy straw is relatively less preferred by animals than wheat and crop residues – lack of characterization of available variety/germplasm for fodder quality
- Lack of cost effective small scale technologies for bio-energy production.
- Less effort has been made for value addition of paddy straw in view of present day mechanized agriculture.
- Lack of authentic database on contribution of straw burning in air pollution and GHGs/carbon footprint.
- Lack of Cataloguing/prioritizing the causes of biomass burning required for policy making to address the problem

6. WAY FORWARD

There is huge potential to use paddy-straw in bio-energy production, composting, as fodder and so on, which can establish it as an important bio-resource. Microbial composting, an up-coming technology for agricultural wastes disposal in which biodegradation of lignocellullosic matter like paddy straw is carried out exploiting ligninolytic and cellulolytic microorganisms. Minimizing the time period for decomposition is considered along with the other key factors viz. C/N ratio (25-30 is optimum), temperature, aeration and moisture affecting the composting process and quality. Therefore, nutrient amendments (urea, DAP, cattle, poultry, swine manures, soybean residues, *Jatropha Curcas*) have been used for decreasing the C/N ratio of rice straw. Based upon the aerobic or anaerobic types of composting process, aeration is necessary and so is the moisture content.

Green revolution in the country was achieved through development of semi-dwarf versions of traditional tall *indica* varieties. This led to a reduction of lodging incidences by changing the centre of mass of the plants. However, the plant height reduction also led to reduced biomass production from a unit area. In the quest for higher yields, the selection of strong culms to sustain heavy panicles also lead to selection of genotypes with higher amount of lignocelluloses in stems. In order to develop varieties suitable for both grain production and better quality feed and biofuel, the lodging resistance can't be compromised which makes the matter more complicated. Digestibility and saccharification efficiency of the straw depends on the cell wall composition. With increased lignin content in shoots, the lodging resistance of the culm increases, whereas, the fodder quality and saccharification potential decreases substantially. Hence, an alternative mechanism where lignin content can be reduced substantially without reducing the culm strength will be a requisite.

Recently, in rice a mutant line "gold hull and internode2 (*gh2*)" have been identified as lignin deficient. The *GH2* (*OsCAD2*) gene encodes cinnamyl-alcohol dehydrogenase (CAD) enzyme. Generally the mutants have lower lignin content and are prone to lodging. A new natural mutation in the same gene was identified where the lignin content was reduced to a great extent, although high culm strength was obtained due to presence of strong, thick culms along with a thick layer of cortical fibre tissue with well-developed secondary cell walls. The new rice variety developed by this mutation produces high biomass suitable for forage and bioenergy and have been named as Leaf star (Ookawa et al. 2014). Some other QTLs have also been identified which increases lodging resistance in rice culms without increasing the lignin or silica content. Rather some QTLs like *prl5* and *lrt5* (Kashiwagi et al. 2008 and Ishimaru et al. 2008) increases the starch content in culms through carbohydrate re-accumulation in stem after grain filling.

All the above discoveries have opened new avenues for breeders for developing new varieties of rice which not only provides good quality grains for human consumption but also superior quality straw for feeding ruminants and producing biofuels with increased efficiency.

Paddy straw has economic potential but there is an urgent need to popularize the array of available technologies for straw utilization such as use for power/electricity generation, ethanol production, biochar production, composting and raw material for paper mill/board making industry.

It is also necessary to develop machinery bank at block or district level equipped with straw management machinery and help in capacity building of the farmers regarding various uses of paddy straw management through various extension strategies such as demonstration, field days and exposure visits. Development of appropriate farm machinery to facilitate collection, volume reduction, transportation and application of crop residues and sowing of the succeeding crop under a layer of residues on soil surface is also the need of the hour.

References

Arora DS, Sharma RK and Chandra P (2011) Bio-delignification of wheat straw and its effect on in vitro digestibility and antioxidant properties. International Biodeterioration Biodegradation 65(2): 352-358.

Bhattacharyya P, Roy KS, Neogi S, Adhya TK, Rao KS, Manna MC (2012) Effects of rice straw and nitrogen fertilization on greenhouse gas emissions and carbon storage in tropical flooded soil planted with rice. Soil and Tillage Research 124: 119-30.

Binod P, Sindhu R, Singhania RR, Vikram S, Devi L, Nagalakshmi S, Kurien N, Sukumaran RK, Pandey A (2010) Bioethanol production from rice straw: an overview. Bioresource Technology 101(13): 4767-4774.

Diep NQ, Sakanishi K, Nakagoshi N, Fujimoto S, Minowa T (2015) Potential for rice straw ethanol production in the Mekong Delta, Vietnam. Renewable Energy 74: 456-463.

Dobermann A, Fairhurst TH (2002) Rice straw management. Better Crops International 16 (1): 7–11.

EBC (2012) ‘European Biochar Certificate - Guidelines for a Sustainable Production of Biochar. European Biochar Foundation (EBC), Arbaz, Switzerland.

EPA (2011) No. EPA 430-R-11-005, Washington, D.C., Environmental Protection Agency, ‘Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009’, United State.

Gadde B, Bonnet S, Menke C, Garivait S (2009) Air pollutant emissions from rice straw open field burning in India, Thailand and the Philippines. Environmental Pollution 157: 1554–1558.

Hadizadeh N, Kheiri F and Shakeri P (2015) Evaluation of the nutritional value and digestibility of rice straw enriched by Oyster mushroom (*Pleurotusflorida).* Cibtech Journal of Zoology 4(2): 76-82.

IPCC (2014) In: Stocker TF, Qin D, Plattner GK, Alexander LV, Allen SK, Bindoff NL, Bréon FM, Church J.A, Cubasch U, Emori S, Forster P (2013) Technical summary. In Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

IPCC [Intergovernmental Panel on Climate Change] (2007) Agriculture. In: Metz B, Davidson OR, Bosch PR (Eds.), Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom/New York, NY, USA.

Josephine RM and Sahana B (2014) Cultivation of milky mushroom using paddy straw waste. International Journal Current Microbiology Applied Science 12(3): 404-408.

Kanokkanjana K, Cheewaphongphan P, Garivait S (2011) Black carbon emission from paddy eld open burning in Thailand. 2nd International Conference on Environmental Science and Technology, Vol.6. IPCBEE, LACSIT Press, Singapore.

Kashiwagi T, Togawa E, Hirotsu N and Ishimaru K (2008) Improvement of lodging resistance with QTLs for stem diameter in rice (Oryza sativa L.). Theory of Applied Genetics 117(5): 749-757.

Kathrina MM, Evaristo AA, Daniel LA and Sofronio PK (2016) Use of effective microorganisms on enhancing the mycelial growth of *Pleurotus florida*on unsterilized rice straw. Journal of Biological Engineering Research and Review 3(1): 30-36

Kumar S and Kumar P (2016) Economic Impact of Air Pollution from Agricultural Residue Burning on Human Health. Climate Change Challenge (3C) and Social-Economic-Ecological Interface-Building p 313.

Ladha JK (2000) Improving the productivity and sustainability of rice-wheat systems of the Indo-Gangetic Plains: a synthesis of NARS-IRRI partnership research (No. 40). International Rice Research Institute.

Lim SK, Son TW, Lee DW, Park BK and Cho KM (2001) Novel regenerated cellulose fibers from rice straw. Journal of Polymer Science 82(7): 1705-1708.

Liu Z, Xu A and Long B (2011) Energy from combustion of rice straw: status and challenges to China. Energy and Power Engineering 3(03): 325.

Lynd LR, Weimer PJ, Van Zyl, WH and Pretorius IS (2002) Microbial cellulose utilization: fundamentals and biotechnology. Microbiology Molecular Biology Review 66(3): 506-577.

Matsumura Y and Yokoyama SY (2005) Current situation and prospect of biomass utilization in Japan. Biomass Bioenergy 29(5): 304-309.

Mohammadi A, Cowie A, Mai TLA, de la Rosa RA, Brandão M, Kristiansen P and Joseph S (2016) Quantifying the greenhouse gas reduction benefits of utilizing straw biochar and enriched biochar. Energy Procedia 97: 254-261.

Mondal SR, Rehana MJ, Noman MS and Adhikary SK (2010) Comparative study on growth and yield performance of oyster mushroom (*Pleurotus florida*) on different substrates. Journal of the Bangladesh Agricultural University 8(2):213-220.

Murali S, Shrivastava R and Saxena M (2010) Greenhouse gas emissions from open field burning of agricultural residues in India. Journal Environment Science Engineering 52(4): 277-84.

NAAS (2013) Climate Resilient Agriculture in India. Policy Paper No. 65, National Academy of Agricultural Sciences, New Delhi: p 20.

Oanh NTK, Bich TL, Tipayarom D, Manadhar BR, Prapat P, Simpson CD, Liu LJS (2011) Characterization of particulate matter emission from open burning of rice straw. Atmospheric Environment 45(2): 493–502.

Ookawa T, Inoue K, Matsuoka M, Ebitani T, Takarada T, Yamamoto T, Ueda T, Yokoyama T, Sugiyama C, Nakaba S and Funada R (2014) Increased lodging resistance in long-culm, low-lignin gh2 rice for improved feed and bioenergy production. Science Reporter 4: 6567.

Saritha M, Arora A and Nain L (2012) Pretreatment of paddy straw with Trameteshirsuta for improved enzymatic saccharification. Bioresource Technology 104: 459-465.

Sarkar N and Aikat K (2012) Kinetic study of acid hydrolysis of rice straw. ISRN Biotechnology Volume 2013, Article ID 170615.

Sharma S, Kumar R, Gaur R, Agrawal R, Gupta RP, Tuli DK and Das B (2015) Pilot scale study on steam explosion and mass balance for higher sugar recovery from rice straw. Bioresource Technology 175: 350-357.

Singh BP, Hatton BJ, Singh B, Cowie AL and Kathuria A (2010) Influence of biochars on nitrous oxide emission and nitrogen leaching from two contrasting soils. Journal Environment Quality 39(4): 1224-1235.

Singh R, Srivastava M and Shukla A (2016) Environmental sustainability of bioethanol production from rice straw in India: a review. ýJournal of Renewable Sustainable Energy 54: 202-216.

Singh Y and Sidhu HS (2014) March. Management of cereal crop residues for sustainable rice-wheat production system in the Indo-Gangetic Plains of India. In Proceeding of Indian National Science Academy 80(1): 95-114.

Srinivasarao C, Gopinath KA, Venkatesh G, Dubey AK, Wakudkar H, Purakayastha TJ, Pathak H, Jha P, Lakaria BL, Rajkhowa DJ and Mandal S (2013) Use of biochar for soil health management and greenhouse gas mitigation in India: Potential and constraints. Central Research Institute for Dryland Agriculture, Hyderabad, Andhra Pradesh, p 51.

Suramaythangkoor T and Gheewala SH (2010) Potential alternatives of heat and power technology application using rice straw in Thailand. Applied Energy 87(1): 128-133.

Thiribhuvanamala G, Krishnamoorthy S, Manoranjitham VP and Krishnan S (2012) Improved techniques to enhance the yield of paddy straw mushroom (*Volvariella volvacea)* for commercial cultivation. African Journal Biotechnology 11(64): 12740-12748.

TirolPadre A, Tsuchiya K, Inubushi K and Ladha JK (2005) Enhancing soil quality through residue management in a ricewheat system in Fukuoka. Japan Journal Soil Science and Plant Nutrition 51(6): 849-860.

Tripathy A, Sahoo TK and Behera SR (2011) Yield evaluation of paddy straw mushroom (*Volvariella*spp) on various lingo-cellulosic wastes. Building Research and Information 4(2):19-24.

Utami CP and Susilawati PR (2017) Rice straw addition as sawdust substitute in Oyster mushroom (*Pleurotusostreatus*) planted media. AIP Conference Proceedings 1868, 090002. https://doi.org/10.1063/1.4995194

Wong ML, Webster EL, Spokes H, Phu P, Ehrhart-Bornstein M, Bornstein S, Park CS, Rice KC, Chrousos GP, Licinio J, Gold PW (1999) Chronic administration of the non-peptide CRH type 1 receptor antagonist antalarmin does not blunt hypothalamic-pituitary-adrenal axis responses to acute immobilization stress 165(4): 53-8.

Yadvinder-Singh S, Humphreys E, Kukal SS, Brar NK (2005) Straw mulch, irrigation water and fertiliser N management effects on yield, water use and N use efficiency of wheat sown after rice. In ACIAR Proceeding 127: 171-181.

Yang HS, Kim, DJ, Lee YK, Kim HJ, Jeon JY and Kang CW (2004) Possibility of using waste tire composites reinforced with rice straw as construction materials. Bioresource Technology 95(1): 61-65.

Zhang Y, Ghaly AE and Li B (2012) Physical properties of rice residues as affected by variety and climatic and cultivation conditions in three Continents. American Journal Applied Science 9(11): 1759-1768.

Zhu N (2007) Effect of low initial C/N ratio on aerobic composting of swine manure with rice straw. Bioresource Technology 31: 98(1): 9-13.❄