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Crop residues management in agro-environmental sustainability

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The advance tools and technologies in agriculture sector of have played a significant role in enhancement of crop yields and food security to most of the countries. However, long term sustainability of current agricultural system is at risk because of soil health deterioration, over use of natural resources and erratic climate patterns due to global warming. In recent years, high crop yields due to improved tools and technologies have resulted in huge quantities of crop residues (CRs) production annually. Burning of CRs is now a common practice at filed conditions causing soil health deterioration, air pollution, loss of agriculturally important soil microbial biomass diversity, etc. Residue incorporation results more microbial activity than residue removal or burning. Paddy CRs decomposition in anaerobic flooded soil conditions substantially increases green house gases emissions particularly methane. Therefore, appropriate sustainable management of huge amount of crop residues produced every year is need of the hour and assumes a great significance to the major agricultural producing countries. Appropriate management planning and environmental education would reduce the CRs burning practices and the related environmental, social and economical loss. In this communication, current concerns and possible options related to efficient management of CRs has been discussed. At present most of the developing countries including India, has challenging tasks to ensure food and environmental security. Hence the CRs, either partly or entirely can be used for agriculture conservation to country's food security, agriculture and environmental sustainability.

INTRODUCTION

Crop residues (CRs) have been defined as the part of the plant that is left in the field after harvest. Globally, it is estimated that the production of agricultural residues increased by 33 %, reaching 5 billion Mg during 2003 to 2013 (Cherubin et al., 2018). The Asian continent is the largest producer of crop residues, 47 % of the total, followed by America (29 %) Europe (16 %) Africa (6 %) and Oceania (2 %), (Figure 1). However, non availability of labour, high cost of residue removal from the field and increasing use of combines in harvesting the crops are main reasons behind burning of CRs in the fields. Burning of CRs causes environmental pollution, hazardous to human health, produces greenhouse gases causing global warming and results in loss of plant nutrients like N, P, K and S. Therefore, appropriate management of huge amount of CRs assumes a great significance in major agricultural producing countries.

Indian economy with gross domestic potential (16%) and nearly 65% of the population directly depends on the agriculture sector. India, having 15 different agro-climatic zones, experiences to cultivate both tropical and temperate types of crops. The Indo Gangetic Plains (IGP) is one of the largest cultivating areas with fertile lands, surrounding a large part of northern and eastern India, southern Nepal, parts of Pakistan and Bangladesh. The states of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal constitute the major part of the region, account for over 10 million ha in terms of growing rice and wheat crops. These two major crops together contribute more than 70% of total cereal production in India (around 27 Mha area of for wheat and about 40 Mha for paddy cultivation).

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In India, about 500 million tons (Mt) of agricultural CRs are generated every year (MNRE, 2009). Furthermore, it is assumed that to feed India's future projected population of 1.35 billion in 2025, agricultural production, especially that of rice and wheat (major staple foods), would have to certainly increase by about 25%. In India, the rice-wheat (RW) cropping pattern of the Indo-Gangetic Plains has contributed significantly in the food security. However, viability and sustainability of this unique cropping pattern is at risk due to the decline of soil fertility, over exploitation of natural resources and emerging adverse impacts of climate change. At the same time, high yields of the irrigated RW system have resulted in production of huge quantities of CRs. As a result the practice of rice straw burning at field sites is common in north-western parts of India causing soil nutrient losses and serious air quality problems.

It has been declared that after China, India is the world's largest paddy producing country. India produces about 98 million tons of paddies with approximately 130 million tons of straw. The data showed that about half of this total paddy straw produced each year is used as animal fodder. However, the rest is mostly burned in the fields and only a small amount is also applied by brick kilns, paper and packaging industry. Burning of paddy straw emits huge amount of trace gases like carbon dioxide, sulphur oxide, methane, carbon monoxide, nitrogen oxide and large amount of particulate matters, which creates severe human health and environmental problems. In India, these paddy CRs fires occur twice a year, after the autumn and spring crop harvesting. Last year, India's capital New Delhi experienced enveloped in a thick haze that was partially due to widespread burning of paddy CRs left over from the paddy harvest in Haryana and Punjab. According to the Delhi Pollution Control Committee, on October 31, 2017 it was monitored that the levels of particulate matters (PMs) less that 2.5 µ reached up to 700 µg per cubic meter in Delhi, more than 10

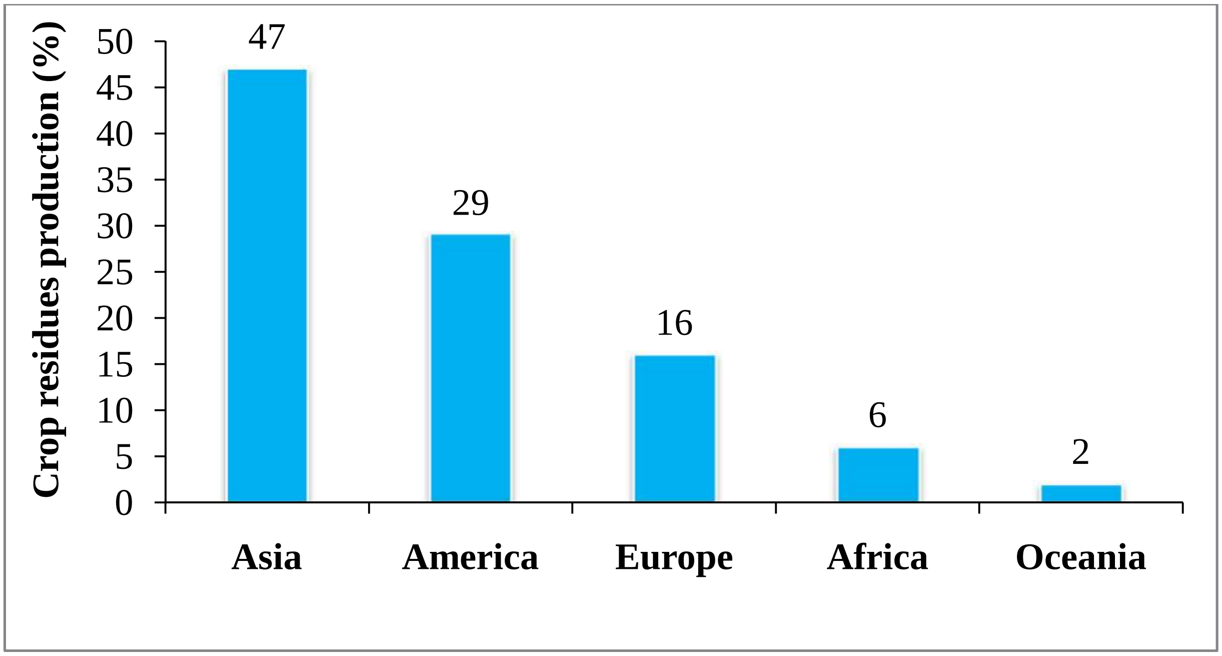

Figure 1 Some major CRs producing countries

times the healthy limit, PM 2.5 µ, or extremely fine PMs, is deleterious to human health because the particles can easily penetrate deep into humans lungs and blood circulatory systems. In recent years, the magnitude of stubble burning was so high that it received international attention. The National Aeronautics and Space Administration (NASA) released a satellite image showing large number of fires across millions of hectares of agriculture fields in various major paddy producing states of India i.e., Punjab, Haryana, Uttar Pradesh, etc. (Figure 2). Management of rice straw, rather than wheat straw is a serious problem, because there is very little turn-around time between rice harvest and wheat sowing and due to the lack of proper technology for recycling. Among options available to farmers for the crop residue management (including burning), important are baling/removal for use as feed and bedding for animals, in situ incorporation in the soil with tillage, and complete/partial retention on the surface as mulch using zero or reduced tillage systems. Therefore, possible efficient management of CRs, produced every year in huge amount should be addressed on priority basis in major agricultural waste (CRs) producing countries including India.

After harvesting the CRs can also be used for bio-fuels and paper generation, manures and other industrial applications. Since the CRs have no economic value and there is a shortage of labour therefore, the farmers don't so interest to invest the extra money in removing the CR from field by using a food processor/chopper. The farmers in north-west India have adopted burning of CRs at filed sited as the cheapest and easiest way of removing large loads of crop wastes produced by wheat and paddy to establish the filed for other seasonal crops. Presently, more than 80% of total rice straw produced annually is being burnt by the famers during October-November (Singh et al., 2015) for establishing the fields for wheat crop cultivation. The field burning of CRs is a major contributor to reduced air quality (particulate matters, GHGs, etc.), and impacts human and animal health both medically, and by traumatic road accidents due to restricted visibility in India. The CRs are sources of nutrients and organic matter when they are decomposed by soil micro-flora and contribute to the maintenance of soil fertility in agro-ecosystems. But the decomposition of CRs may be influenced by many physical, chemical and biological factors, such as placement in the soil profile, climatic conditions, chemical composition of the residues, diversity, abundance and activity of the microbial decomposer community, etc. Recent research efforts have developed conservation agriculture-based crop management technologies which are more resource-efficient than the conventional practices. The conservation agriculture practices can make efficient use of crop residues. It is important that at large scale attempts should be done in the country towards identification of the competing uses of crop residues and suggesting their management options gainfully. This article has mentioned the issues related to sustainable management of CRs at national, regional and local scales.

THE PROBLEMS OF CR$_S$ DISPOSAL AND BURNING

These CRs are used for animal feeding, soil mulching, bio-manure making, thatching for rural homes and fuel for domestic and industrial use. Thus CRs are of tremendous value to the farmers. However, a large portion of the residues is burnt on-farm primarily to clear the field for sowing of the succeeding crop (Figure 3). The problem of on-farm burning of crop residues is intensifying in recent years due to shortage of human labour, high cost of removing the crop residues by conventional methods and use of combines for harvesting of crops. The residues of rice, wheat, cotton, maize, millet, sugarcane, jute, rapeseed-mustard and groundnut are typically burnt on-farm across different states of the country. The problem is more severe in the irrigated agriculture, particularly in the mechanized rice-wheat system of the northwest India.

It has been observed that the main reason of burning the huge amount of CRs by framers at field sites was the lack of options to dispose of the straw. The problem worsened when matured crops undergoes mechanization methods of harvesting. When the paddy and wheat is harvested by machines, only the grains get plucked and long stumps of the crop are left rooted at farm sites. While the harvesting is carried out manually, the crop is removed almost from its base and no residues are left at field sites. But during these days reports said that there are several problems associated with machine based crop harvesting such as damage and loss of grain quality and reduction

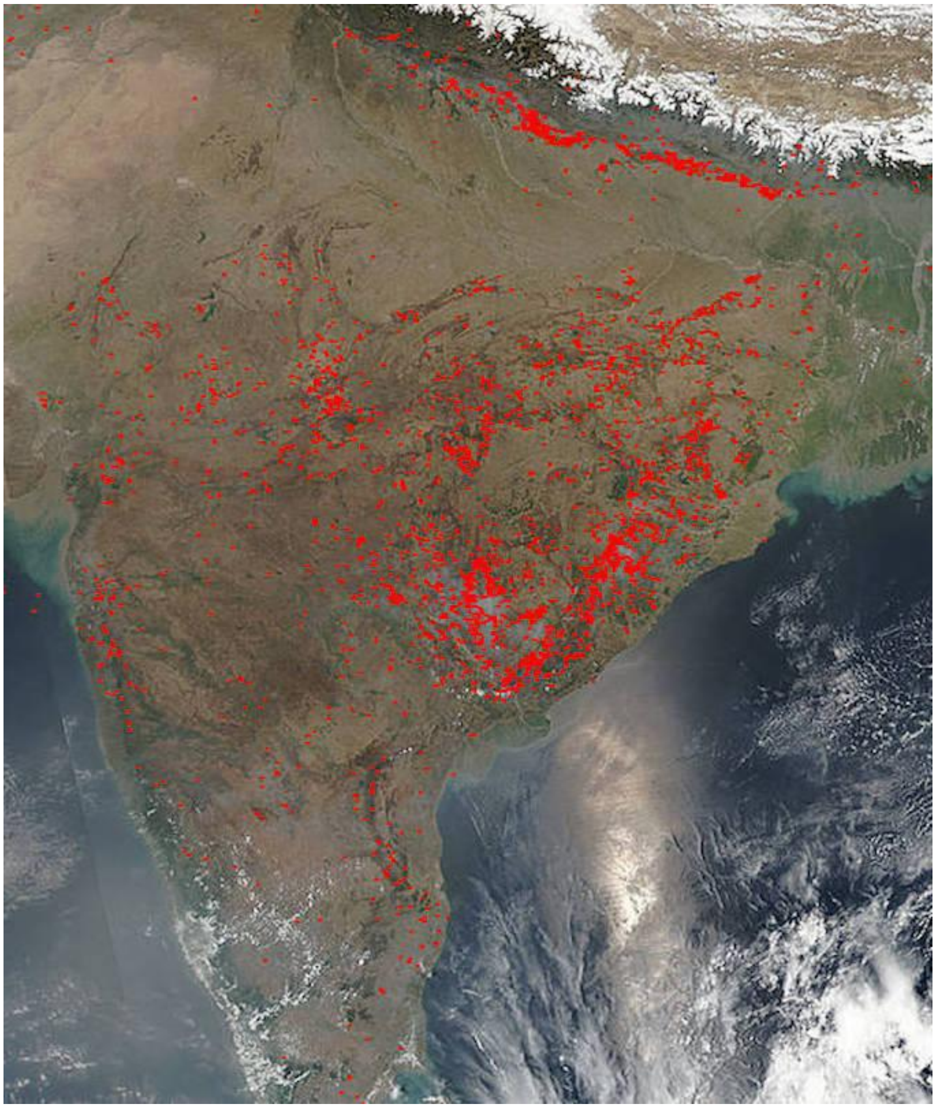

Figure 2. A satellite image of agricultural crop residues fires (red dots) distributed across different provinces of India during October 2016. (Photo by the curtsey of Jeff Schmaltz / NASA)

its market value. Therefore, farmers have reverted towards manual crop harvesting. This caused a significant decline in the practice of burning CRs at field sites.

Functioning of various ecosystems depends on the flux of chemical signals, carbon, and nutrients across the trophic levels, mainly mediated by microbial interactions in the soil-plant-animal food web. Soil microbial diversity and abundance/biomass play key roles in the agro-ecosystem sustainability by maintaining essential functions of soil health, through carbon and nutrient turnover (Singh & Gupta, 2018). Even after disturbances, an ecosystem with a higher microbial diversity and biomass may have a higher capacity to sustain the ecological processes through microbiological buffering (Singh et al., 2016). The number of microorganisms in a teaspoon of soil has been found about 10^9 (one billion bacteria, several yards of fungal filaments, several thousand protozoa and scores of nematodes). It has been reported that bacterial counts in different soils ranged from 4×10^6 to 2×10^9 g^{-1} dry soils (Whitman et al., 1998). It is important to consider that soil microorganism play a key role in the maintenance, functioning and sustainability of agro-ecosystems, mainly regulating C and N cycling, with direct implications on soil fertility and plant nutrition (Singh, 2015, Singh, 2015, Singh, 2015, Singh, 2016, Singh & Strong, 2016).

Although soil microorganisms account for 1 to 5% of soil organic matter, they act both as a source and sink of mineral nutrients and a driver during the decomposition and mineralization of organic materials. Among the various ecological drivers, soil microbes (N_2-fixers, P-solubilizers, growth hormone producers, etc.) and their biomass pools may be considered as major ecological drive in controlling the diverse ecosystem productivity globally (Singh & Kashyap, 2006; Singh et al., 2017, Vimal et al., 2017). These beneficial microbial activities might be greatly influenced by environmental stresses including agriculture CRs burning at field sites. It is demonstrated that the heating of soil due to CRs burning resulted in quantitative reduction in soil microbial diversity and their biomasses (soil microbial biomass-C, -N and -P). Field fires may affect the soil microbial biomass not only quantitatively, but also by modifying its species and community composition and, consequently, its various beneficial soil performances such as nitrogen mineralization, nitrification and denitrification processes [Singh, 2011; Singh & Pandey, 2013; Souza et al., 2012). Heat generated from the burning of CRs elevates the soil temperature that may cause death of active beneficial microbial population having plant growth promoting attributes like PGPRs.

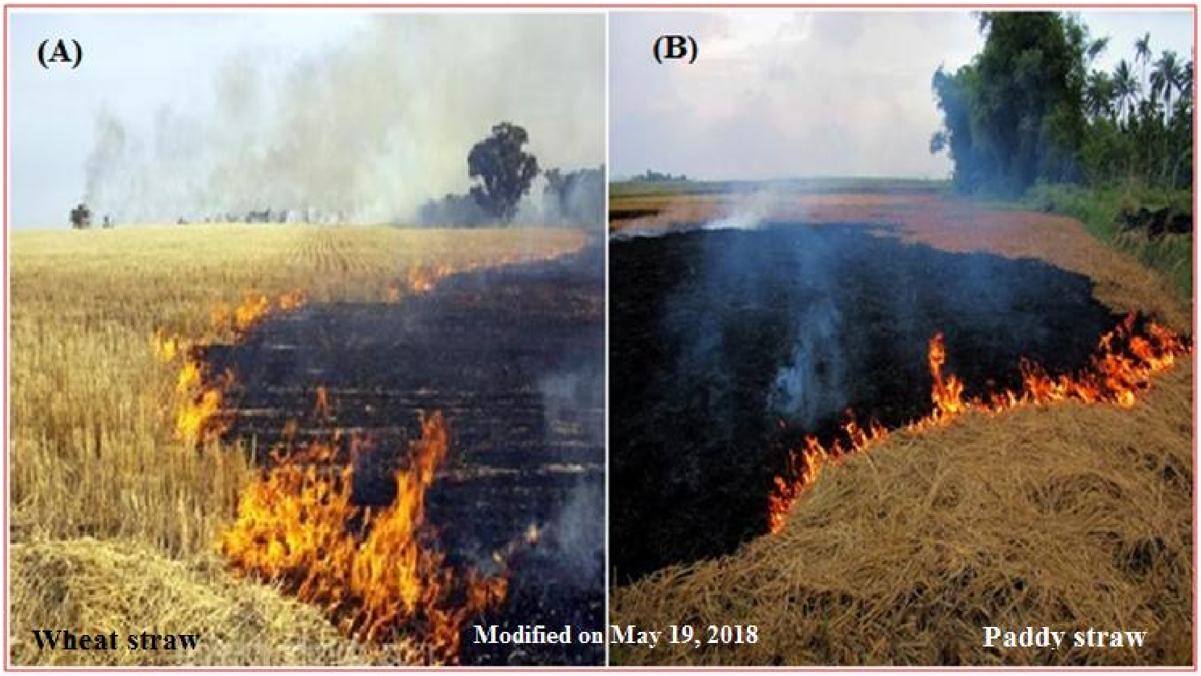

Figure 3 The burning of wheat (A) and paddy straw (B) at agriculture field site heated the soil surface and kills agriculturally beneficial soil microorganisms and deteriorates soil productivity. Farmers should be educated and encouraged to use the crop residues for useful purposes.

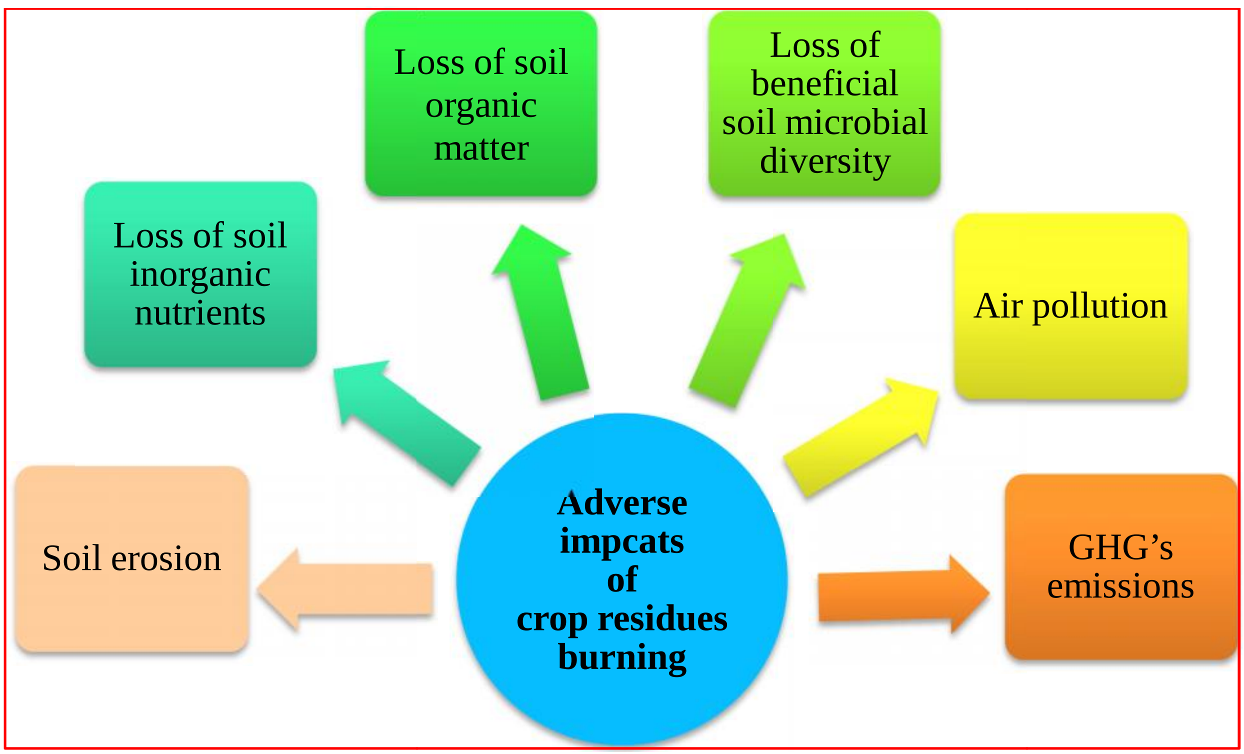

Figure 4 Possible adverse impacts of CRs burning at agriculture field sites. The farmers should be educated about these deleterious impacts of CRs

Based on the above discussion and reports the overall some major harmful effects of CRs burning at fields (Figure 4) may be listed as:

Air pollution and GHG's emissions

The open burning of CRs results in emissions of trace gases like CO_2, CO, CH_4, N_2O, NOx, aerosols, particulate matters, etc. which pose a health hazard to inhabitants of local and adjoining area. These harmful gases are of major cause for concern for their global impact and may lead to increase in the levels of aerosols, acid deposition, increase in tropospheric ozone levels and stratospheric ozone layer destruction. These trace gases may subsequently undergo trans-boundary migration depending upon the wind speed/direction, reactions with oxidants like

OH^- leading to harmful physico-chemical transformation reactions in the atmosphere.

Loss of soil organic matter and inorganic nutrients

In addition to damage caused by air and environmental pollution, burning of CRs also results in loss of soil organic matter and plant inorganic nutrients, which adversely affects the soil fertility and health. It is estimated that about 90% of N and S and 15-20% of P and K available in CRs are vanished during CRs burning. It has been reported by National Academy of Agricultural Sciences (NAAS, India) that burning of 23 million tonnes of rice residues in north-west region of India, results to a loss of about 9.2 million tons of C per year and a loss of approximately 1.4×10^5 tons of N annually. Long-term CRs burning at farm sites reduces soil total -N and -C, and potentially mineralizable N (inorganic-N available to crop plants) in the upper soil layer (0-15 cm). It has been demonstrated that one ton of CRs burning accounts for the loss of about 5.0 kg of N, 2.3 kg of P, 25 kg of K and 1.2 kg of S in the soil.

Loss of beneficial soil microbial diversity

The soil microorganisms are the most active components in the soil carbon pool, which is very sensitive to environmental perturbations including higher temperatures. The soil microbial attributes are more sensitive to soil management changes when compared to chemical and physical attributes. Studies conducted around the world have shown that the maintenance of sugarcane straw promotes increases in microbial biomass (Rachid et al., 2016) and microbial community diversity (Singh, 2013), especially in surface soil layers. It is noted that the heat due to burning the crop straw penetrates about 1 cm into the soil depth and increases the soil surface temperature 33.8 to 42.2 ^{0}C that kills the beneficial bacterial and fungal populations critical for a fertile soil. Direct burning the CRs at field sites strongly increases the top soil temperature which significantly destroys abundance and diversity of agriculturally beneficial microorganisms such as PGPRs, nitrifying and ammonifying bacteria, methanotrophic bacteria, etc.

Soil erosion

Crop residue harvest and removal from the agriculture fields may also makes the soil more susceptible to structural degradation, leading to compaction and consequently, resulting in lower infiltration and storage of water and therefore, decreased plant root growth. Additionally, the crop residues may also act as physical/mechanical barriers that could help to protect the soil heavy rainfall on soil surface and reducing the risk of soil erosion due rain stream surface runoff. Furthermore, the crop residue mulch at farm site may acts as a temperature isolator of surface soils, reducing the intensity of soil temperature, death of surface soil micro-flora diversity and soil moisture evaporation.

CURRENT CRS MANAGEMENT PRACTICES

Research has shown that although, it may be some short-term benefits to burning CRs, there is a slow and steady reduction in soil health that will eventually result in reduced productivity which cannot be overcome with the applications of chemical fertilizers (Singh, 2013; Singh, 2014; Singh & Seneviratne, 2017). Burning decreases readily assimilated carbon sources for microbes, decreases soil ammonium levels and available soil phosphorus. That’s to say nothing of increased erodibility, lower organic matter levels and reduced soil moisture and WHC. In view of the above the CRs burning at farm sites should be typically discouraged because adequate CRs is one of the most important factors for maintenance of health and fertility of agriculture soils in long term. The CRs can provide a protective layer for soil erosion by wind or water, may increase the organic matter and water holding capacity (WHC) of the soil and therefore, provide feed and forage to beneficial soil micro-flora and earth worms. The burning of CRs can lose these benefits, plus other damages may also be arise that could harm the agriculture soil health.

Generally, farmers burn crop residues without recycling them. This is a great loss to the farmer as well to the land, as the land is deprived of biomass, which helps build precious soil organic carbon. This harmful practice is leading to increased CO_2 emissions besides depriving crop residue to the soil. Farmers resort to burning of the crop residue as removing it involves higher costs for labour to uproot, chop and mix in the soil. However, progress made so far in terms of efforts being made to reduce CRs burning, the following management options available (Figure 5) for the gainful management CRs are:

Livestock feed

The CRs (particularly paddy straw) are normally utilized for the animal feed as such or after processing with the addition of some supplements. But as CRs are unpalatable and poor in digestibility (because of lignin) it cannot be solely use for the purpose of livestock. Furthermore, the paddy straw has been considered as poor animals feed because it contains high amount of silica. However, the nutritional quality of paddy straw can be improved by physical, chemical and biological (lignin digesting micro-flora) treatments. Similarly, about 75% of wheat straw is consumed by animals as fodder after converting the whole wheat dry plant in to small pieces with the help of machine cutters.

Mushroom cultivation

The CRs or agricultural wastes are very good source for the cultivation of mushrooms. Some of them are most commonly used such as wheat straw, paddy straw, rice husk, rice bran, molasses, coffee straw, banana leaves, tea leaves, cotton straw, saw dust, etc. Since CRs are rich in lignocellulosic compounds, difficult to breakdown, but can be efficiently utilize for mushroom cultivation. Use of residues in mushroom production represents a valuable conversion of inedible CRs into valuable food (mushroom), having two to three times as much protein to that of milk, eggs or meat. Wheat and paddy straws are nowadays has been recognised as excellent source for the cultivation of various mushroom types such as *Agaricus bisporus* (white button mushroom) and *Volvariella volvacea* (straw mushroom). Thus the CRs provide the opportunity for cost effective farming of a valuable and nutritious food item. Even after being used for mushroom cultivation, it can be used later on as manure for agricultural field because it still has nutrient contents at acceptable range. It seems that cultivation of mushroom on these CRs wastes is one of the most eco-friendly practices to fight the malnutrition and environmental problems caused by huge amount of these wastes produced annually. Detail experimental works and field demonstrations are still going on to exploit the potential of CRs either by using these in blending or after pretreatment.

Biochar preparation

In the recent year, biochar produced from CRs have attracted lots of attention as a viable strategy for maintaining soil health and crop productivity (Singh & Seneviratne, 2017; Zhang et al., 2012). Biochar is a fine-grained charcoal having high C material produced through slow pyrolysis (heating in the absence of oxygen) of plant biomass/CRs. Biochar derived from plant biomass contains a unique recalcitrant form

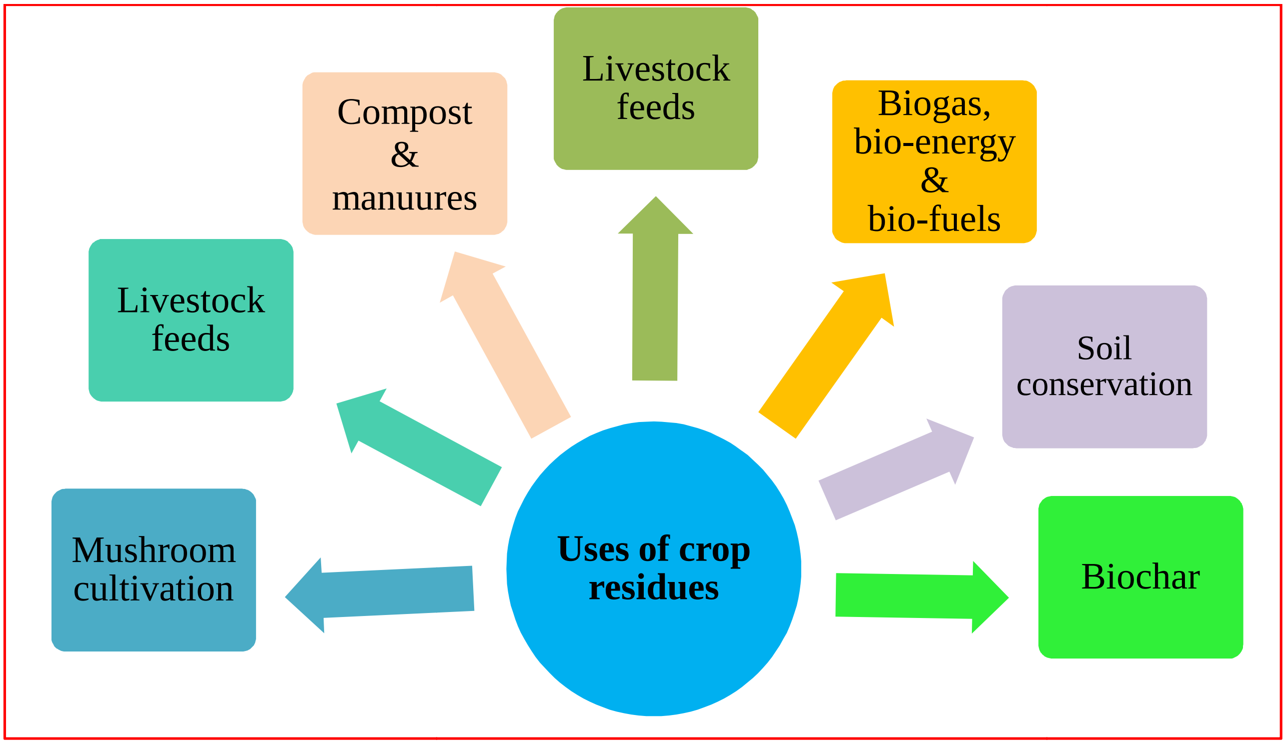

Figure 5 Possible uses of CRs. The farmers should be educated about usefulness of CRs

of carbon that is resistant to microbial degradation, therefore, when applied in the soil, can potentially play a major role in the long-term C sequestration. In addition, biochar application has been shown to reduce the significant amount of greenhouse gas (GHG) emissions from agricultural fields and also improve water quality through its strong absorption nature of contaminants (Whitbread et al., 2003). In recent years, increased concerns for healthy food production and environmental quality and increased emphasis on sustaining the productive capacity of soils have raised interests in the maintenance and improvement of soil organic matter through appropriate land use and agriculture management practices (Puget & Lal, 2005; Jiang et al., 2012). Therefore, huge quantities of rice and wheat straw and other surplus CRs available in different states of India could potentially be pyrolysed to produce biochars, thereby may reduce the CRs burning at fields and the use of biochar could help to improve soils, avoid methane emissions and sequester C in agriculture soils. Due to its greater stability against microbial decomposition and its superior ability to retain nutrients compared to other forms of soil organic matter, applying biochar to soil also offers a significant potential for mitigating climate change and enhancing environmental quality. Furthermore, the biochar can stimulate the activity and performance of beneficial indigenous soil microbial communities and may support the PGPRs to enhance crop growth and rhizobia for N_2 fixation in leguminous plants. Currently, very little research has been done on various aspects of CRs mediated biochar production and its application to the different cropping systems in India. Long-term studies on CRs biochar application in field trials seem to be essential for better understanding the biochar effects and to investigate its behaviors in agriculture soils. Therefore, there is a need to evaluate and optimize the benefits of CRS derived biochar application on soil health, carbon sequestration and nutrient use efficiency in different soils under different cropping systems in field conditions.

Energy and bio-fuel generation

The plant biomass and CRs can be resourcefully utilized as a source of energy and is of attention worldwide for the reason that of its environmental advantages. In recent years, there has been an increase in the usage of CRs for energy generation and as substitute for fossil fuels. It is now well accepted that compared to other renewable energy re-sources such as solar and wind, plant biomass/CRs re-source is eco-friendly, cost-effective, energy-efficient and can be stored for a long time. However, the logistics for transporting huge amount of CRs produced annually, required for efficient energy generation could be a major cost factor irrespective of the bio-energy outputs. Availability of CRs, cost incurred during its transportation cost infrastructural developments (crop harvest machinery, modes of collection, etc.) are major constrains and limiting factors of using the CRs for energy generation. Thus, it is expected that a significant increase in bioenergy production in the near future, the stakeholders of this sector should have to have increase their interest and investments to use the CRs as raw material for bioenergy and bioelectricity production. The use of CRs as a bioenergy feedstock may be also considered as a potential strategy to mitigate the GHGs emissions.

Compost and manure production

The crop residues have been traditionally used for preparing compost. For this, crop residues are used as animal bedding and are then heaped in dung pits. In the animal shed each kilogram of straw absorbs about 2-3 kg of urine, which enriches it with N. The residues of rice crop from one hectare land, on composting, give about 3 tons of manure as rich in nutrients as farmyard manure (FYM). Indian Agricultural Research Institute (IARI), New Delhi, has successfully developed a biomass-compost unit for making of good quality compost. This mechanized unit efficiently uses waste biomass and crop residues generated in the IARI farm. The decomposition process, which is hastened by a consortium of microorganisms, takes 75-90 days. During the year 2010-11, the unit prepared about 4000 tons of compost and in the subsequent year it increased to over 5000 tons.

POSSIBLE MANAGEMENT STRATEGIES AND POLICIES TO MINIMISE THE CRS BURNING

As discussed above, in India several technologies have been adopted for the management of CRs waste. However, there are still some constraints, which limit the adoption of these technologies at larger large-scale. One of the major problems in using huge quantity of CRs is the enough high cost and man power necessity for its collection and transport. Only few nations have developed and adopted strategies for the management of CRs to evade CRs burning at agriculture farm sites. It has been pointed out that in China, about 700 Mt CRs generated annually, about 31% of CRs are left at the agriculture field, 31% are consumed for the animal feed purposes, 19% are applied for biofuels and bioenergy generation and 15% as fertilizer use (Karlen & Johnson, 2014). In USA, the farmers of California should require a permit for CRs burning and is permitted and monitored by the local authorities in consultation with the California Air Resource Board (CARB). The maximum amount of CRs is used as a source of energy in some countries such as Philippines, Indonesia, Indonesia, Nepal, Thailand, Malaysia and Nigeria.

In India, to address the various problems arises due to CRs residue burning; the Central and State Governments of the affected States should implement the rule regulations to provide a sustainable solution to the problem CRs burning. Strict implementation of such rule and regulations would be the main advantage to improve the economic returns to the farmers and will improve the soil health, while eliminating environmental pollution and reducing GHG (Singh & Gupta, 2016) from the area covered by appropriated technologies at minimum cost. The various stake holders of the country such as NAAS, Indian Council of Agriculture Research (ICAR), state and central agriculture universities and other organizations can play an important role in implementing the various strategies to stop/minimise the CRs burning such as:

a. By organizing interactive gatherings and meetings among the agriculture officers of the affected states, industry representatives and experts, service providers and other stake holders.
b. By developing and advertising the conservatory materials showing the harmful impacts of CRs burnings and usefulness of CRs by means of posters, leaflets, short videos, TV programmes, etc.,
c. By arranging the farmers training events, providing technical back up to the farmers and industry and, monitoring and evaluation of impacts.
d. By developing new paddy and wheat crop varieties to produce more root biomass to improve the agriculture soil resource.
e. By developing the new microbial consortia and inoculants for enhancing the decomposition rate of CRs at farm sites.
f. By designing innovative and efficient long-term experiments to study the impact of CRS burning and conservation of agriculture resources on soil health, C sequestration, GHGs emission and ecosystem stability.
g. Due to establishing greater number of biomass-based power projects that can consume and utilize major amounts of paddy straw generated annually.
h. By generating greater scope of subsidy provision, so that agricultural implements can be made widely available with the aim to reducing the CRs burning at farms.
i. Utilization of CRs in the form of biomass fuel pellets, which can be commercially, sold as the main fuel for industrial/thermal power plants boilers in place of coal. Alternate usage of CRs to produce paper, card boards and packing materials needs to be promoted in place of synthetic compounds.
j. The farmers should be paid attractive amount of money per acre under some agriculture scheme so they can avoid the practice of CRs burning. It is necessary to understand why the farmers burn the CRs and then address their basic problems related to management of CRs.

CONCLUSIONS AND FUTURE RECOMMENDATIONS

There is an old belief among the Indian farmers that burning of crop straw enhances the soil fertility. Therefore, it should be justified via giving training to the farmers about the mistaken belief and to erase from their minds, while the straw-burning have always harmful effects on soil and environment. At present most of the developing countries including India, the most populous country by 2050 with one of the largest malnourished population, has challenging tasks to ensure food security. Hence agricultural practices should be effectively addressed at local, national and international levels to face the challenges of food, water and energy issues related to climate change and degradation of natural resources. The CRs are of great economic values as livestock feed, bio-fuel and bioenergy source, raw material for various industries, and agriculture conservation (Tiwari & Singh, 2017). Thus the CRs, either partly or entirely can be used for agriculture conservation to country's food security, agriculture and environmental sustainability. All stakeholders i.e., farmers, researchers, policymakers and consumers need to be come together to understand and harness the CRs as a valuable resource for sustainability and resilience of Indian agriculture.

The soil microbial biomass (SMB), important soil fertility index, has been considered as a sensitive key biological indicator of soil productivity. Research practices on restoration ecology of degraded lands; have mainly focused on the aboveground patterns of plant biomass with lesser emphasis on the CRs burning on belowground SMB, which could play a vital role in soil productivity agro-ecosystems. Therefore, the study of belowground SMB patterns and its relationship to CRs burning can enhance our understanding in soil nutrient status and agriculturally important microbial diversity (Vimal el al., 2018) of the agriculture field. Large scale awareness campaigns at different stages of cropping seasons via various useful activities such as farmers' fair, exhibitions, seminars, use of digital technologies (ICTs), social media, electronic and print media, etc. need to be launched and monitored for implementation and adoption. It is supposed that the research, policy and development programmes as outlined in this communication will shed some lights and serve a great deal to manage the CRs at local and regional scales.

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