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Management options to alleviate the menace of rice (*Oryza sativa*) straw burning – An overview

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ABSTRACT

Burning of rice (*Oryza sativa* L.) straw in the states of Punjab, Haryana and western Uttar Pradesh in India has become an environmental and health hazard not only in the region, where it is practiced, but also in the surrounding states. It is responsible for thick smog in the months of November and December each year. This is due to a short (2-3 weeks) turn-over period between rice harvest and wheat sowing. Management options, such as, its incorporation in soil have not found favour with the farmers despite addition of plant nutrients and building soil fertility. Happy Seeder or Turbo Seeder, an equipment that cuts the rice stubbles left after the rice harvest by combines and spreads the straw as mulch after seeding wheat without primary tillage is being accepted by the farmers and gives higher yield of wheat as compared to traditional land preparation practices. Rice straw can profitably be used as mulch in vegetable crops and orchards. Its industrial uses include production of ethanol and paper. However, these technologies require heavy investment and specialist workers. A low cost industry of making rice straw-jute mattresses is suggested. Also it can be transported to meet the animal feed shortage in neighboring state of Rajasthan. However, the major problem with rice straw is its bulk and thus a large amount is to be removed within 2-3 weeks. This would require careful preparedness, planning and government intervention in providing necessary facilities in the way of railway bogies and special trains.

Key words: Biochar, Burning, Ethanol, Mulch, Rice straw

Traditional Asian agriculture involving 'humans-draught animals-raising food crops' was a sustainable ecosystem. Humans and animals worked together to grow food crops and at harvest, humans took away the protein, starch and fat rich grains, while the draught animals (cattle, buffalo, camels etc.) were contended with the low protein and cellulose rich straw or stalks. Dairy cattle and horses were provided protein supplements, such as, green legume foliage or grains and edible oilseed cakes. In addition to tilling the land and transporting the food grown, farm animals also used to add dung manure and urine (rich in urea), which improved the soil health. However, the production levels were low and not enough to support the increasing food needs associated with increasing population (Prasad 2003, 2013) and agriculture had to be modernized involving farm machines, fertilizers, pesticides etc. Although production from agricultural fields increased, the sustainability of the system became doubtful (Swaminathan 1996, Prasad 2006, 2016), because mechanized tillage (Holland 2004, Sims and Kienzle 2017) and overuse of pesticides, plastics (Greg 2000) and fertilizers (Esler *et al.* 2007, Prasad and Shivay 2015, Prasad *et al.* 2016) are detrimental to the environment. However, due to ever increasing population and associated food needs it is not possible to go back to the old agricultural systems, although attempts are being made to salvage the situation by developing conservation tillage (Holland 2004, Bhan and Behera 2014, Yadav *et al.* 2017) to partly make the system relatively more sustainable. Once the draught animals were out of the system, the surpluses of straw and stalks arose. Burning of rice (*Oryza sativa* L.) straw menace is the outcome of the modernization of agriculture.

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Amounts of crop residues produced and burned

Hiloidhari *et al.* (2014) estimated that about 686 million tonnes (Mt) of crop residues are made available by 26 crops in India, out of which cereals contribute 398 Mt (54%) followed by sugarcane, contributing 111 Mt (16%). In another study, Jain *et al.* (2014) reported that total amount of crop residue generated in India in 2008–09 was 620 Mt, out of which ~15.9% residue was burnt on farm. Rice straw contributed 40% of the total residue burnt followed by wheat straw (22%) and sugarcane trash (20%).

Rice straw

About 90% of rice is grown in Asia, where it is the staple food. Globally rice crop leaves about 731 Mt of straw in the field (Kim and Dale 2004). The estimates of rice straw production for some major rice producing countries are: China 154.2 Mt (Ai *et al.* 2015), India 97.2 Mt, Thailand

Table 1 Estimates of rice straw burnt in the north west rice–wheat cropping system (NWRCS) belt of India

State	Rice area (M/ha)	Rice–wheat area (M/ha)	Rice straw output (Mt)	Rice straw burned (Mt)	Rice straw burned (% of total produced)
Punjab	29.0	26.0	22.0	18.7	85.0
Haryana	1.3	1.0	7.5	3.9	52.0
Uttar Pradesh[a] and Uttarakhanda[a]	1.3	0.7	4.4	1.3	29.5
Total	31.6	27.9	33.9	23.9	67.8

Source: Damodaran (2017); a- Meerut, Saharanpur and Bareilly divisions of Uttar Pradesh and Nainital, Haridwar and Dehradun districts of Uttarakhand.

21.9 Mt and Philippines 10.7 Mt (Gadde *et al.* 2009 a,b); of this 23% in India, 48% in Thailand and 95% in Philippines is burnt in the fields.

Out of the total 97.2 Mt rice straw produced in India, about 34 Mt is produced in the North West Rice–Wheat Cropping System (NWRWCS) belt in the states of Punjab, Haryana, Uttar Pradesh and Uttarakhand (Damodaran 2017). Further, out of the total 34 Mt of rice straw produced in NWRWCS belt, a little over two-thirds is burnt (Table 1).

There are four main reasons for burning rice straw in RWCS belt in north–western India: 1. The turnaround period between the harvest of rice (middle to end October) and wheat sowing (around mid-November) is too narrow (2-3 weeks) (Prasad 2005). 2. Most of the rice in NWRWCS is combine harvested, leaving stubbles of 20-25 cm in height besides some loose straw spread on ground surface. 3. Removal of rice straw requires heavy equipment, labour and cost, while burning it is the easiest way out. Gupta (2012) reported that burning of rice straw depends on the rice variety; about 76% of rice straw was burnt in the case of coarse varieties, while it was about 57% in the case of *Basmati* rice. 4. Agriculture in NWRWCS belt, especially in Punjab is completely mechanized, and draught cattle are not used as is the practice in rice regions of the country and therefore rice straw is not needed as a cattle feed. On the contrary, wheat straw is used as a dairy cattle feed.

As a contrast to NWRWCS belt, rice straw in rice belts covering southern, eastern and northeastern states of India is not burnt, but is used for feeding the cattle and for several other purposes. For example, a study in West Bengal covering 60 farmers in Burdwan district showed that no farmers burnt rice straw in the field, while 100% of the farmers used rice straw as a cattle feed. Percentage of farmers putting rice straw in other uses were: thatching 92%, fuel 80%, compost making 17%, mushroom production 58%, packing material 42%, incorporation in soil 17% and mulching 13% (Roy and Kaur 2015).

Health hazards

Smoke arising out of burning of rice straw creates health problems not only in areas where straw is burnt, but also even in far way places (Koppmann *et al.* 2005, Tipayarom and Oanh 2007). Delhi faces a lot of smog (smoke + fog) in November and December each year due to rice straw burning in Punjab and Haryana, which affects the traffic movement and increases the cases of asthma (Torigoe *et al.* 2000) and other pulmonary diseases. It is the human health problem that has drawn public interest in rice straw burning all over the world. There are a number of causative factors responsible for environmental pollution and smog including vehicle exhaust, coal and wood combustion, incense sticks in some countries (Thailand) and burning of rice straw (RS) after the harvest of rice crop. Rice straw smoke contains particulate matter (PM) of varying particle sizes (0.1 to 10 nm), SO_2, NO_2, polycyclic aromatic hydrocarbons (PAHs), organochlorine particles (OCP) and several other constituents. In recent years, PAHs have received considerable attention and these are quite a few in numbers; to name a few, these include naphthalene, pheanthrene, anthracene, pyrene, chrysene, cyclopentapyrene, and benzopyrene, perylene. Rice straw burning may contribute 5.0 to 33.5% of total PAHs (Chen *et al.* 2008) in the atmosphere. In a study in Thailand carbon balance and emission ratio method was used to determine PM emission factors (EFs) in hood and field experiments of rice straw (RS). The obtained EFs varied from field to hood experiments reflecting multiple factors affecting combustion and emission (Oanh *et al.* 2011). In the hood experiments, EFs depended on the burning types (spread or pile), moisture content and the combustion efficiency. In the field experiments, burning rate and EFs were also influenced by wind speed. Hood pile burning produced significantly higher EFs (20±8 g/kg RS) than hood spread burning (4.7±2.2 g/kg RS). The majority of PM emitted from the field burning was PM 2.5 with EFs of 5.1±0.7 g/m or 8.3±2.7 g/kg RS burned. The coarse PM fraction (PM 2.5-10) was mainly generated by fire attention activities and was relatively small; hence the resulting EFs of PM 10 (9.4±3.5 g/kg RS) was not significantly higher than PM 2.5. PM size distribution was measured across 8 size ranges (from <0.4 µm to >9.0 µm). The largest fractions of PM and organic compounds (OC) were associated with PM 1.1. The most significant components in PM 2.5 and PM 10 included OC, water soluble ions and levoglucosan. Relative abundance of some methoxyphenols (e.g., acetylsyringone), polycylic aromatic hydrocarbons (e.g. fluoranthene and pyrene), organochlorine pesticides and polychlorinated bipheyls may also serve as additional signatures for the PM emission. Presence of these and other toxic compounds in PM of smoke from burning straw increases the potential toxic effects of the emission. PMs may contain some mutagenic substances (Mast *et al.* 1984), which may be involved in the etiology of cancer (Raaschou Nielsen *et al.* 2016), heart diseases (Parker *et al.* 2017), skin diseases (Magnani *et al.* 2016) and eye infections (Shiela *et al.* 2013).

From a study in Patiala, Agarwal *et al.* (2012) reported that smoke from the burning of rice straw contained gases carbon dioxide (CO_2), sulphur dioxide (SO_2), nitric oxide (NO_2) and particulate matter (PM) of different sizes varying from 2.5 to 10 nm. The decrease in the Forced Vital Capacity (FVC) of lungs due to an increase of 10 µg/m in PM was 1.541% with PM 2.5 1.002% with PM 10, 1.178% with suspended PM and 0.232% with NO_2. Thus, PMs adversely affected the pulmonary function in humans.

Loss of plant nutrients

About 40% of the N, 30–35% of the P, 80–85% of the K, and 40–50% of the S absorbed by rice remain in the vegetative parts at maturity (Dobermann and Fairhurst 2002). On burning of rice straw, the non-metallic plant nutrients, such as, N, P, S are lost, while the metallic elements, such as, Ca, Mg, Fe, Zn, Cu are turned into their oxides and remain in the field. Singh *et al.* (2008) reported that by burning of rice straw 35 kg N, 3 kg P (7 kg P_2O_5) and 2.7 kg S is lost per hectare in Punjab while Gupta *et al.* (2004) reported that about 23–73% of applied nitrogen is lost by burning rice straw.

Rice straw contains 0.6–0.9% N, 0.07–0.2% P and 1.8–3.7% K and 0.07–0.1% S (Shivay *et al.* 2015). Taking the lowest values of 0.6% N, 0.07% P and 0.07% of S, each metric tonne will contain 6 kg N, 0.7 kg P (1.6 kg P_2O_5) and 0.7 kg S. Taking a straw yield of 5 t/ha and assuming that 75% is lost in burning, about 24 kg N, 2.8 kg P (6.4 kg P_2O_5) and 2.8 kg S is lost from each hectare of rice field. These are about 20% of N, P and S recommended for application to each hectare of rice. Further, considering that about 24 Mha of rice area is burnt in north-western RWCS belt, the amount of N lost works out to 576000 t equivalents to 1.2 million metric tons of urea, which is about one-third of urea produced annually by National Fertilizers Limited, India, at their three plants (Nangal, Panipat, Bhatinda) in this region. Similarly 67200 t of P (154000 t P_2O_5) and 67,200 t of S are lost. This is a colossal loss of plant nutrients by just one operation '*the burning of rice straw'*. Loss of N has been frequently talked about, but loss of P and S should receive special attention, because there are no natural deposits of these plant nutrients in India and most of these needed by the fertilizer industry in India have to be imported. Most soils in NWRWCS belt are deficient in P and about 50% soils are deficient in S.

Global warming and production of greenhouse gases

Gupta *et al.* (2004) in their study estimated that burning of straw raises the soil temperature up to 33.8–42.2 °C (1-cm depth). A number of estimates are available on the nature and amounts of emissions. Venkataraman *et al.* (2006) estimated that burning of crop residues in India, accounted for 25% of black carbon, organic matter and CO, 9–13% of particulate matter PM 2.5 and CO_2 emission and about 1% SO_2 emission. Jain *et al.* (2014) estimated that burning of crop residues in India, emitted 8.57 Mt (million tonnes) of CO, 141.15 Mt of CO_2, 0.037 Mt of SOx, 0.23 Mt of NOx, 0.12 Mt of NH_3 and 1.46 Mt NMVOC, 0.65 Mt of NMHC, 1.21 Mt of particulate matter for the year 2008–09; the variability annual emission of air pollutants during 1995 to 2009 was 21.46%. As regards straw burning (mostly rice) in the Indo-Gangetic region in India, Badrinath *et al.* (2008) reported that total emissions were 261 Gg (thousand metric tonnes) of CO, 19.8 Gg of NO_x, 3 Gg of CH_4, 28.3 Gg of PM 2.5 and 3.0 Gg of PM 10.

Romasanta *et al.* (2017) conducted close chamber and field studies to measure methane (CH_4) and nitrous oxide (N_2O) production from rice straw burning under combustion chamber as well as field conditions. In combustion chamber studies emission factors (EFm) were 4.51 g CH_4 and 0.069 g N_2O per kg of dry (10% moisture) rice straw. Under field conditions the production of CH_4 and N_2O expressed as kg CO_2 equivalent global warming potential (GWP) was: 8023, when straw was retained and incorporated as compared to 3470 when straw was completely removed including stubbles. As compared to this, partial removal of straw with stubble incorporation and burning of straw with incorporation of ash and unburned residue recorded values of 4531 and 4913, respectively.

Management options for surplus rice straw

Rice residue management options need to be evaluated using the criteria of feasibility, financial requirements, productivity, profitability, regional acceptability, environmental impact and sustainability.

Incorporation in soil: Taking a lead from the crop residue management practices in USA (Prasad and Power 1991, Uri 1998; Islam and Reeder 2014), a large number of studies have been made at the Punjab Agricultural University (PAU), Ludhiana (Yadvinder-Singh *et al.* 2005, Bijai-Singh *et al.* 2008, Yadvinder-Singh and Sandhu 2014, Jat *et al.* 2016), Indian Agricultural Research Institute, (IARI), New Delhi (Prasad *et al.* 1999) and elsewhere (Gangwar *et al.* 2006) in India as well as in Pakistan (Khalid *et al.* 2014). Incorporation of rice straw showed some N deficiency in the early stages of wheat growth and extra N application of 25–30 kg/ha had to be made to overcome this (Gangwar *et al.* 2006, Bijai, Singh *et al.* 2008). A study at IARI was made to evaluate the effect of cellulolytic fungi *Trichus spiralis* for speeding the decomposition of incorporated rice straw, but it showed no advantage (Sharma and Prasad 2002). Most studies showed that yields with incorporation of rice straw were comparable with those obtained after straw burning or straw removal, but soil fertility was improved (Yadvinder-Singh *et al.* 2004, Prasad *et al.* 1999. Sharma and Prasad 2002, Sharma *et al.* 2010). However, the practice did not catch up with the farmers due to extra-cost involved in incorporation and fertilizer N. Farmers paid no heed to soil fertility improvement, because it could not be monetized.

Zero-till seeding and mulching: In continuation of research on incorporation of rice straw, PAU scientists have come up with a better solution in the form of version 2 of the 9-row Happy Seeder, which cuts the rice stubbles (left after combine harvest of rice crop) and picks them up in front of the sowing tynes, which engage the bare soil, and deposit the cut stubbles behind the seed drill as mulch. In on-farm trials on the farmers; fields, Happy Seeder gave 9–11% higher wheat yields than those obtained with direct drilling after burning the straw (Sidhu *et al.* 2007). Use of Happy Seeder also reduced weed infestation (Sidhu *et al.* 2007), and N loss due to volatilization, increased nitrogen use efficiency and resulted in more residual N after wheat harvest (Brar *et al.* 2010). Happy seeder is priced at ₹ 140000–155000 which is fairly high and adoption has been low to date, despite a 50% price subsidy. Constraints to adoption include the low window of operation of the machine (25 days/year), the low machine capacity compared with conventional seed drills, the inability to operate in wet straw, and the lack of straw spreaders on combine harvesters (Sidhu *et al.* 2015). Rotary disc drill could be another potential machine for direct drilling of wheat in a field with rice residue (Sharma *et al.* 2008).

Rice straw as mulch: Rice straw as a mulch, when added as a leftover after combine harvesting of rice and spread by a Happy Seeder is certainly advantageous. In a simulation study conducted using the APSIM model and 40 years of weather data, Balwinder–Singh (*et al.* 2016) found that the effect of mulch on yield varied with seasonal conditions and sowing date. With irrigation at 50% SWD (soil water deficit), mulching of wheat sown at the optimum time increased average yield by up to 0.5 t/ha. The beneficial effect of mulch on yield increased to 1.2–1.3 t/ha as sowing was advanced to 15 October. With irrigation at 50% SWD and 7 November sowing, mulch reduced the number of irrigations by one in almost 50% of years, a reduction of about 50 mm on the sandy loam and 60 mm on the clay loam.

Rice straw as a mulch has proved quite useful in vegetables and orchards. Sekhon *et al.* (2008) reported that application of 6 t/ha rice straw mulch increased the yield of hybrid chilli (*Capsicum* sp.) by 2.4 t/ha in Punjab. Rice straw mulch could be useful in potato (*Solanum tuberosum* L.), which is a cash crop and widely grown in north western rice-based cropping system (NWRCS) belt. Kar and Kumar (2007) reported a potato tuber yield of 14.9 t/ha in plots receiving 6 t/ha rice straw mulch as against a tuber yield of 11.2 t/ha from the plots receiving no mulch. Kumar *et al.* (2008) reported from Bhubaneshwar that application of 1 kg/m^2 rice straw mulch increased the yield of turmeric (*Curcuma longa* L.) by 29% over no mulch (control). In China, rice straw is recommended as mulch in citrus orchards (Liu *et al.* 2014) and is recommended for apple orchards in cold dry region (Zhou *et al.* 2014). Apple growers in Himachal Pradesh and Uttarakhand could use rice straw mulch in the years, when precipitation or snow fall is low. Further, after its use as mulch in fruit orchards, the material can be used for packing the fruits, making rice straw a doubly benefitting material. However, the quantities of rice straw that can be used as mulch in vegetables and orchards would be rather small in comparison to total production and would demand transport and storage. Nevertheless it is a good use of rice straw.

Compost making: Organic food market in India is increasing at the rate of 25–30% per annum; from US$ 0.36 billion in 2014 it is expected to increase to US$ 1.3 billion in 2020 (Economic Times 2015). With the increase in demand for organic food, organic farming is catching up and farm compost/vermicompost is in high demand. Rice straw is fairly suitable for composting and a number of technologies involving cellulolytic organisms with or without finely ground phosphate rock are available (Singh and Nain 2014, IISS 2015, Shukla *et al.* 2016). Rice straw is also good for making vermicompost (Reddy and Okhura 2004, Shak *et al.* 2014). At least the smallholder farmers in NWRWCS belt should take advantage of this opportunity and start making and marketing compost/vermicompost.

Mushroom cultivation: Rice straw is a well-known substrate for culturing paddy straw mushroom (*Volvariella volvacea*) in India (Ahlawat and Tewari 2000; Thiribhuvanamala *et al.* 2012) and for Oyster mushrooms (*Pleurotus ostreatus or P. sajor-caju*) in China (Zhang *et al.* 2002, Yang *et al.* 2013) in and other Asian countries (EETC 1998).

Transport to fodder deficit states: Probably the best way to manage surplus rice straw in NWRWCS is supplying it to bordering states short of animal feed. Rajasthan, a bordering state of NWRWCS belt has an annual fodder demand of 68.81 Mt as against an availability of 51.54 Mt, showing a deficit of 17.27 Mt (Chand *et al.* 2015). This is very close to 18.7 Mt or rice residues burned in Punjab (Table 1). Animal deaths due to shortage of fodder deficit have been reported from Rajasthan even in recent times (Poddar 2017).

Rice straw is poorly palatable (Singh *et al.* 1995), since it is not as clean as wheat straw, which is harvested in dry season (temperatures 35°C or above in April–May). Rice grows under partly flooded conditions and the rice stalks gather a lot of mud and the straw gets spoiled on storage. Cattle in the rice growing regions do not have a choice and are used to consuming rice straw, which is the common animal feed in Asom, West Bengal, Jharkhand and part of Bihar (Saud *et al.* 2011). Similarly, cattle and other animals even in other regions, who have no choice, will consume it. Even camel can be fed with rice straw (Farid *et al.* 2010). It may be brought out that rice straw is richer than wheat straw in protein and several minerals (Table 2) including zinc, the deficiency of which in animals has received considerable attention in recent years (Oberleas and Harland 2008; Brugger and Windisch 2016). However, it has high silica (SiO_2) content (5.5–19.6%) (Widystuti and Abe 1989) as against 2.3% in wheat straw (Dodson 2011). Silicon is considered essential for normal growth of rice (Prasad and Power 1997) and silicon imparts resistance to diseases and pests (Singh *et al.* 2005). Widystuti and Abe

Table 2 Comparative values (g/kg) of some constituents in rice and wheat straw

Constituent	Rice straw	Wheat straw
Crude protein	40–42[a]; 39–57[b]	24–36[a]; 23–228.7[d]
Ash	189[a]	61[a]
Silica	130[a]	31[a]
Ca	2.4[a]	3.2[a]
P	0.9[a]; 0.7–2.1[b]	0.8[a]
K	13.2[a]; 17.8–37.0[b]	11.8[a]
Mg	1.2[a]	0.9[a]
S	1.3[a]; 0.7–1.0[b]	1.4[a]; 2.0–2.6[d]
Zn	0.04–0.1[b]	0.029–0.039[c]

Source: a. Theander and Aman (1984); b. Shivay *et al.* (2015); c. Shivay *et al.* (2008); d. Shivay *et al.* (2016).

(1989) reported that for each 1% increase in silica content, digestibility of rice straw decreased by 0.88%. Nevertheless, digestibility of rice straw is reported to be 40–50% in cattle, buffalo, sheep and goat (Prasad *et al.* 1991). As a contrast digestibility of wheat straw by goats and sheep was reported to be 52–71% (Brown and Johnson 1985).

What is really needed is a sincere effort by the State/Central Governments and some non-governmental organizations (NGOs) to bail, transport and store the rice straw at different points in Rajasthan for use, when needed. Indian Railways must provide enough carriages and special trains for this purpose, since trucks and road transport are not enough to take care of such a huge task in a short span of 2–3 weeks. Rice straw can be easily stored in open compounds.

Biochar: The environmentalists have come up with the idea of making biochar from surplus biomass. Biochar is a high-carbon fine grained residue produced by pyrolysis (thermal decomposition) of biomass in the absence of oxygen (preventing combustion). The products of pyrolysis are: biochar (at temperatures 400–500°C) and bio-oil or bio-fuel and syngas at temperature 700°C and above (Gaunt and Lehmann 2008). High temperatures produce syngas. Some mobile units are also available for biochar production (Badger and Peter 2006). Typical yields of pyrolysis are: 60% bio-oil, 20% biochar and 20% syngas. Bio-fuel and syngas can be used for driving vehicles under certain conditions. Biochar is recommended as a soil amendment for carbon sequestration and mitigating climate change (Lehmann *et al.* 2006, Wolf *et al.* 2010). When incorporated in soil, it helps in improving its physical and chemical properties (Glaser *et al.* 2002) leading to higher productivity (Jeffery *et al.* 2011). Making of biochar has been specially recommended for tropical regions, such as, in Brazil, where *slash and burn* is widely practised to deforest the land for agricultural purposes. Switching from *slash-and-burn* to *slash-and-char* farming techniques in Brazil can decrease both deforestation of the Amazon basin and carbon dioxide emission, as well as increase crop yields. *Slash-and-burn* leaves only 3% of the carbon from the organic material in the soil, whereas *slash-and-char* can keep up to 50% of the carbon in a highly stable form (Lehmann *et al.* 2006). Biochar can sequester carbon in the soil for hundreds to thousands of years, like coal and it is estimated that sustainable use of biochar could reduce the global net emissions of carbon dioxide (CO_2), methane, and nitrous oxide by up to 1.8 Pg CO_2-C equivalent (CO_2-C_e) per year (12% of current anthropogenic CO_2-C_e emissions; 1 Pg=1 Gt), and total net emissions over the course of the next century by 130 Pg CO_2-C_e, without endangering food security, habitat, or soil conservation (Lehmann *et al.* 2006). Nevertheless, it is high energy requiring technology and how far it can be useful in connection with managing surplus rice straw in the north-west India needs to be carefully examined.

Industrial uses

Ethanol or biofuel production: Rice straw can potentially produce 205 billion liter bioethanol per year in the world, which is about 5% of total of consumption (Belal 2013). Rice straw contains 51–74% carbohydrates (32–47% cellulose, 19–27% hemicelluloses), 5–24% lignin and about 18.8% ashes. The carbohydrates include 41–43.4% glucose, 14.8–20.2% xylose, 2.7–4.5%, arabinose, 1.8% mannose and 0.4% galactose (Roberto *et al.* 2003). The lignin acts as a physical barrier and must be removed to make the carbohydrates available for hydrolysis. Therefore, some pre-treatment is ~~a~~ necessary to separate lignin from the carbohydrates, before hydrolysis. The pre-treatments include: milling and grinding, pyrolysis, high-energy radiation, high pressure steaming, alkaline or acid hydrolysis, hydrogen peroxide treatment, hydrothermal treatment, steam explosion, wet oxidation and biological treatment such as enzyme or microbial conversion (Fan *et al.* 1982, McGinnis *et al.* 1983, Olson and Hahn-Hagerdahl 1997, Kovacs *et al.* 2009, Soni *et al.* 2010). Mostly fungi are used for degradation of celluloses and hemicelluloses and a number of these have been reported to be effective. These include: *Acremonium* spp., *Chaetomium* spp., *Trichoderma reesei, Trichoderma viride*, *Penicillium pinophilum*, *Phanerochaete chrysosporium* (*Sporotrichum pulverulentum*), *Fusarium solani*, *Talaromyces emersonii*, *Trichoderma koningii*, *Fusarium oxysporum*, *Aspegillus niger* and *Rhizopus oryzae* in the cellulose degradation process (Bhat and Bhat 1997; Belal 2013). At Hisar, commercial cellulose along with 3 strains of yeast, namely, *Saccharomyces cerevisiae* HAU 1, *Pachysolentan nophilus* and *Candida sp*. were tested individually and in combination (Goel and Wati 2016). All the three strains were effective in ethanol production, which varied from 5.3 to 24.94 g/L, depending on fermentation and timing; the combination of *S. cerevisiae* HAU 1, *P. tannophilus* was most effective.

Production of ethanol from rice straw has a great potential in India (Singh *et al.* 2016). India's first 2G or cellulosic ethanol demonstration plant with a capacity of 10 tonnes/day came into operation at Kashipur (Uttarakhand) in 2016 (Press Trust of India, April, 22, 2016).

Paper production: The domestic consumption of paper in India is 16 Mt/year of which 2 Mt/year is imported and by 2024-25 it is expected to rise to 23–36 Mt/year (Indian Paper Mills Association, January 2017, via internet). Thus, despite digitization, paper demand in India is going to increase. As regards, per capita paper consumption, it is 57 kg/year in India, 75 kg/year in China, 156 kg/year in Europe and 224 kg/year in USA (Ranjan Parida February 2, 2017 via internet).

Bulk of the paper is made from the wood from forest; however, India has only 23.65% forest cover and cannot afford any further deforestation. Deforestation is not only an Indian, but a global concern (Lawrence 1999, Van der Warf and Petit 2002, Williams 2006). An earlier study in India showed that the forest wood raw material for paper making decreased from 84% in 1970 to 43% in 1994, while the use of agricultural based non-wood raw materials increased from 9% to 32% during the same period (Gupta 1994). Paper Industry is thus forced to utilize agricultural waste products, such as, rice and wheat straw, bagasse from sugar factories, jute fibre etc. (Jahan *et al.* 2009) and even grasses, such as, *Ipomea carnea* and *Cannabis sativa* (hemp) and green manure legume *Sesbania aculeata* (Dutt *et al.* 2004). Cellulose is the major component and the length and width of cellulose fibres decides the quality of paper that can be made from it. Average length (mm) and width (µm) of pulpwood fibres from different sources is reported to be: softwoods (pines, firs etc.) 3.0–4.2 mm (length) and 28–35 µm (width); hard woods (*Eucalyptus*, poplars etc.) 0.9–1.2 mm and 10–35 µm; sugarcane bagasse 1.8–3.0 mm and 20–30 µm and cereal straws ~ 1.5 mm and 8–18 µm and (Peel 1999). Cereal straws thus, have the lowest length and width of cellulose fibres. In addition, rice straw has high silica content and it requires special processing and the paper made retains more moisture (Subramanyam *et al.* 2004, Kaur *et al.* 2017). Another major problem with rice and wheat straws is their low bulk density and even after bailing, it requires a lot of space in transport and storage. Nevertheless, globally crop straws make up about 50% of the non-wood raw material for making paper (Dutt *et al.* 2004) and with the increasing paper demand in India, the country's paper industry is going to use the rice straw.

Rice straw-jute mattresses

To utilize the coconut waste coir, Kerala has developed a big industry of coir mattresses in India (Coir Board, Ministry of Micro, Small and Medium Enterprises (MSME), Government of India). Rice straw mattresses are used in Japan and China and low cost rice straw making machines are available. It is high time someone starts manufacturing and marketing rice straw mattresses. To keep the price low these mattresses should preferably be covered by a thin jute cloth, which will also help the ailing jute industry, which is at low due to plastic bags having taken over jute bags for packing fertilizers and other materials (Pandey 2016). Rice straw mattresses will be a boon for below poverty line (BPL) people in India and to night shelter houses in big cities like New Delhi, where people sleep on cold ground in bitter winter. Rice straw-Jute mattresses will also permit night shelter houses to make 2/3 tier sleepers, which will allow accommodating more people in the shelter houses. Interestingly, once the rice mattresses have lived their life, the waste straw can still be used a feed in areas where there is shortage of animal feed or it can be used for making compost, the demand for which is increasing in organic farms in India.

Epilogue

After reviewing the available management options to alleviate the menace of rice straw burning, two new ones are suggested. These are: Ministry of Cottage Industries, Government of India needs to examine the possibility of setting up of a cottage industry to manufacture rice straw mattresses in Punjab. Ministries of Agriculture and Railways, Government of India and State Governments of Punjab and Rajasthan, need to explore the possibilities of bailing, transporting and marketing the surplus rice straw in Punjab as an animal feed in Rajasthan. It may need roping in interested NGOs.

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