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Ecofriendly Management of Paddy Crop Residues for Sustainable Environment and Development

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Abstract:

The world-wide mechanization leads to large amount of rice crop residue or stubbles production. The management of rice (paddy) crop's post harvested residue is done by burning, incorporation/ amalgamation, surface retention, mulching, bailing and direct removal. The farmers prefer burning of residue in field because it is cheap and less time consuming process. But it causes air pollution, smog and addition of toxic particle into the environment leads to poor air quality and hazy floating clouds. Despite some advantages like killing deleterious pests and clearing weeds from the field, the burning leads to loss of nitrogen up to 80%, phosphorus 25%, potassium 21%, sulfur 60%, soil organic matter (SOM) and increases air pollution and CO_2 concentration. The incorporation of post harvested crop residues in soil by using available agricultural implements causes immobilization of inorganic nitrogen (N_2). It also affects soil temperature, moisture, bulk density and pH. Therefore, Governments and scholars together regularly preparing and amending several policies to not to burn paddy crop residues and promoting management of post harvested paddy crop stubbles by environmentally safer ways. The ecofriendly methods for residues management provides a new dimension for the application of post harvested residues as bedding material for cattle, fodder (treated with NaOH, NH_3, Urea, lignolytic fungi and enzymes to reduce the silica content), packaging material, fuel, biogas generator, and in paper production, mushroom cultivation, and bio-thermal power plants, for sustainable environment and development. Paddy crop residues are used as an alternative fuel source in thermal plant for electricity generation in Malaysia. The microbial degradation of crop residues in the soil can be accelerated using different amendments (paddy straw + 5% cow dung slurry, 5kg ha^{-1} *Trichoderma harizianum*, 5kg ha^{-1} *Pleurotus sajor*, nitrogen fixing and phosphorus solubilizing microorganisms in the soil) for the ecofriendly development of crop yield. Thus, sustainable use and management of paddy crop residues proved beneficial for farmers, society as well as environment by enhanced economy, soil fertility and reduced pollution level.

Keywords: Paddy crop residues, Stubble burning, Ecofriendly management, Sustainable development, Incorporation, Mulching, Bailing, Microbial degradation.

INTRODUCTION

The one-half of the world population, together with East and Southeast Asia, is exclusively dependent upon rice as a staple food, (95% of the world's rice is eaten by humans). The cultivated rice plant, *Oryza sativa* is an annual grass of the family Gramineae. It grows to about 4 feet in height with long and flattened leaves. The panicle or inflorescence of the paddy plants is made up of spikelets bearing flowers that produce the fruit or grains. The earliest archaeological evidence comes from central and eastern China, reflected as the place of origin but distributed world-wide with civilization. The plant is cultivated on submerged land in the coastal plains, tidal deltas, and river basins of tropical, semitropical, and temperate regions except upland rice varieties. The seeds are sown in prepared beds, and 25-50 days old seedlings that has been enclosed by leaves are transplanted to the field submerged under 5-10cm of water (Singh et al., 2017a,b). The harvested rice kernel, known as paddy, or rough rice, is enclosed by the hull, or husk. The milling usually removes both the hull and bran layers of the kernel, and a coating of glucose and talc that occasionally applied to give the kernel a glossy finish. The rice which is processed to remove only the husks, are called brown rice. The brown rice is containing about 8% protein and traces of fats. It is an excellent source of thiamine, niacin, riboflavin, iron and calcium among rice. The rice which is milled to remove husks and bran as well is called white rice. It is greatly reduced in micro and macro nutrients. The white rice forms a major portion of the diet now a day therefore, it is a great risk of beriberi to societies depend up on white rice, a disease due to deficiency of thiamine and minerals. The hulls are used for fuel, packing material, industrial grinding, fertilizer manufacture, and in the manufacture of an industrial chemical called furfural. The straw is used for feed, livestock bedding, roof thatching, mats, garments, packing material, and broom straws. The international scientific effort to diminish the threat of world hungers by producing improved strains of numerous food crops in 1960s, the so-called Green revolution. The principal rice-producing countries are China, India, Japan, Bangladesh, Indonesia, Thailand, Myanmar, Vietnam, Brazil, South Korea, Philippines and United States. A glimpse of world-wide estimated production of rice in yesteryear is presented in Table 1. However, the estimated production in India is summarized in Table 2. The global rice production and trade in 2017-18 are to be decrease by 0.41% and 0% respectively over previous year. The world-wide consumption is also anticipated to up about 0.20% in 2017-18 (Gina, 2013; Stockton and Robert, 2018).

Table 1: World-wide production, trade, consumption, and carry over stock of rice (in million tons).

Particulars	2016-17	2017-18	2018-19
Production	487	486	493
Trade	47	46	47
Consumption	487	487	493
Carry over stock	123	123	123

Source: International Grains Council (IGC)

Table 2: Production, trade, consumption, and carry over stock of rice in India (in million tons).

Particulars	2016-17	2017-18	2018-19
Opening stock (beginning of the crop year)	18.18	16.31	18.18
Production	109.7	111.52	111.52
Total available stock	127.88	127.83	129.7
Trade	11.54	11.08	6.28
Consumption	100.49	100.93	98.59
Carry over stock	16.30	14.45	24.83

Source: Department of Food & Public Distribution (DoF & PD), Department of Commerce (DoC), Directorate of Economics & Statistics (D&ES), Department of Agriculture & Cooperation (DAC)

PADDY STUBBLE

Stubbles or residues are the post harvested and threshed consolidated part of plants left in the field. These materials at a time have been regarded as unwanted constituents that necessitates disposal. But recently it has been progressively comprehended that these are important natural resources for sustainable environment and development and recommended, to not to be treated as waste. The managed processing and recycling of crop residue has the advantages of converting the surplus farm residues into useful products for fulfillment of nutritional requirements of field crops. It also conserves the soil's physico-chemical conditions (Powel and Unger, 1997) and improves the overall ecological balance of the crop production system (Mandal et al., 2004). Sum of $350x10^6$kg yr^{-1} residues produced from paddy and wheat in India. Out of that, wheat and rice crop residues constitute about 27% and 51% *w/w* respectively (Lal and Krimble, 2002). Qualitatively it contributed to soil 2.604 million tons of $N+P_2O_5+K_2O$ (Tandon, 1996) in ratio as 0.61% N, 0.18% P_2O_5 and 1.38% K_2O_4 (Singh and Singh, 2001). An estimate showed that about 10tons ha^{-1} crops may remove 730kg NPK (N, Nitrogen; P, Phosphorus; K, Potassium) from the soil that is often not returned to the soils (Gupta et al., 2002). It is supposed that, if these residues are not returned, may lead to mining of soil for major nutrients and leading to net negative balance as well as multi- nutrient deficiencies (MNDs) in crops. Therefore, it is one of the prompt reasons for declined productivity in the rice-wheat cropping system. Thus, there is an imperative need to accomplish the residues of these crops for sustainability and stability of the system and mankind.

MANAGEMENT OF POST HARVESTED PADDY RESIDUES

The preeminent technique of paddy stubble or residue execution or management is dependent upon the time of crop harvesting or disposal, weather, condition of soil, financial budget of farmer, convenience and availability of tool or equipment etc. There are various ways for management of post harvested crop residues are burning, incorporation, surface retention, mulching, bailing for domestic or industrial fuel, composting, direct seeding, bio-char or gasification, as fodder and direct removal from field (Fig. 1).

Figure 1: A glimpse for post harvested paddy crop residues management alternatives.

a. Burning of post harvested rice crop residues

The conventional way for residue management is direct removal of post harvested parts of the crop from field by traditional method. The stubble of paddy is removed from field for use as cattle feed/ fodder and other purposes. The introduction of mechanized harvesting techniques promoted farmers for burning of large quantities of crop residues left in the field. Because of the larger size of stubble after mechanical harvesting that interfere with tillage and seeding operations for the subsequent cropping. The open burning of stubble in the field responsible for the loss of nutrients, soil organic matter (SOM), flora and fauna of crop ecosystems and enhancement of air pollution and health risk (Fig. 2). The large populations of farmers chop-off the rice stubbles with a stubble shaver followed by drying of residues and ultimately complete burning of stubbles to facilitate timely planting of wheat leading to all kinds of environmental pollution (Biederbeck et al., 1980). Thus, single choice is burning despite the large losses (up to 80%) of nitrogen (Raison, 1979.), 25% of phosphorus , 21% of potassium (Ponnamperuma, 1984) and 4-60% of sulfur (Lefroy et al., 1994). The burning practice of paddy residues also causes substantial air pollution and killing of advantageous soil insects and microorganisms. The burning may kills soil borne injurious pests and pathogens (Abrol et al., 2000). Thus, it is an urgent need for farmers to ecofriendly management of rice residues (about 5-7tons ha^{-1}) and still avoids burning and overcome the problems for planting next crop. Therefore, scientists of the Rice-Wheat Consortium (RWC) are continuously motivating farmers to cut down the burning of crop residues, which aggregate to as much as 10tons ha^{-1} (Nuttall et al., 1986; RWC-Summit, 2003). The burning of rice residue has also bring about in an amplified potassium content in the surface soil and excellently eradicates large volumes of biomass and helps control weeds as well as variety of pests and diseases (Ponnamperuma, 1984). However, research designates that the advantages of burning are counterbalance by the disadvantages, including nutrient loss, depletion of soil organic matter (SOM), and decline in the presence of beneficial soil biota (Mandal et al., 2004). The paddy residues or stubbles burned in the field also grounds greenhouse gas emissions (GHGE), and emission of other gaseous pollutants such as SO_2, NO_3, HCl and, to some extent dioxins and furans (Jenkins et al., 2003; Oanh et al., 2011,). The burning of post harvested paddy crop residues is also an important source of aerosol particles such as coarse dust particles (PM_{10}) and fine particles ($PM_{2.5}$) (Miura and Kanno, 1997; Chang et al., 2013), affecting local air quality and the radiation budget of the earth (Engling et al., 2009; Hayashi et al., 2014). Due to the aforesaid explanations and exorbitant health risks and the rice crop residues, straw or stubbles burning poses pollution to the environment, the open-field burning of post harvested paddy crop residues has been banned or is strictly regulated in agricultural regions across the world.

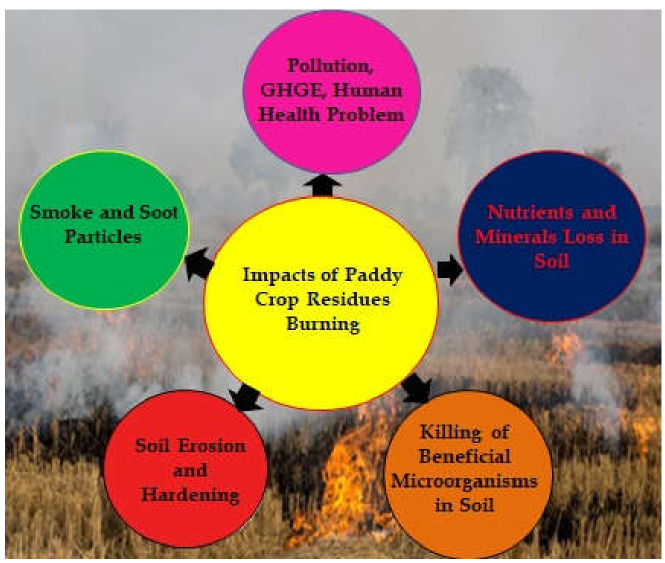

Figure 2: The effects of open field burning of post harvested rice crop stubbles or residues.

b. Incorporation and amalgamation of rice crop residues in soil

Incorporation of the remaining part of paddy crop into soil may return most of nutrient and help to conserve the quality of the soil. The straw or stubbles are incorporated with soil augments its fertility, so, there will be less need of fertilizers for subsequent crops. In comparison to residue removal, the incorporation has been found to increase available phosphorus, exchangeable cations (K, Ca and Mg) and base saturation (Geiger et al., 1992; Steven et al., 1993). The decomposition of residual parts of the crop can be accelerated by the application of an innovative and efficient integrated machine, Yanmar India (A machine with multiple functions like combine harvesting, chopping rice straw, and spraying *Trichoderma* into chopped straw). Incorporation of rice straw into paddy soil is an effective strategy to manage rice straw, but doing it inadequately and ineffectively may result in a decline in production efficiency (Dobermann and Fairhurst, 2002; Mandal et al., 2004; Singh et al., 2005) and an increase in greenhouse gas emissions (GHGE) (Sander et al., 2014). Most of the farmers, however, do not exercise incorporation because of the slow decomposition rate of rice straw, which may not be completed within the short reversal time of less than three weeks before the subsequent cropping system. The yesteryears report at International Rice Research Institute (IRRI) showed that about 3,500kg carbon dioxide equivalent (CO_2-eq) per ha emitted and converted from CH_4 and N_2O in a rice crop season with straw incorporation. This amount of GHGE was almost 1.5 times greater than the amount emitted from the practice of rice straw removal. This has led scholars to conduct research on accelerated decomposition rate of rice stubbles (Goyal and Sindhu, 2011; Ngo et al., 2012; Singh et al., 2018a,b).

c. Shallow tillage

In past years most of the farmers follow dry shallow tillage method as conventional exercise for the management of post harvested residues. They perform the tilling at 5-10cm depths to incorporate crop residues in soil that is it responsible to increases the soil aeration and soil fertility (Dobermann and Fairhurst, 2002). The shallow tillage of dry soil is to be carried out up to 2-3 weeks after harvesting. The shallow tillage of dry and moist soil can increase the carbon (C) content of agricultural field soil by aerobic decomposition of crop residues (approximately 50% of carbon content within 5-6 weeks), thus minimizing negative effects (phytotoxicity) of anaerobic decomposition products on subsequent crop. This method of management may also responsible for improved soil aeration, reoxidation of iron, nitrogen and phosphorus contents in soil. On the other hand it may reduce weeds growth during fallow period, limited irrigation during land preparation, and smaller CH_4 emissions compared to straw incorporation.

d. Surface retention and mulching

The surface retention of residues assists in shielding the fertile surface soil against wind and water erosion. The large quantities of stubbles remaining on the surface often hints to machinery failures, thus affecting sowing of seeds of the subsequent crop. Therefore, farmers usually follow this method where no- till or conservation tillage practices are prevalent. The surface retention of some or all of the post harvested residues may be the best option in various situations. The crop residues decompose slowly on the surface, enhancing the organic carbon and total nitrogen in the top 5-15cm of soil, while protecting the surface soil from erosion (Rasmussen and Collins, 1991). The retention of paddy crop residues on the surface might increase soil NO_3 concentration by 46%, nitrogen uptake by 29%, and yield by 37% compared to burning method (Bacon and Cooper, 1985). The surface retention and mulching of residues, however, provides habitat for both harmful as well as useful organisms in one hand, and on the other it provides carbon substrate for heterotrophic nitrogen fixation, increases microbial activity, soil carbon and nitrogen, and reduce fertilizers requirement for rice. The decomposition of post harvested crop residues and release of nitrogen to soil can be accelerated when this is treated with urea and applied during field preparation (Singh and Charaya, 2010; Singh et al., 2015a,b).

e. Baling the straw

The collection and assortment of rice straw encompasses three main tasks namely: picking up of rice straw materials, compressing them into bales, and hauling them to storage or processing area. In these actions, a collecting machine (baler) is the chief compacting entity. The baler occasionally consist of the other two operations like picking up of straw and hauling of baled material that depend on operational circumstances and determinations. A fixed baler with only a compaction unit can be used appropriately in collecting straw disposed from paddy threshers. On the other hand, a traveling baler (self-propelled or pulled by a tractor) is proper for collecting rice straw left in the field by combine harvesters.

f. No tillage

The no tillage method for stubbles management involves the direct drilling of subsequent crop seeds in rice residues the residual moisture is efficiently utilized for seed germination and saving of irrigation water. The revolution of tillage across the Indo-Gangetic plains of South Asia may be one of the best prospects to accomplish sustainability of rice-wheat cropping system (Gupta and Rickman, 2002). No tillage technology for wheat as a subsequent crop of after rice demonstrated better in terms of saving of fuel, cost of cultivation and progressing sowing time than rotavator and conventional tillage methods (Chauhan, 2011, 2012; Chauhan et al., 2012). The facilitated drill operations can be attained through the attached combines with flappers for shredding of rice residues and to spread them more homogeneously. The modifications in the available no-till drill machines available in the province that could be applied for wheat crop seeding in existence of loose residues. In mono-cropped areas, the post harvested residues of the previous rice crop are left on the surface to decompose for several months before wheat cropping. However, some farmers run through double cropping or multi-cropping and avoid burning of crop residues, therefore, to overcome the problems, they practiced no-till system, and an inverted-T coulter or a chisel opener is attached to a normal seed drill for the placement of seed and fertilizer in one pass (Gupta et al., 2002). The no tillage profits instantaneous advantage of residual moisture from the previous rice crop, and cuts down on the subsequent irrigation requirements and reduced water use during cropping (Gupta and Rickman, 2002).

g. Removal

The straw removal can involve scraping loose straw, baling in small bales and road siding the bales, and/ or conventional hiring of manpower for the entire process. The straw was cut low using combine and kept in a windrow that may simply be baled and hauled. However, some farmers may opt to wrapping the stubble, thus generating more tonnage of baled straw but at a higher total cost. The removal methods became more complex after the evolution of bale formats either round, square, large or small, etc.) may depend upon the ultimate use. The uses of rice straw ranged from bedding in horse stalls and chicken coops to serving as an ingredient in bricks, wallboard and other building materials (Steven et al., 1993).

EFFECT OF RESIDUE MANAGEMENT ON SOIL QUALITY

The soil quality is the capacity of a specific kind of soil, to function with in natural or managed ecosystem boundaries, to sustain plant and animal productivity. To maintain or enhance soil, water and air quality may support human health and habitation. The soil physical properties namely: soil moisture, temperature, aggregate formation, bulk density, soil porosity and hydraulic conductivity can be affected by the pattern employed in management of post harvested crop residues. The greater amounts of rice residues on the soil surface reduce evaporation rates and increased duration of first-stage drying tend to improved soil moisture content than bare soil. The soil temperature is affected through the mechanism of change in radiant energy balance and insulation by surface residues (Hay, 1977; Unger and McCalla, 1980). The crop residues may increase soil hydraulic conductivity and infiltration by modifying mainly soil structure, proportion of macropores, and aggregate stability (Mando et al., 1996). The hydraulic conductivity under straw-retained direct drilled treatments was 4.1 times greater than that of straw-burnt conventional tillage treatments (Chan and Heenan, 1993). The soil physical properties were improved as a result of incorporation of rice straw. The Farmyard manure (FYM) and rice straw + FYM cured field had advanced percentage of water stable masses (>0.25 mm diameter), higher mean weight, higher porosity, lower bulk density, higher available water capacity and greater hydraulic conductivity of saturated soil. The enhancement in physical properties joined with nutrients from FYM and rice straw resulted in steadily superior grain productivity than burning (Bhagat and Verma, 1991).

The yesteryears research finding showed that when the organic residues are returned to the soil, then soil pH can be increased due to the decarboxylation of organic anions on biological or ecofriendly decomposition of post harvested crop residues by microorganisms. The increase in the pH after burning was generally attributed to ash accretion as ash residues are generally dominated by carbonates of alkali and alkaline earth metals but also contain variable amounts of silica, heavy metals, phosphates and small amounts of organic and inorganic nitrogen (Raison, 1979). The rice crop residues are highly siliceous in chemical nature and it has been reported that the silica rich plant material has the potential of transforming the electrochemical properties of acidic soils that reduces phosphorus fixation; improved base retention and increase the soil pH, hence the soil of field may shifted into acidic soils. The crop residue influence soil pH through the accumulation of CO_2 and organic acid during decomposition. A sharp decline in soil pH of flooded soils due to application of rice straw has been recorded by Mandal et al (2004).

The paddy crop residues provide substrate for the growth and activities of soil microorganisms. The nitrogen immobilization can last 4-6 weeks in optimum temperature and moisture conditions. Soil microbial biomass (SMB) can be influenced by the residue management exercises. The decline in microbial biomass was reported after residues burning. Residue incorporation leads to more microbial activity than residue removal or burning (Raison, 1979; Kanwar and Tisdall, 1992.). A negative microbial balance has been observed in rice-wheat system at low nitrogen levels in north India (Beri et al., 1992). The decreasing nutritional value in the soil affect the sequestration of carbon in the soil and lead to decline in soil fertility (Azmal et al., 1997). I was noticed an increase in microbial populations due to application of rice straw (Nugroho and Kuwatsuka, 1992) and simultaneous application of rice straw and NH^{4+} to soil under upland conditions increased the number of denitrifies and soil fungi in India than in soil where residues were either burnt or removed (Beri et al., 1992).

SUSTAINABLE MANAGEMENT OF PADDY STUBBLES

The agriculture farming of rice produces two major types of remainders are straw and Husk. These residues of paddy crop having striking potential in terms of energy. Even though the technology for rice husk employment is well demonstrated and established in industrialized countries of Europe and North America, such technologies are so far to be introduced in the developing world on commercial scale. The significance of rice husk and rice straw as an attractive source of energy could be gauged after a report (Zafar, 2018). The one ton of paddy produces 290kg rice straw that can produce about 100kWh of power equal to 2400kcal/kg calorific value. Likewise one ton of rice may produces 220kg of rice husk is equivalent to 410- 570kWh electricity with calorific value 3000kcal/kg and moisture content about 5-12%. The rice husk is one of the most productive agricultural residues in rice producing countries around the world. It is one of the chief by-products from the rice milling process and constitutes about 20% of rice by weight that consists mainly of ligno-cellulose and silica, is not utilized to any significant extent and has great potential as an energy source. The rice husk can be used for power generation through either steam or gasification route as well as for diesel engines in a dual fuel operation. It also provides electricity and serves as a way to dispose of agricultural waste, thereby increasing local incomes and reducing the need to import fossil fuels. The technology employed for rice straw combustion boilers are used in combination with steam turbines to produce electricity and heat. The by-products are fly ash and bottom ash, which have an economic value and could be used in cement and/or brick manufacturing, construction of roads and embankments, etc. The straw fuels have showed to be extremely difficult to burn in most combustion furnaces, especially those designed for power generation. The principal issue concerning the use of rice straw and other herbaceous biomass for power generation is fouling, slagging, and corrosion of the boiler due to alkaline and chlorine components in the ash (Zafar, 2018). The surplus straw from agriculture may be used for a number of useful purposes such as livestock feed, fuel, building materials, livestock bedding, composting for mushroom cultivation, bedding for vegetables such as cucumber, melons etc. and mulching for orchards and other crops.

The rice straw can be used to generate fuel, heat, or electricity through thermal, chemical, or bioprocesses. However, there are still barriers to using rice straw for energy conversion. The high silica amount of rice straw requires component processing machines, such as the chopper or grinder, to wear out. The content of volatile matter in rice straw is comparatively higher than wood and much higher than the coal, whereas the fixed carbon is significantly lower than the coal. Similarly the ash content in rice straw is much higher than that of wood and coal was reported by Jenkins et al. (1996;

Jenkins, 1998). The augmented content of ash, alkali, and potassium in rice straw causes agglomeration, fouling, and melting in the components of combustors or boilers (Baker, 2000; Jeng et al., 2012). The lignin walls in rice straw hampers digestibility, which reduces the efficiency of bio-energy conversion processes (Klass, 1998).

A study on the feasibility of establishing a rice straw power plant at the International Rice Research Institute (IRRI) was recently conducted by the Institute and Enertime Company (Guillemot et al., 2014). The proposed system uses an advanced technology for biomass combustion, which is the Organic Rankine Cycle (ORC). An ORC turbo-machine generates electricity using thermal energy from thermal oil (or saturated steam) that is generated from the combustion of biomass in a boiler. The vaporized working fluid fuels the turbine, which then sets the asynchronous generator in motion. The disadvantage of having a relatively low efficiency is compensated by the fact that the ORC process can deal easily with varying temperatures, which is an advantage when dealing with difficult fuels like rice straw. The rice straw can be used in biogas production by anaerobic digestion (AD). The anaerobic digestion is a potential small-scale energy conversion technology for rice straw which is used to generate biogas fuel for cooking, heating air for drying, or for generating electricity. A case study on using rice straw for small-scale anaerobic digestion was conducted by Can Tho University, Vietnam in 2013. The rice straw was mixed with manure from livestock at a rate of 50–80% and production biogas was enhanced with methane content of 50–55%. There were still many problems encountered during the study, such as rice straw sticking to the digester and the unstable gas generation. A small-scale batch-AD system using rice straw is being studied at the Punjab Agricultural University (PAU) in India. This system includes the main components of a batch-digester and a gas holder or reservoir. Both these components are built using cement materials. This AD technology was piloted in 2012, with five models distributed around Punjab.

The rice straw is used for various purposes in mushroom industry at different level. The mushroom cultivation is a moneymaking agri-business attempt that produces food from rice and wheat straw while simplifying the proper clearance of this by-product in an ecofriendly way. The paddy straw mushroom, *Volvariella volvacea* is considered to be one of the stress-free mushrooms to cultivate because of its short incubation period of two weeks (Reyes, 2000). The application of rice straw in mushroom production can enhance the productivity about 5–10% (Zhang et al., 2002; Ngo, 2011). Hence, the husbandry of the oyster mushroom *Pleurotus sp*. and paddy straw mushroom, *Volvariella volvacea* propose an on-farm technology for the bioconversion of poor quality straw into nutritious food products. The one of the carbon rich substance, biochar can be produced from rice starw. Biochar is a carbon rich product, used as soil improvement to develop soil productivity, carbon storage, and filtration of percolating soil water. The biochar can be produced by the thermal decomposition of organic materials, paddy straw, stubbles or biomass under a reduced supply of oxygen at temperatures from 500-700°C (Lehmann and Joseph, 2009).

Paddy straw are used in production of hydrochar by an advanced carbonization technology, called hydrothermal carbonization (HTC), has been developed in recent times. The HTC of lignocellulosic biomass (Paddy straw) is a process that entirely breaks down the plant cell wall and allows the speedy conversion of biomass into a carbon-rich and lignin-like product (hydrochar). Hydrochar has a substantially higher heating value than the raw material (Ling-Ping et al., 2012). The carbon sequestration in the solicitation of biochar helps to minimize the threat of climate change caused by GHGs emissions in the atmosphere (Gaunt and Lehmann, 2008). Regardless of its huge prospective, the meting out biochar needs energy for carbonization and money for shipping of rice straw and biochar products. Therefore, it is still a need for research that demonstrates the practicability of biochar production from rice straw in terms of energy balance and economic benefits.

The use of rice starw for cattle feed is most common practice in in India and Southeast Asia. A report mentioned that on average, the daily maximum intake of rice straw by ruminants is about 1.0-1.2kg/100 kg live weight (Devendra and Thomas, 2002). The rice straw in its raw and un-supplemented form has little amounts of digestible energy and essential nutrients for developing and growing cattle. Out of the parts of rice straw, the stems are more digestible and comparatively have lower silica content than leaves, therefore, leaves considered poor feed for animals (Drake et al., 2002;

Singh and Sidhu, 2014). For that reason, the rice crop should be cut as close to the ground as possible if the straw is to be fed to livestock. Application of nutrient amendment is often done by treating the rice straw with urea, is harmless and more applied to use than anhydrous or aqueous ammonia. During or after amendment, the urea suits a source of nitrogen, of which rice straw is deficient. The digestibility of cellulose in rice straw and leaves can be improved by using sodium hydroxide or ammonia. Singh et al. (2017c) have also reported that uses of urea and single super phosphate (SSP) for accelerated degradation of lignocellulose.

The effective recycling of paddy straw through microbial degradation may responsible for the enhanced grain and straw productivity of paddy farming as well as other subsequent crops. The rice straw is one of the potential sources of instant organic substance available in the field itself. The rice straw contains a good amount of plant nutrients and one ton of rice straw is reported to contain 0.5-0.8% N, 0.16-0.27% P_2O_5, 1.4-2.0% K_2O, 0.05-0.10% S and 4-7% Si on dry matter basis (Dobermann and Fairhurst, 2002). It was reported that, the paddy straw consist digestible organic matter (51.5%), cellulose (47.2%), lignin (3.0%) and soluble phenolic compounds (4.3%) soil is an abode of microorganisms capable of degrading lignocelluloses material of dead plants. The fungal species are predominately cellulose and lignin decomposing biota that is converted into simple sugars and phenolic acids (Singh and Charaya, 2003; Man and Ha, 2006; Singh et al., 2016a), which further supports a host of other microbes in the soil (Jayadeva et al., 2010; Singh and Charaya, 2003; Singh et al., 2015c). The paddy straw is also being used in conjunction with wheat straw in 40:60 ratio for paper production. The sludge can be subjected to bio-methanization for energy production. The technology is already operational in some paper mills, which are meeting 60% of their energy requirement through this method. Paddy straw is also used as an ideal raw material for paper and pulp board manufacturing. More than 50 % pulp board mills are using paddy straw as their raw material (Kumar et al., 2015).

The paddy stubbles are used as bed material for cattle during winters is been a regular, conventional and traditional practice in most of province of India. The paddy residues as bedding material assists in improving milking ability in terms of quality and quantity contributing to relaxed sleep of cattle warmth, udder health and leg health (Kumar et al., 2015). The paddy straw used for bedding could be subsequently processed for composting. It was reported that about 1kg of paddy straw can absorb 2–3 kg of urine from the animal shed. Moreover, it can be composted by alternative methods on the farm itself through application of amendments and microbial organisms (Singh et al., 2016b,c). The residues of rice from of one hectare gives nearly 3.2tons of manures as it possess plentiful of nutrients as farmyard manure (Indian Agricultural Research Institute; 2016).

GOVERNMENT POLICIES ON PADDY RESIDUE MANAGEMENT

There are many more suggestions and recommendations required to stop the progress of prevalent practices leading to pollution and wastage of potential resources (IARI, 2012, 2016; Penalty Imposed by Burning act, In Haryana 2016). These are:

i. Provision of incentives to farmers for not burn paddy residues in the open.
ii. Anticipation of assistance (seeds, fertilizers, pesticides, electricity, diesel, etc.) provided to the farmers if they persist with the defaults.
iii. Maximum lands cover facilitation using conservation agriculture (CA) practices and enforcement of rice-wheat cropping system.
iv. Targeting crop residue to generate renewable energy for improvement of air, soil quality, reduces climate change effects and global warming.
v. Establishment of energy plants encouraged to utilize the surplus crop residue for energy generation in a sustainable, eco-friendly and cost effective way.
vi. Crop residues should be categorized as recycling process. Their use in agriculture field should draw subsidy like any other mineral fertilizers get.
vii. Provide higher subsidy rate to farmers who retain their residue in the field as crop residues are a supplement to chemical fertilizers.
viii. Free electricity should not be provided as the same policy has led to installation of high powered tube wells that are responsible for over drawing of water from deep inside the earth.

ix. *In situ* management in the field, fast decomposition by chemical or biological means and straw mulching by mechanical means must be promoted.
x. The machines like use of double disc coulters, zero tillage and happy seeder would help in mulching the crop stubble.
xi. Paddy residue could be collected from the fields and may be used for formulating useful products viz. making compost, organic manure and bio-char to improve soil health, soil fertility and gasification as an alternate fuel for power generation.
xii. During harvesting of paddy crop, the crop stem may be cut from the root level itself. This practice would require a suitable reaper cum harvester that should be developed using indigenous techniques.
xiii. Use of high horse-power segment of tractor for deep cutting may be facilitated to small farmers on cooperative basis.
xiv. Intimating small farmers to understand the prominence of chaff making out of the paddy residues is of greater advantage.

Besides of the aforesaid policies, the State Governments may be given full assistance for promotion through awareness by way of demonstration, training and capacity building. The higher slabs of subsidy may be given to farmers for uses of machinery. More custom hiring centers may be promoted for easy reach of costly equipment for small and marginal farmers at village level. Inspire the farmers for adoption of various residue management operations, support for funding R&D/technological up-gradation to States as well as for the strengthening of Agricultural Engineering Extension Services (AEES), a Special Directorate of Agricultural Engineering (SDAE) also constituted.

CONCLUSIONS

The half of the world population, including East and Southeast Asia, is chiefly dependent upon rice as a staple food, and 95% of the world's rice produced is consumed by humans. The cultivated paddy plant, *Oryza sativa* is an annual grass flora of the Graminae family. The stubbles or residues are the post harvested and threshed consolidated part of rice plants left in the field. These left over parts instantly considered as undesirable constituents that demands disposal. By the study, it is supposed that, if these residues are not returned to the field soil, may lead to mining of soil for major nutrients and leading to net negative balance as well as multi- nutrient deficiencies in subsequent crops. Therefore, it is one of the main factors for declined productivity in the rice-wheat cropping system. Hence, there is a commanding requisite to accomplish the residues of these crops for sustainability and stability of the system and mankind by ecofriendly and sustainable management. The outstanding technique of paddy stubble or residue implementation or management is dependent upon the time of crop harvesting or disposal, weather, condition of soil, financial budget of farmer, convenience and availability of tool or equipment etc. There are various ways for management of post harvested crop residues are burning, incorporation, surface retention, mulching, bailing for domestic or industrial fuel, composting, direct seeding, biochar or gasification, as fodder, cattle bedding and direct removal from field. The world-wide mechanization leads to large amount of rice stubbles production now a day. The farmers prefer burning of residue in field, because of cheap and less time consuming process for the preparation of field to subsequent cropping. But it is questionable, objectionable and hazardous for human health and ecosystem due to air pollution, smog and addition of toxic particles into the environment leads to poor air quality and hazy floating clouds. Despite some compensation like killing of damaging pests and clearing weed from the field, the burning leads loss of minerals, nutrients (nitrogen up to 80%, phosphorus 25%, potassium 21%, sulfur 60%) and soil organic matter (SOM). The environmentally safer or ecofriendly methods of stubbles management results in immobilization of inorganic nitrogen (N_2), reduced mining of minerals, recycling, balancing pH, moisture, porosity, density and humification. The accelerated decomposition of paddy crop residues by the application of microorganisms and inorganic and organic amendments resulted as the safest and Go Green Technology aspect for post harvested residues management. The ecofriendly methods for residues management affords a new dimension for the application of post harvested residues as bedding material for cattle, fodder, packaging material, fuel, biogas generator, paper production, mushroom cultivation, and bio-thermal power plants for electricity generation as well as for sustainable environment and development. Thus, sustainable use and management of paddy crop residues proved beneficial for farmers, society as well as environment by enhanced economy, soil fertility and reduced pollution level.

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