Chapter

Sustainable Biowaste Management in Cereal Systems: A Review

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Abstract

Among the field crops, cereals being the staple food for humans and feed for cattle, occupy 50.8 per cent of the cultivated land and contribute 52.5 per cent of the body calories. Cereals are the good source of carbohydrate, minerals, and dietary fibre for humans and animals. With the ever growing human population the agricultural production and agri-wastes are increasing across the globe. In Asia, Africa and Latin America, near about 66, 21 and 13 per cent of total estimated 2,060 Tg of biomass are generated every year. Burning has been the cheapest, simplest, easiest and quickest way of eliminating bulky unwanted biomass *in-situ* before raising of the succeeding crop(s). Rice, wheat, sugarcane and maize constitute 24, 23, 5 and 48 per cent of the global burnt residues. Although killing of problematic weeds, insects, and pathogens, and addition of valuable plant nutrients are the very basic objectives of this anthropogenic post-harvest residue management strategy but it releases noxious gases into the atmosphere polluting air and contributing to the global warming. Shorter sowing windows very often compel the farmers to remove crop residues through burning, especially in absence of alternative options for its productive and profitable disposal. Rising labour cost and their seasonal scarcity sometimes also insist the farmers to burn crop residues. However, stringent punitive actions have yet failed to curb such open burning in many countries in absence of the farmers' friendly and financially viable options of crop residue management. In this chapter, attempts have been made to elucidate various sustainable crop residue management strategies in cereal systems.

Keywords: biofuel, biomass, bio-waste, cereal system, residue management

1. Introduction

In this 21st century, feeding the teeming millions is the greatest challenge before us. The green revolution of 1960s although could alleviate the growing demands for food to a great extent but at the cost of food quality and environmental health. Long term applications of chemical fertilizers in crop production systems have been resulting in unpredictable reduction in yields and increase in the cost of cultivation. However, with the shrinking land, the burgeoning competition for water, land and other resources from non-agriculture sector might aggravate agricultural production in the near future. Hence, intensive farming through enhanced cropping intensity has been the way out for mitigating the population driven demands for food, feed, fodder and fibre without much scope for recycling of the agricultural wastes in majority of cases. For raising of multiple crops in a year the farmers burn farm residues *in-situ* in absence of appropriate sustainable recycling technologies that ultimately pollute the environment and increase carbon foot print. Globally, annual plant waste production is estimated at around 5.5 billion tons in 2013 that accounts for 13 per cent of the greenhouse gas emission from agriculture sector [1]. Some of these wastes are although used as cattle feed and organic manure but a plenty are still available for alternative uses. Hence, it is high time to adopt the best possible technologies for recycling of bio-wastes from crop fields for harnessing the nutrients and green energy as well.

Near about half of the habitable land on this planet is under agriculture [2]. Of the 1,600 million hectares of cultivated land [3], 50.8 per cent is occupied by cereals [4]. About 52.5 per cent calories for humans are available from cereals at global scale [4] with major contributions from corn (1,116.34 million tons), wheat (764.49 Mt), rice (495.78 Mt), barley (156.41 Mt), sorghum (57.97 Mt), oat (22.83 Mt) and rye (12.17 Mt) [5]. Cereals are special not because of their uses as staple food but due to production of ethanol and cattle feed in many advanced nations. However, in many underdeveloped and developing countries this precious wealth has not yet been fully utilized [6]. It is high time to use this precious waste from crop field in judicious manner not only to recycle the carbon and sequester it back into the soil but also to harness clean and green energy out of it through appropriate measures.

2. Types of agricultural biowastes

Farm residues can be broadly divided into crop residues, and wastes from livestock and aquaculture depending on the activities carried out. Field crop residues are plant parts left over in the field without much attention unless otherwise is immediately followed by a succeeding crop. Crop residues can be put under

Agro-industrial wastes	Chemical composition (%)						References
	Cellulose	Hemi-cellulose	Lignin	Ash (%)	Total solids (%)	Moisture (%)	
Sugarcane bagasse	30.2	56.7	13.4	1.9	91.66	4.8	[8, 9]
Rice straw	39.2	23.5	36.1	12.4	98.62	6.58	[8]
Corn stalks	61.2	19.3	6.9	10.8	97.78	6.40	[8]
Sawdust	45.1	28.1	24.2	1.2	98.54	1.12	[8, 10]
Sugar beet waste	26.3	18.5	2.5	4.8	87.5	12.4	[8]
Barley straw	33.8	21.9	13.8	11	_	_	[9]
Cotton stalks	58.5	14.4	21.5	9.98	_	7.45	[9]
Oat straw	39.4	27.1	17.5	8	_	_	[10]
Soya stalks	34.5	24.8	19.8	10.39	_	11.84	[11]
Sunflower stalks	42.1	29.7	13.4	11.17	_	_	[11]
Wheat straw	32.9	24.0	8.9	6.7	95.6	7.0	[9, 10]

Table 1.
Chemical composition of agri-industrial wastes [7].

agricultural and agri-industrial categories. Agricultural residues remaining after threshing and separation of the economic plant part(s) can be of (a) processed residues such as husks and hay and (b) field crop residues such as stalks and stubbles. Husk and hay are often left over in the crop field due to engagement of crop combined harvesters and axial flow threshers. Sometimes, the distance between crop field and farm house plays a decisive role in stacking of hay and husk in the crop field after threshing. That apart, farm mechanization in many developed countries has also shifted from animal driven to fossil fuel based farm power and thus excluding the need for gathering feedstock in the haystack. Furthermore, the risk of fire in haystack due to storage of dried crop residues can also not be eliminated completely. Hence, many farmers are not interested in transporting such bulky by-products from crop field to farmhouse. In mono cropped areas, natural weathering and decomposition by soil organisms usually degrade the field crop residues but the residue management challenge is mostly under sequential cropping.

Agri-industrial residues in the other hand are derived from industries such as peels of potato, orange, and cassava; bagasse and molasses of sugarcane; oilcakes of groundnut, mustard, sunflower, sesame, soybean and coconut; and husks and bran of rice [7]. Huge quantities of organic wastes are produced by food and vegetable oil processing industries every year- but if left untreated and unutilized, may cause environmental pollution as well as human and animal health issues. A representative chemical analysis report of few agri biomass are depicted under **Table 1** for comparative studies.

3. What is agricultural burning?

Agricultural burning is the intentional setting of fire in the open field for preparation of the land for the next crop or killing the weeds and insect pests. Natural causes such as lightening and planned anthropogenic fire account for only 10–20 per cent of the total open burning across the globe [12]. Burning of agricultural residues is different from fire in forests, grasslands or any vegetation.

4. Drivers of open burning of crop residues

Slash and burn cultivation has been a traditional system in agriculture to clean up vegetation on virgin land and cultivate crops for a few years before shifting to a new area. Tradition, timing, ease, weather and location factors encourage the farmers to burn residues in many regions. Burning is the cheapest and quickest way of eliminating unwanted thrash from the crop fields. Addition of plant nutrients and killing of pathogens, insects and weed species also influence decision to burn residues *in-situ* [12]. Moreover, shorter sowing window for one or two weeks compels the farmers to remove crop residues through burning, especially in absence of alternative options for its productive and profitable disposal. So also, rising labour cost and their seasonal scarcity insist the farmers to burn residues *in situ*. However, absence of stringent punitive action very often fails to curb such open burning of crop residues.

5. Status of agricultural burning in the world and India

Burning of crop residues *in situ* has been a traditional practice in many countries as it is the cheapest, easiest and quickest way of getting rid of such bulky materials immediately before raising the succeeding crop. It also checks weed and pest infestation in the succeeding crop. More so over, it does not require much technical skill and expertise in doing so. This practice was widespread and popular across the globe until 1990s when many governments restricted open burning of crop residues. In China and England, stubble burning is banned but in Australia, it is restricted to only need-based burning. In America and Canada, residue burning is still allowed in some counties and provinces. China, India and America are in the forefront of burning of crop residues followed by Brazil, Indonesia and Russian federation. Some African countries have top rated in the global ranking of intensive burning per hectare. Mexico and Tanzania are at the top position in intensive burning followed by Brazil, United States and Nigeria [12]. Globally, 24 per cent of the burnt residues are from rice, 23 per cent from wheat, 5 per cent from sugarcane and 48 per cent from maize [12]. An estimate in 1985 indicated burning of 2060 Tg of biomass in the developing world; of this, Asia, Africa and Larin America contributed 66, 21 and 13 per cent, respectively [13].

Large scale burning of paddy stubbles in Punjab, Haryana and western Uttar Pradesh in India in the month of late October and November every year is estimated to be 35 Mt. This practice is spreading to other parts of the country like wildfire due to the advent of precision farm-equipments that allow resowing with the minimum soil disturbance. The crop field is made ready for the succeeding zero till wheat crop by burning of straw and stubbles leftover in the field from the crop harvested by combined harvester. India generates around 500 Mt. of residues from rice, wheat, sugarcane, maize, millet and other crops every year [14] of which 142 Mt. are

Country	Agricultural waste generated (million tons/year)
Myanmar	19
Indonesia	55
Bangladesh	72
India	500

Table 2.
Agricultural waste generation in India and adjacent countries [15–17].

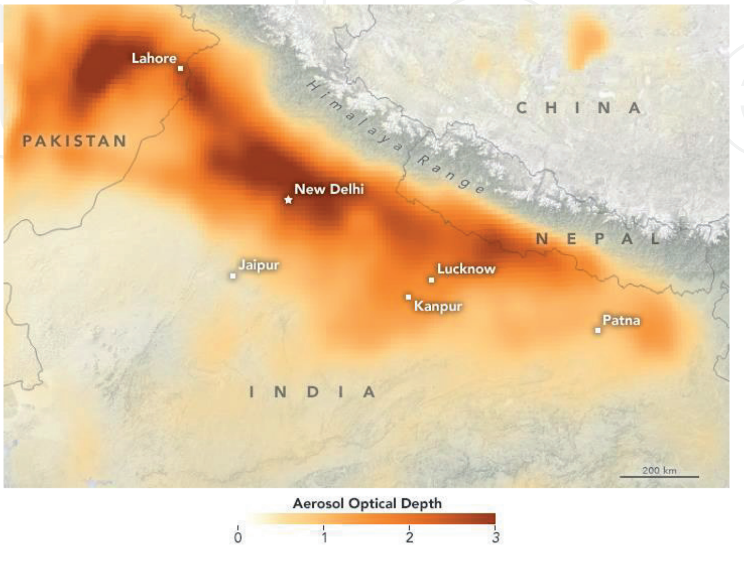

Figure 1.
NASA Earth Observatory image of the aerosol pollution in India, Pakistan and Nepal on 7 November 2017 [21].

leftover after fuel, fodder and industrial uses [15] and 92 Mt. are burnt every year across the country. **Table 2** compares the agricultural wastes generated in India and its adjacent countries which reveal that the volume of waste is far more than the total waste generated by other countries.

Near about 70 per cent of crop residues in India are cereals of which 34 per cent come from rice, and 22 per cent from wheat crops [14]. Estimation indicated burning of about 80 per cent of the total 20 Mt. of rice stubble in Punjab alone [14]. Whereas another estimate indicated 9.8 and 1.23 Mt. of rice residue-burning in Punjab and Haryana, respectively [18]. Burning of rice is more compared to wheat in the North West India as rice contains more silica (12–16 per cent vs. 3–5 per cent) which is not easily digestible. About 75 per cent of wheat straw is collected and stored as fodder. Rice stem contains lower silica than leaves and hence rice is to be cut as close to ground if used for feeding animals [19]. Management of rice straw is difficult compared to wheat due to shorter window for sowing of wheat and low temperature which compels the farmers to resort to burning during October–November every year [20]. Several major cities of North India—including New Delhi, Lucknow, and Kanpur—faced elevated levels of aerosol pollution [21]. The extent of aerosol pollution in India, Pakistan and Nepal region, mostly from crop residue burning, can be observed from the captured image of the NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) on Aqua satellite on 7 November 2017 (**Figure 1**).

6. Legal implications

Agriculture comes under the state list of the Seventh Schedule of the Constitution of India and hence, the State Governments have to take austerity measures against residue burning. Burning of crop residues is a crime in India according to the Air Pollution Act, 1981 and Section 188 of the Indian Penal Code [14]. Courts in India have banned open burning of crop residues and made provisions of penal actions by collecting fines from the errant farmers. In 2018, the national green tribunal (NGT) of India imposed penalty of Rs.2,00,000 on the Delhi government for not filing an action plan for incentives and infrastructural assistance against stubble burning [22]. Subsequently, the NGT asked the Delhi government to deposit 250 million rupees (INR) with the Central Pollution Control Board (CPCB) as performance guarantee [23]. Consequent up on Public Interest Litigation in M. C. Mehta vs. Union of India (order IA No.158129 and 158129 of 2019 in writ petition (C) No.13029 of 1985) [24] an ordinance dissolving the Environment Pollution (Control and Prevention) Authority has been passed by the Indian government to set up a new Commission with over 20 members to regulate pollution in Delhi-NCR region [25]. In this ordinance, the Ministry of Law and Justice has made provisions for imprisonment up to five years or with fine up to rupees one crore or both for abrogation of the rule/provisions or order/directions of the Commission [25]. The Hon'ble Supreme Court of India has also realized the need for incentives to small and marginal farmers those abiding to the rules by paying a sum of Rs.100 per quintal of crop residues [24].

In the United States, agricultural burning policy has been formulated to monitor open burning of agricultural wastes and weeds for fire, weed and pest control adjacent to the crop field so as to allow regulated burning in small scale to maintain agricultural production but without impairing public health and air quality parameters. The agricultural burning managers are authorized to monitor burning at state, local and tribal level and no burning should be carried out without approval from the competent authority [26].

Figure 2.
Open burning of rice straw before land preparation for second rice crop in Bargarh district of Odisha.

7. Environmental impacts of open crop residue burning

Cereals generate huge agriculture as well as agri-industrial wastes across the globe. If not managed judiciously then in long run, that may lead to the environmental pollution and global warming. Open burning of agricultural wastes is detrimental to both environment and human health. Poisonous gases like carbon dioxide (CO_2), carbon monoxide (CO), sulfur oxides (SO_x), nitrogen oxides (NO_x), methane (CH_4) and particulate matters ($PM_{2.5}$ and PM_{10}) are released into the atmosphere (**Figure 2**). An estimate reveals burning of crop residues release 149.24 Mt. of CO_2, 9 Mt. of CO, 0.25 Mt. of SOx, 1.28 Mt. of PM and 0.07 Mt. of black carbon [14]. The situation is austere in India due to intensive rice-wheat cropping system [27]. One ton of stubble burning leads to the loss of 5.5 kg nitrogen, 2.3 kg phosphorous, 25 kg potassium and 1 kg sulfur besides organic carbon [14]. As per an estimation, stubble burning releases substantial quantity of heat that elevates the surface temperature from 33.8 to 42.2°C killing soil fertility maintaining biota [14]. The population of microorganisms, earthworms and beetles get reduced drastically in the upper layer of soil affecting the rate of soil formation. The population of beneficial insects reduces drastically and the enemy inset population increases to a great extent.

Stubble burning increases the particulate matters in the air creating pulmonary diseases (COPD), bronchitis, lung capacity loss, emphysema, cancer, etc. [27] in humans and animals besides irritation in eyes, nose and throat [14]. The Ministry of Earth Sciences' monitoring agency SAFAR in Delhi has estimated the share of stubble burning in $PM_{2.5}$ pollution as high as 36 per cent [28]. In Punjab (India) alone an estimated 760 million rupees (INR) is spent annually to alleviate stubble burning related diseases [27]. The Energy and Resources Institute (2019) reported 5 million deaths in South Asia in 2012 due to air pollution which was around 22 per cent of the total deaths in the region [27].

8. Agri-waste management options

The crop stubbles and agricultural wastes, if managed properly, could generate profits to the farmers and protect the environment from the severe pollution as well. Some of the available alternative management practices include soil incorporation, compost and biochar making, thermal power generation, pulp and

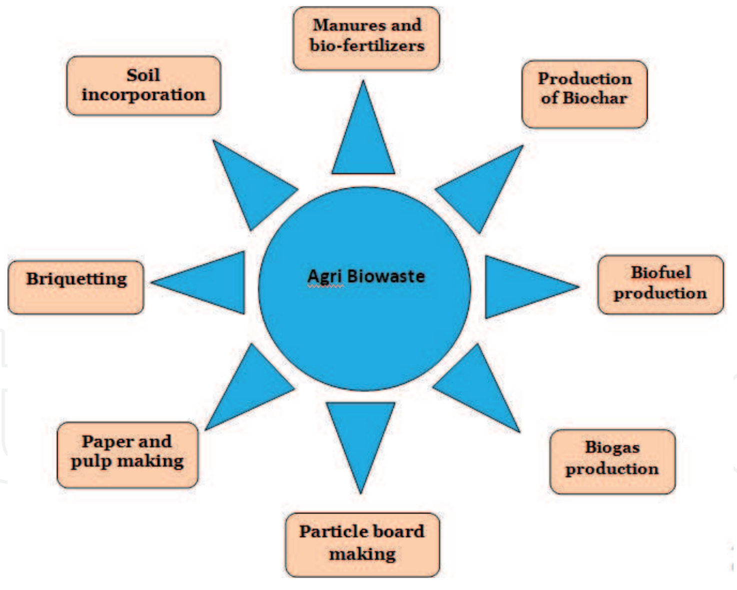

Figure 3.
The management of agricultural wastes.

paper manufacturing, cement brick making, mushroom production, or biofuel production (**Figure 3**) [27]. However, most of the farmers in North India are not yet fully aware of many such alternatives that lead to *in-situ* open burning of crop residues.

8.1 Residue incorporation

Since long back, *in-situ* incorporation of crop residues has been the simplest, easiest, quickest and cheapest technique of agri-waste management next to open burning. Rotavators, soil turning or mould board ploughs, and puddlers are most effectively and widely used these days to shred down larger plant parts and to incorporate into the soil. Rotavator, a low cost precision implement of around 0.1 to 0.12 million rupees (INR) with the working efficiency of 5–6 hectares per day is suitable for both *kharif* and *rabi* crops. Residue incorporation improves soil bio-physicochemical properties and increases crop productivity as well. Rotavator readily and economically incorporates biomass of weeds and green manuring crops as manual removing or chopping and mixing would cost higher [29].

Incorporation of maize crop residues in clayey Andosol in Ethiopia at 6 Mg per hectare for consecutive three years indicated 22–52 per cent reduction in penetration resistance in top 5–10 cm soil, 39–57 per cent lower evaporative flux and elevated (22 per cent) macro and meso porosity [30]. After 17–18 cycles of residue incorporation in rice-wheat system, the mean weight diameter (MWD) of water stable aggregates, bulk density (BD), and water holding capacity (WHC) of soil increased [31].

Crop residues on the soil surface protect the soil from erosion, act as mulch that keep the soil cool and improves soil tilth [32]. In the USA, near about 40 per cent cropland are under no till farming with minimal investment and more than 10 M ha has been sown under cover crops with basic objectives to incorporate residues *in situ* and regenerate crop without tillage [32]. In Indo-Gangetic plain of India, mulching with the preceding rice residues has been a good agronomic practice in absence of tillage that increases soil organic carbon in long run, WHC, water use efficiency and profitability in wheat [33]. Surplus residues of the wheat crop can also be incorporated into the next rice crop with improvement in physical, chemical and biological properties of the soil [33].

Rapid reduction in the soil organic carbon (SOC) across the globe due to intensive monocropping without biomass incorporation has been the greatest challenge before us in this 21st century. With the changing climate and advent of chemical farming, the role of soil in maintaining the ecosystem services has brought forth so many issues and if left unattended may end in peril. About 29 and 60 per cent increase in carbon stocks in silt-loam and clayey soil in top 20 cm soil whereas the effect was seen in the upper horizon only in sandy soil has been reported [34].

Residue incorporation needs energy and time. Extra N at the time of incorporation is needed for preventing temporary immobilization of nutrients (mostly N) and correcting high C:N ratio of substrates [35]. The rate of immobilization lasts for four to six weeks under favorable soil type, moisture and temperature conditions and management factors. Starter N dose of 15 to 20 kg ha^{-1} could very well increase the yield of succeeding wheat or rice crop without any adverse effect on the next crop. Wheat yield depression of 0.54 to 0.08 t ha^{-1} has been reported with soil application of 60 and 180 kg N ha^{-1}, respectively [36]. However, release of greenhouse gases such as CO_2 and CH_4 that leads to global warming can also not be set aside. Incorporation of cereal straw (having wide C:N ratio) with green manure (having narrow C:N ratio) facilitates decomposition before rice transplanting. Wheat yield reduction in initial 2 to 3 years of rice straw incorporation a month before wheat planting were although reported but in subsequent years, straw incorporation had no significant adverse effect on wheat yield. Rather, wheat yield increased by 0.6 t ha^{-1} over 2.91 t ha^{-1} with straw removal [36]. In contrast, yield advantage in wheat sown after 3 weeks of rice straw incorporation was reported in clay loam soil but not in sandy loam soil. After incorporation of rice straw, about 10–20 per cent of it is assimilated by the rice crop itself, 10–20 per cent is lost to the atmosphere through various pathways and 60 to 80 per cent is immobilized in soil [36]. Nutrient up to 40 kg ha^{-1} could be harnessed through incorporation of 10 t of rice straw 4 to 5 weeks before transplanting of rice in the main field [36]. Residue incorporation increases soil N and available P and K [36]. Long-term comparative studies on wheat crop residue incorporation versus inorganic fertilizer application in India showed significantly higher yield in rice and wheat through inorganic nutrition but in subsequent years, the yield under residue incorporation plus inorganic fertilizer was at par with sole inorganic one. In the fourth year, the combined mode of nutrition out-yielded the inorganic one [36].

8.2 Composting

Composting is the method of aerobic or anaerobic decomposition of organic solid wastes. It is not new; rather, it has been the oldest practice of recycling the plant nutrients in the soil. Small scale backyard composting is a usual practice in many developing and underdeveloped countries. Up till now, composting had not gained the status of agriculture industry. But with the gaining popularity of organic farming or eco-farming, its demand has increased these days. Its bulkiness, low nutrient content and high labour requirement are the major challenges in undertaking such organic waste composting projects. However, on-site composting without transportation of crop residues could be the befitting answer for maintaining soil fertility and sustaining crop production in long run. Compost improves biophysiochemical properties of the soil while the need for synthetic fertilizers and plant protection measures could be eliminated completely. Its application improves nutrient uptake and cycling, soil microbial activity and biodiversity, and deficit moisture stress conditions as it regulates soil pH, improves soil texture, structure and aggregates, increases water holding capacity, cation ion exchange capacity and soil biodiversity [37]. It reduces soil erosion, protects crop against soil borne diseases, increase carbon sequestration and reduce compaction [37]. Composting releases heat during thermophyllic stage that kills most of the pathogens, insect larvae and eggs, and weed seeds [37].

On decomposition, biomass turns into a humus like substance called compost. The rate of compositing depends on the type of substrate and microbes, ambient air temperature, moisture level, aeration, presence or absence of toxic chemicals and heavy metals and surface area of the residue. Aerobic decomposition releases CO_2 and H_2O while anaerobic composting releases CH_4.

$$C_6H_{12}O_6 + 6O_2 \rightarrow CO_2 + H_2O + \Delta E\left(3{,}880\ \text{kJ mol}^{-1}\right) \quad \text{Aerobic decomposition}$$

$$C_6H_{12}O_6 + 2H_2O \rightarrow CO_2 + H_2O + \Delta E\left(405\ \text{kJ mol}^{-1}\right) \quad \text{Anaerobic decomposition}$$

The total carbon and nitrogen (C:N) ratio of the substrate is important for deciding the rate of decomposition of organic matter. Higher the ratio then longer is the duration for degradation. The desired C:N ratio for decomposition is 24:1 [38]. This 24 part of carbon is divided into 16 parts for energy and 8 parts for microbial body as most microbes have a body with C:N of 8:1 [38]. When C:N ratio exceeds 24 then microbes explore other available sources with moderate ratio. Immediately after addition of biomass, the microbial population increases resulting in immobilization i.e. transformation of N from available form to non available form. When these microbes die and decompose, the N mineralizes and becomes available for crop removal. Cereals have higher C:N ratio than legumes and hence, legumes decompose faster [38]. The **Table 3** depicts C:N ratio of different agricultural crops.

The C:N ratio changes with stage of the crop. It also differs in different plant parts and with the progression of decomposition [38]. Cereals take longer period for composting that can be reduced by mixing with legumes or supplementing nitrogenous fertilizers. In compost pits cereal substrates are put in alteration with the vegetables or pulse residues. For example, rice straw and grass put together resulted in the highest rate of vermicompost production at the end of 120 days cycle compared to either of these substrate composted separately [39]. Similarly, [40] suggested addition of food stuff with rice bran for getting superior vermicompost with average C:N ratio of 20.85, 183.3, 16.86 and 15.16 from 1:1, 1:2, 1:3 and 1:5 ratio of rice bran: food stuff, respectively.

Crop residues are used for vermicomposting, enriched composting, farm yard manure, etc. Vermicomposting is the biological degradation of substrates by combined action of earthworms and microorganisms. Windrows method of vermicomposting is popular and widely practiced by adding rice straw, animal manure, and

Name of crops	C:N ratio
Wheat straw	80:1
Rye straw	82:1
Oat straw	70:1
Rice straw	67:1
Corn stover	57:1
Legume hay	17:1

Table 3.
C:N ratio of different agricultural crops at harvest [38].

shredded banana trunks and maintaining the moisture at 60 per cent [41]. Tank, pit or heap method of vermicomposting can be followed as per convenience and quantity of available residues to be managed. Spent straw from mushroom farm containing C and N of 14.3 and 0.7 per cent can also be recycled through composting [41]. *Eisenia fetida* is the most widely used species of earthworm for vermicomposting in many parts of the world. However, *Lampito mauritii*, *Lumbricus rubellus*, *Eudrilus eugeniae* and *Perionyx excavates* are also inoculated depending on the purpose of composting, availability of culture and ecological conditions.

Unlike open burning, composting preserves essential plant nutrients and almost all nutrients remain inside the compost. Only the loss of N occurs in form of ammonia and nitrous oxide due to volatilization [42]. As much as 75 per cent of total N in manure is lost in form of NH_3 and 1.5 to 7.3 per cent in form of N_2O [43, 44]. Most composts do not contain more than 2 per cent N and its release depends on the C:N ratio, soil temperature, moisture and microbial activity [44]. Composts are better supplements for crop plants unlike most chemical fertilizers that are devoid of trace or micronutrients. The CHNS analyses of rice straw and its compost revealed increase in oxygen, sulfur and moisture but reduced total organic carbon, hydrogen and nitrogen [45]. Application of effective microorganisms (EM) to composting rice is reported to have increased macro and micronutrient content. The N, P and K content of the rice-compost is higher with EM and the Fe content was significantly higher without significant increase in Zn and Cu [46].

8.3 Production of biochar

Production of biochar or pyrogenic carbon was the age-old practice in the Amazonian river bank which was evident from the *Terra preta* culture to enrich soil and cultivate crops sustainably. Modern researchers are constantly looking for imbibing such technology to smother greenhouse gas emissions and increase carbon sequestration as well. The process of carbon sequestration needs higher residence time and resistance to chemical oxidation of carbon to carbon dioxide or methane [47]. Use of agricultural wastes for biochar-making could be a viable option in the era of massive deforestation and loss of habitats. Biochar is a porous fine-grained carbonaceous material released from thermo-chemical conversion of biomass called pyrolysis at relatively moderate temperature [48]. It contains carbon, hydrogen, oxygen, nitrogen, sulfur and ash. On its addition, the bio-physicochemical properties of the soil improve and crop yield enhances. Apart from agriculture-use, biochar is used in water treatment plant, food and cosmetic industry, metallurgy, construction industry and many more purposes.

Researchers have observed that the pyrolytic temperature of 400°C brings in high alkalinity, cation exchange capacity, high level of available P and exchangeable cation in rice straw biochar which is suitable for soil amendment and used as fertilizer [49]. At this temperature, rice straw biochar shows the largest Cu (II) absorption capacity (0.37 mol kg^{-1}) that is mostly of non electrostatic absorption [50]. Corn stalk biochar can also be used as efficient absorber of Pb^{+2} [51] and Cd^{+2} [52]. Continuous application of rice straw biochar and rice straw has positive influence on soil physicochemical properties with 26.9 and 70.2 per cent increase in total porosity and air permeability [53]. Its application increases soil microbial biomass carbon and nitrogen [53] and increases wheat productivity and accumulate P in grain [54]. Corn cob biochar is reported to have increased the pH, organic matter, soluble and available K in calcareous sandy soil [55]. Maize straw biochar application to soil reduced harmful bacteria diversity but selectively promoted community of functional bacteria population [56]. The C sequestration capacity of corn stalk (0.26) was increased to 0.64 to 1.0 on charring as resistance of char to decomposition prohibits C losses during charring [57].

8.4 Biofuel production

Plant residues contain cellulose, hemicelluloses and lignin with small fractions of sugars, pectin, protein, nitrogenous, lipids, tanins and inorganic materials [58]. Lgnin mostly provides the structural support and is almost resistant to chemical reactions and biological degradation compared to cellulose and hemicelluloses and thus resists fermentation [59–61]. In crop plants, the nonfood portion such as stalk, husk, straw, stover and bare corn cob contain lignocellulosic biomass. As in agriculture, cereals occupy the maximum area and production so also the largest quantity of such lignocellulosic materials. The residue management in cereal-cereal system such as in rice-rice and rice-maize/wheat is the biggest challenge before researchers. Very often the farmers opt for onsite open burning of the crop residues to get rid of huge biomass with higher lignocellulosic materials in it [62]. But with the advent of innovative green energy technologies, such so called wastes are now converted into precious biofuels to mitigate the growing demands.

Biofuels are produced through pretreatment of lignocellulosic materials by fungi, bacteria and enzymes that break down the lignin, a complex polymer and degrade cellulose and hemicelluloses to corresponding monomers and sugars for effective fermentation and fuel conversion [63]. The pretreatment is mostly chemical or biological but it could be mechanical and physicochemical too that result in increased surface area and porosity, and decrease in crystalinity. Biomass degradation results into ethanol, biodiesel, biobutanol, syngas, and woodtar/oil. The ethanol produced from crop residues is known as 2G bioetahol. Depending on the feedstock and process design, several by-products such as stillage, evaporator condensate and solubles, spent cake and/or distiller's grains are produced which can be used in agricultural amendment, civil construction or sanitary landfills. Stillage is a nutrient rich biodegradable material rich in both total suspended solids (TSS) and Chemical Oxygen Demand (COD) that requires significant processing for remediation. Lignin, a waste product from bioethaol plant is used for generating heat energy required for other processes and thus the final produce is in a form of ash. Ash is alkaline in reaction with significant quantities of Si, P, K, Ca, AL, Fe, and Mg in it which can very well be used in agriculture. In **Figures 4** and **5**, the harvested paddy straw is gathered by square baler and stacked in the collection centre at Thuapali village of Bargarh distract in Odisha, India as a pilot study programme under the direct supervision of the BPCL, India.

Figure 4.
Post harvest operation of square baler in farmer's field in Bargarh district of Odisha, India.

Figure 5.
Stacking of square bales of rice straw in stockyard in Bargarh district of Odisha.

8.5 Biogas production

Anaerobic digestion of biomass produces biogas, a renewable energy containing methane as primary constituent and a final solid nutrient rich residue. Stages of anaerobic digestion include hydrolysis, acidogenesis, acetogenesis and methanogenesis. In hydrolysis, the water splits into H^+ and OH^-. Larger polymers such as proteins, fats and carbohydrates breakdown to smaller monomers such as amino acids, simple sugars, and fatty acids in presence of an acid catalyst. In acidogenesis, acidogenic bacteria further break down organic matter still too large for methane production. Acetogenesis is the formation of acetate by acetogens for further breaking down of the biomass to a point from where methanogens can further act and degrade the remaining material to generate methane as biofuel [64]. Dried cereal crop residues should not be directly injected into the biogas unit rather mixing of animal dung in partial combination is preferable to increase the biogas efficiency. However, maize silage can be directly used for biogas production [65]. Biogas generation technology is older than biofuel production technology. The methane production potential of wheat straw is of 0.145 to 0.39 $m^3\ kg^{-1}$ and rice straw of 0.241 to 0.367 $m^3\ kg^{-1}$ [15]. By 2030, grasses and cereals could be the primary source of biomass for the biogas plants across the globe [66]. **Table 4** enlists the major composition of bio-wastes from major crops.

8.6 Particle/composite board making

Rice husk and cereal straw are used for making of particle boards. Rice husk is cleaned and cereal straw thus defibred into particles is mixed with rice husk

Source	Composition
Rice	Husk, bran and straw
Wheat	Bran and straw
Maize	Stover, husk, and skins
Millet	Stover

Table 4.
Residues produced from major crops [67].

at desired proportion and then blended with cashew nut shell liquid or cardanol phenol formaldehyde resin [68]. The mixture is spread into a mat or layer of uniform desired thickness and hot pressed like conventional method of particle board making [68]. Rice husk is 20 per cent of total rice produced which can be used as cheaper, lighter, denser, stronger, durable and more uniform substitute for conventional wooden and ply boards thereby protect against deforestation and environmental degradation. Because of high Si content rice husk is difficult to burn. Apart from rice husk, rice and wheat straw can also be used for making straw-wood particle composite boards and insulation boards. However, use of rice husk in comparison to bamboo for particle board making resulted in poor quality due to higher Si content in rice husk and non-availability of suitable blender for effectively binding rice husk [69]. Advance researches are still continuing to develop an efficient and effective adhesive for rice husk boards.

8.7 Paper making and packaging

Rice straw can be used as raw material for making quality paper. It contains lesser lignin compared to conventional wood and thus requires milder chemical pre treatment. Cheaper soda and soda-AQ methods are used for making paper in many developing countries but blending pollutes water by releasing more than 500 chlorinated compounds that are highly toxic, bioaccumulative and carcinogenic [70]. The graduates of IIT, Delhi have developed a pulp making process in a start up called Kriya Labs [71] that can be used in making paper, plates and cups [72].

Bio-Lutions India in Bengaluru purchases crop wastes from farmers and transforms them into biodegradable packaging materials for fruits and vegetables which can be degraded completely within three months [72]. Bio-plastics, derived from rice straw by mixing with starch, cellulose, glycerol and protein are ready to substitute the conventional plastic very shortly as it is readily biodegradable within 180 days of use compared to 500 years required for plastics to degrade [72].

8.8 Briquetting

The straw functions very well as bedding for animals such as horses. When briquetted, straw absorbs 5 times more fluid than normal straw for bedding. This minimizes the cleaning work in the stable, and creates a better environment for the animals. Furthermore, briquetted straw is useful for burning, and it is an excellent source of energy through generating heat, steam and electricity in conventional boilers or gasification plants.

9. Conclusion and future outlook

With the advent of modern scientific agricultural practices, the agriculture and agri-waste production have increased at exponential rates across the globe. Cereals, being the staple food for humans as well as feed for cattle, contribute the most to the pool of such agri-wastes. Sustainable management of crop residues, especially in cereal systems, has been the greatest challenge before us in this world with the ever burgeoning population, agricultural production and economic growth. Rice and wheat contribute the most to the agri bio-waste pool due to wider cultivation and large scale production. However, many countries in Asia, Africa and America, at present, have failed to cope up with the large volume of crop residues although a majority of these are used as fodder and fuel. In India, northern states such as Punjab, Haryana, and western Uttar Pradesh burn crop residues in the month of

October and November every year thereby releasing toxic fumes into the atmosphere that are very often drifted to the adjacent cities and states. Most of these residues are byproducts of wheat and rice. Small farmers usually resort to burning of crop residues as it is the inexpensive alternative in absence of technical know-how on any other better profitable and sustainable residue management or disposal opportunities.

Large scale burnings of crop residues shockingly increase air pollution and serious health issues. In the past few decades, the authorities have relentlessly tried to explore multiple waste management options to cater such unequivocal but perilous agri-wastes from the cereal systems. The possibilities of waste incorporation and decomposition through soil addition and composting are few preferred acceptable alternatives. Penal actions have also been provisioned against the errant promoters of open burning. In this line, in India, the National Remote Sensing Agency (NRSA) and Central Pollution Control Board (CPCB) have come together to monitor open burning of crop residues through aerial surveillance and to penalize farmers for doing so. However, continued air pollution in the month of November and December in spite of much touted successful, sustainable and effective actions against open burning has raised many eyebrows. Hence, efforts are being made to explore farmers' friendly and financially viable options of residue management such as composting, biochar making, biofuel and biogas production, particle and composite board making, paper manufacturing, etc. In many developed countries, 1G and 2G ethanol production have now gained momentum that use waste biomass judiciously for generation of liquid and gaseous fuels. Corporate social responsibility (CSR) funds are being allocated in many countries for conducting research and development on large scale profitable biofuel production. It is high time to develop national gas-grid line with the support of remote sensing and GIS tools to monitor and regulate biomass production and utilization. Community biomass collection centres could facilitate easy and speedy collection and back up storage of biomass for further residue management strategies. And importantly, the residue management options should involve environment, education, social, and economic sectors holistically in addition to agriculture and energy sectors beyond the disciplinary boundaries.

Conflict of interest

The authors declare no conflict of interest.

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