Cultivating Sustainability: Harnessing Paddy Straw Management to Mitigate Carbon Footprint

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Rice is the staple food for much of the world's population, particularly in Asia (Singh *et al.*, 2016), but its production generates massive amounts of straw, with the straw-to-paddy ratio ranging from 0.7 to 1.4 depending on variety and growth. Paddy straw production on a global scale ranges from 800 to 1,000 million tonnes per year, with Asia producing 600 to 800 million tonnes per year (IRRI). Each kg of milled rice produced yields approximately 0.7-1.4 kg of paddy straw (Bakker *et al.*, 2013), implying that for every tonne of rice grain produced, 700 to 1500 kg of paddy straw is produced, depending on variety, stubble-cutting height, and moisture content during harvest. Only 20% of paddy straw is currently used for practical purposes, such as the production of biofuels, paper, biofertilizers, and animal feed; the rest is either burned in place, incorporated into the soil, or used as mulch for the crop that follows. However, incorporated paddy straw degrades slowly and may harbor diseases, whereas burning is becoming socially unacceptable due to extensive atmospheric pollution, including greenhouse gas (GHG) emissions and smoke. In terms of GHG emissions, burning one kilogram of dry paddy straw produces nearly 700-4100 mg of methane (CH_4) and 19-57 mg of nitrous oxide (N_2O) (Bhattacharyya *et al.*, 2021). These contribute directly to environmental pollution and are also to blame for the haze in the National Capital Region (NCR) and the melting of Himalayan glaciers. Nonetheless, the practices and their negative consequences have spread across India's states.

Burning paddy straw raises soil temperatures to 33.8 to 42.2 ^{o}C (Singh and Verma, 2021) and harms beneficial soil organisms, leading to increased pest susceptibility and reduced solubility capacity. Sustainable solutions are needed to improve rice production while using paddy straw for soil conditioning via composting and carbonization, as well as for bio-energy production and material recovery such as silica and bio-fiber (for industrial use). Even if all of the possible options are not economically viable.

Pusa Decomposer

The Pusa bio-decomposer, developed by IARI, is a cost-effective microbial agent that accelerates the decomposition of crop residues, particularly paddy stubble. It's created from seven fungi strains that produce enzymes like pectin, cellulose, and lignin, enhancing straw decomposition. Farmers make a liquid solution using these capsules, which ferments for 8 to 10 days. This mixture is then sprayed on fields with crop stubble to expedite decomposition. Using 4 capsules, jaggery, and chickpea flour, farmers can prepare 25 liters of the solution, which, when diluted with 500 liters of water, covers one hectare and decomposes the stubble in about 20 days (Tiwari *et al.*, 2022).

Fig. 1. Pusa Bio Decomposer

Biochar

Biochar is a carbon-rich, consistent, and long-lasting product that farmers use to improve soil health and quality. Biochar is produced by thermally treating paddy straw. Carbonization, combustion, torrefaction, gasification, and pyrolysis are among the thermal treatments used in biochar production. Because of its simplicity and effectiveness, pyrolysis is the most popular technique for producing biochar. Pyrolysis can be accomplished in a furnace under oxygen-deficient conditions. Biochar has shown promise in improving soil carbon sequestration, increasing crop productivity, remediating contaminated soil and water, reducing greenhouse gas emissions, and reducing nutrient leaching (Tokas *et al.*, 2021).

Burning Issues and Alternative Management Options

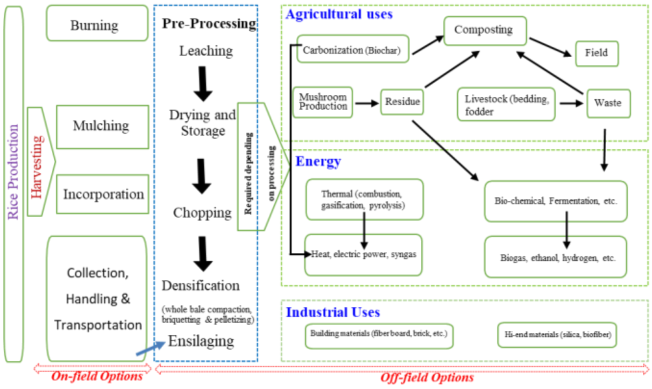

Fig. 2: Paddy-straw management options (Gummert et al., 2020)

In multi-cropping systems, intensification of rice-cropping systems has been linked to the use of high-yielding, short-duration varieties with shorter turnaround time between crops. Furthermore, the rapid introduction of combine harvesters is a game changer due to the increased amounts of straw left on the field. Because of the high labour cost, manual straw collection in the field is unprofitable. In intensive systems with two to three cropping per year, incorporation poses challenges. This is due to a lack of time for decomposition, which results in straw with poor fertilization properties for the soil and hinders crop establishment. As a result, despite being prohibited in most rice-growing countries due to pollution and health risks, open-field burning of straw has increased dramatically over the last decade. As a result, it is critical to seek out sustainable solutions and technologies that can both reduce environmental impact and add value by increasing the revenues of rice production systems. Fig. 1 depicts management options for paddy straw. Paddy straw has the inherent ability to be used for soil conditioning via composting and carbon sequestration, as well as for bio-energy production and material recovery (such as silica and bio-fiber) (for industrial use). It should be noted that not all possible options are economically viable. This is because the processing material and transportation costs in value-added solutions are still higher than in other more traditional options.

Biogas Production

Anaerobic Digestion (AD) is a biological process that degrades paddy straw in the absence of oxygen through the coordinated actions of a wide range of microbial communities. It is divided into four stages: Hydrolysis is the breakdown of insoluble organic compounds such as cellulose, protein, fat, and some insoluble organic compounds by enzymes (produced by bacteria) and anaerobic bacteria (Deublein and Steinhauser, 2011).

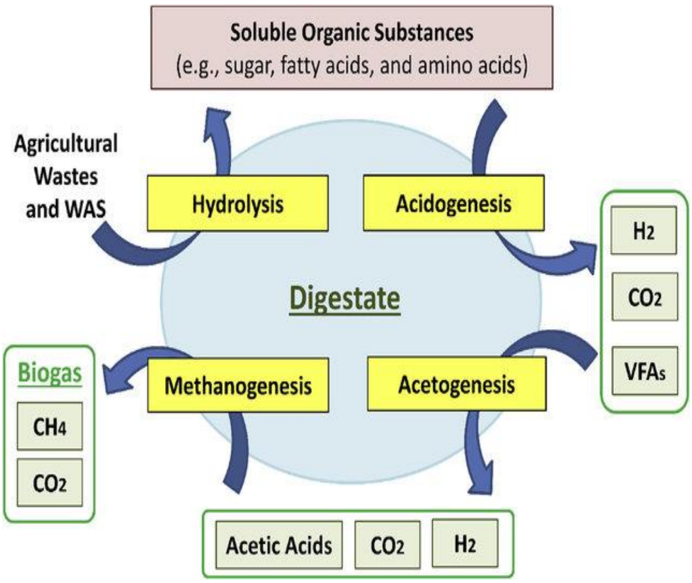

Fig. 3: Biogas Production (Pan et al., 2021)

Simple sugars, fatty acids, and amino acids are fermented to form organic acids and alcohol during acidogenesis (acid production) (Gerardi, 2003). Acetogenic bacteria grow alongside methanogen bacteria during Acetogenesis (acetic acid production), and methane is released under completely anaerobic conditions during Methanogenesis (methane production) (Ziemiski and Frc, 2012).

Medium for Mushroom Production

Paddy straw can be used as the primary substrate for mushroom cultivation. Mushrooms can decompose organic material that other microorganisms cannot. Different types of mushrooms (including *Agaricus spp.*) (Kamthan and Tiwari, 2017) thrive in paddy straw compost. Mushrooms are regarded as an important food in terms of nutrition security and human health. *Volvariella volvacea*, also known as the straw mushroom or rice-straw mushroom (RSM), is an edible mushroom that is widely cultivated in East and Southeast Asia. RSM production adds value to rice production and increases the income of developing-country poor farmers.

Conclusion

Burning paddy straw has a wide range of consequences both on and off the farm, including losses in soil organic matter, soil nutrients, production and productivity, air quality, biodiversity, water and energy efficiency, and human and animal health. Incorporating paddy straw into the soil is an option, but it must be carefully considered to ensure timely decomposition, minimize GHG emissions and helps in carbon sequestration. Management of environmentally friendly paddy straw options such as cattle bedding, mushroom cultivation, soil nutrition, power generation, combustion material, pellet making, bio-gas, bio-ethanol, biochar, acoustic material, 3D objects, cardboard and composite board, packaging materials, production of bio-composite, cement bricks, and handmade paper, used as an energy source, mulching, industrial raw material, biofuel, and animal feed.

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