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Practices of Sustainable Crop Residue Utilization

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Agriculture plays a major role in the overall economic development of the nation. India generates a large amount of agricultural waste with crop cultivation throughout the year. Agricultural waste is mainly controlled by the owners of the agricultural sector which is mainly in the private sector, with little public sector participation. Increasing demand for food in developing countries has led to a tremendous increase in agricultural production. Therefore, agro-based activities represent profitable businesses.

Crop residues are biomass left after harvesting in an agricultural area or orchard. Stalks, stems, leaves and seed pods are some common examples of crop residues. According to the Indian Ministry of New and Renewable Energy (MNRE), India generates an average of 500 million tonnes of crop residue per year. The same report states that most of this crop residue is used as fodder and fuel for other domestic and industrial purposes. However, there is still a surplus of 140 million tons, of which 92 million tons are burned each year. This article has chosen alternatives to crop residue utilization technologies to be practised at the farmer's level in rural areas.

Crop residue availability in India

Waste from the agricultural industry can be used in various agro-based applications and other industrial processing. However, the cost of collection, processing, and transportation can be much higher than revenue. The state of Uttar Pradesh (60 MT) has the highest production of crop residue followed by Punjab (51 MT) and Maharashtra (46 MT). A total of 500 MT of crop residue is produced per year of which about 92 MT is being burnt or left on the open field. Among the residues of various crops, rice comprises 43 %, followed by wheat at about 21 %, sugarcane at 19 % and oilseed crops at about 5 %. It is reported that 80 % of the combustion of crop residues occurred during the kharif and rabi harvests. The reason behind this is attributed to labour shortage and cropping patterns. For higher economic return, farmers grow three crops per year leaving a limited time between harvesting and sowing between two consecutive crop farms (Jitendra et al., 2018).

Adverse effects of crop residue burning on the environment

The burning of crop residues causes many environmental problems. The main adverse effects of crop residue combustion include the emission of greenhouse gases (Lyu et al., 2022, global warming, particulate matter emission (PM) and increased levels of haze that cause health hazards, declined biodiversity of agricultural land, and soil fertility. The World Health Organization standard for permissible levels of PM2.5 in air is 10 micrograms per meter cube, and according to India the permissible level for PM2.5, the national ambient air quality standard, has been 40 micrograms per meter cube. In addition to the emission of gases and aerosols, there is a continuous degradation of soil fertility due to burning. Burning of 98.4 MT of crop residue has resulted in the emission of about 8.57 MT of CO and 141.15 MT of CO_2. Heat from residue burning increases soil temperature and reduces bacterial and fungal populations. Burning the residue increases the temperature of the subsoil from about 33.8 to 42.2 °C by 10 mm depth. Repeated burning reduces nitrogen and kills the carbon potential of the soil and microflora beneficial to the soil and the organism. The carbon-nitrogen balance of the soil is completely lost with crop burning. The average crop residues of various crops contain approximately 80% nitrogen, 25% phosphorus, 50% sulphur and 20% potassium (Bhuvaneshwari et al., 2019). It causes a loss of organic carbon, nitrogen, and other nutrients, which otherwise would have been retained in the soil.

Conversion of crop residue

Alternative measures of crop residue use have been suggested by scientists and agronomists for a long time but due to lack of awareness and social consciousness, these measures have not been fully implemented by farmers. Cultivation should involve the generation of crop residue-based product which has a safe marketplace in the surrounding area. In some cases, the distance to transport the material also adds to the cost. In this context, it is believed that the best option is those whose end-products can be used by the agricultural industry and on-site if possible. This section details three agricultural applications that are either ignored or left out due to various reasons. They are in-situ management, biogas, and biochar through mechanical intensification.

1. Manure through in-situ management

Composting is not a new concept for India. While small-scale organic manure-making is a simple process for the agricultural industry in India. A recent publication discussed the common challenges faced by organic waste composting projects. The challenges are that most technologies are not economical, and the end product does not always secure a stable market, but the farming community does not have to worry about these challenges if they make manure as they can store their crop residues on site. Organic matter is the natural process of degradation by microbes under controlled conditions.

Compost plays an important role in maintaining soil fertility. Composting is mediated by various microbes operating in aerobic environments. Bacteria, fungi, actinomycetes, algae and protozoa are naturally present in organic biomass or artificially added to facilitate decomposition. It is biological maturation under aerobic conditions, where organic matter of animal or plant origin is decomposed by materials with small molecular chains.

It is estimated that the burning of one tonne of rice straw accounts for the loss of 5.5 kg Nitrogen, 2.3 kg phosphorus, 25 kg potassium and 1.2 kg sulphur besides, organic carbon. If the crop residue is incorporated or retained in the soil itself, it gets enriched, particularly with organic C and N (NPMCR, 2014).

More stable, hygienic, humus-rich compost is beneficial for crops and soil recycling. Recent advances in the decomposition of crop residue have been implemented by specifically isolated bacterial and fungal species and newly developed enzymes. Pusa decomposer is one of the examples. Through various government efforts under the Central Sector Plan (CSS) on promoting agricultural mechanization for in-situ management of crop residues, there has been a 27 % decrease in the incidence of crop residue burning in Punjab in 2022.

2. Biogas Production

The biogas generation is a progressive step taken by the Government of India to curb crop burning. Biogas technology has been in operation since the 1970s under many programs. Renewable energy biogas for power generation, cooking and lighting are run by electricity generation. The various types of biogas plants are mainly in the form of floated drum type and fixed dome type. For industrial biogas production vertical column-type biogas plants are used with stirrer systems, and temperature control systems to increase biogas production. Conventional biogas digesters are also classified as batch type and continuous type based on the availability of crop residues. Recent technologies have opened the possibility of the use of crop residues and other vegetable waste, for biogas in an integrated approach. Biogas slurry produced as a by-product is a high-quality fertilizer for agriculture. In this way, crop residues can be converted into fuel for cooking through the bio-methanation process which can also be used for power generation and composting to increase soil fertility which will save the expenditure of commercial fertilizers.

Table 1: Biogas Digestate Element Structure (Barbosa, 2014)

Carbon (%)	41.1
Nitrogen (%)	3.2
Phosphorus (%)	1.5
Potassium (%)	3.75
Calcium (%)	3.21
Magnesium (%)	0.57
Sulfur (%)	0.39
Manganese (%)	0.15

There are currently 56 biogas-based power plants operating in India, most of them in the states of Maharashtra, Kerala and Karnataka. Small family-type biogas plants have also been started in rural areas, which can produce 1 to 10 cubic meters of biogas per day. About 4000 cubic meters of biogas is being generated from 10 tonnes of agricultural residues at the Indian Institute of Technology, Delhi and 120,000 tonnes of rice straw collected from about 15,000 farmers at a major academic university like Punjab Agriculture University (PAU) to be consumed in a 12 MW biogas plant (Chandra et. al., 2017). According to the PAU, secondary users such as bio-gas plants gave farmers Rs. 500 to Rs. 1500 per ton of straw (NITI Ayog, 2018). Crop residue-based Bio CNG has potential. However, the infrastructure for baling, transportation, pre-treatment, leak-proof digestion, purification of biogas to produce bio-CNG and bottling and dispensing units are inadequate. Further, there is a need to work out combinations of feed material, their pretreatments and size reduction and determination of the C-N ratio for optimal bio-CNG production. Low-density paddy straw needs to be baled and transported to the plant is one of the crucial and cost-effective processes in Bio CNG generation (Dhillon, 2018).

3. Biochar

Biochar has been proven to be a renewable resource and environmentally friendly material for improving soil fertility. Biochar is a biological material produced in the absence of oxygen produced from biomass.

Biochar is a carbon-rich material with a porous structure and functional groups (Atinafu et al., 2020). This biochar also can be used as a low-emission fuel for thermal applications such as cooking, brick kilns, etc. The Agricultural Energy and Power Division of CIAE. Bhopal has developed three types of biochar production reactors: Biochar kilns, Annular Biochar Production Reactors and cylindrical reactors of 300 to 600 kg per batch capacity operating on electricity and biomass briquettes.

Table 2: Fundamental Properties of Biochar (Source: NICRA-Central Research Institute for Dryland Agriculture, 2009)

Nutrient present in the biochar	Value(g/kg)
Total organic carbon	520.0
Total inorganic carbon	2.5
Total Nitrogen	13.4
Total Phosphorus	4.0
Total Potassium	4.7

The application of biochar along with nitrogen and phosphate fertilizers can also be a great source to improve soil fertility due to the slow release of fertilizer into the soil. It has also been documented that biochar also provides a habitat for a wide variety of microorganisms that are beneficial for soil fertility (Azeem et al., 2021). The basic structure of biochar typically includes carbon, nitrogen, hydrogen, and some micronutrients. Numerous studies have shown that biochar can improve soil composition, increase impermeability, decrease bulk density, and may increase aggregation and water retention. In addition, biochar has also been suggested to reduce soil acidity (Basak et al., 2022). In summary, the mechanism of improving soil fertility can have a biochar effect on soil physical and chemical properties, soil biota, etc.

Conclusions

The technologies discussed in this article are facilitating a reduction in the expenditure incurred on chemical fertilizers by 34 to 40% through on-site or in situ crop residue management and biogas generation. Nowadays organic farming has become a trend, and the use of crop residue instead of chemical fertilizer is helping to increase crop production without chemicals. Along with supplementing nutrients, these technologies provide energy in the form of electricity, fuel etc. This energy can be used for agricultural, agro-industrial and household purposes such as threshing, pumping, electricity, cutting machinery, cooking etc. These technologies are working on simple principles and require little skill for operation. Crop residue management technologies are favourable for farmers. Reduction in crop residue burning will contribute to reducing greenhouse gas emissions. Many research institutes have provided technologies from crop residues to onsite crop residue management, biochar production and biogas production. The Government of India also has some encouraging incentives regarding the reduction of crop residue burning. Farmers and rural youth should take advantage of these policies to generate empowerment and revenue from waste management.

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