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ORIGINAL RESEARCH

Alternative strategies for mitigating global warming through the application of rice straw waste composting technology

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Abstract

Purpose: The purpose of this article is to determine the composting method of rice straw waste that is adaptive to global warming mitigation efforts. Two composting methods are commonly known as innovations in rice straw waste management, namely aerobic and anaerobic, but no one has studied methods that are in line with global warming mitigation.

Method: The writing of the article was carried out with a literature study method approach. The author collected data from books and scientific papers related to the mentioned issues, including rice straw waste management, global warming, greenhouse gas emissions, agricultural industry, rice straw composting, and climate change mitigation. Information was collected through online searches using specific keywords on sites such as Google Scholar, PubMed, and Web of Science.

Results: Rice straw composting helps prevent straw burning that causes global warming while increasing crop productivity and reducing environmental pollution. Development and selection of composting methods are important to obtain a composting strategy that is adaptive to global warming mitigation efforts.

Conclusion: Aerobic composting is a better option in reducing greenhouse gas emissions. The aerobic method is more suitable for in-situ composting in paddy fields, it is practical, easy, and fast. Besides being an innovation in waste management that is adaptive to global warming mitigation, aerobic composting is also in line with the implementation of the LEISA concept and circular economy.

Keywords: Mitigation, Composting, Global Warming, Rice straw, Waste

Introduction

The threat posed by global warming is growing as a result of the atmosphere's concentration of greenhouse gases, especially CO_2. Approximately two thirds of the greenhouse effect's rise is caused by CO_2 alone. The primary causes of CO_2 emissions into the atmosphere are land use changes, deforestation, and the combustion of fossil fuels (coal, oil, and gas) (Kumar and Pooja, 2020). Due to changes in the ideal temperature range brought on by climate change, which is a result of global warming, many species are at risk of extinction. This accelerates the loss of biodiversity by gradually altering the structure of ecosystems (Abbass et al., 2022). The ecosystem's equilibrium and the demise of numerous species as a result of acidity will both be impacted by rising ocean temperatures. Nature's imbalance is determined by greenhouse gas emissions, which produce global warming (Mukhopadhyay, 2014). The worldwide environment is still suffering greatly from the threat of global warming. The majority of individuals do not believe that global warming will become a serious issue in the upcoming years and are unaware of it (Shahzad and Riphah, 2015).

All facets of human life are profoundly impacted by climate change, including food security. Climate change and food security are related in two ways. Food security is impacted by climate change on the one hand, while climate change is impacted by efforts to achieve food security on the other (El Bilali et al., 2020). Even if the average world temperature is predicted to rise by 2 °C by 2100, agricultural production is still quite fragile, which might have a big effect on food security and poverty. There will be more food insecurity in areas where hunger and malnutrition are already prevalent due to the effects of climate change (El Mokhtar et al., 2019). In other words, food security, food production, and climate change are all interconnected. Changes in one factor negatively impact the others (Islam and Wong, 2017).

Assuring food security and boosting agricultural output, especially rice production, are the present challenges in the fight against global warming (Hussain et al., 2020). In order to fulfill the demands of the expanding global population for rice consumption, more rice must be produced (Jena et al., 2023).. Conversely, growing more rice results in greenhouse gas emissions from rice farming. The kind of soil, the method of rice farming, and management techniques all affect greenhouse gas emissions. Greenhouse gas levels are influenced by crop type, soil type, fertilizer application, and water management techniques (Ariani et al., 2021; Boateng et al., 2017). About 30 % of the world's agricultural greenhouse gas emissions come from rice fields as CH_4 and 11 % as N_2O, respectively (Mboyerwa et al., 2022). In the next century, rice output and cultivation are predicted to decline by over 51 % due to global climate change. Nevertheless, agriculture also plays a role in global warming, contributing between 10 and 14 percent of greenhouse gas emissions worldwide and 18 % of methane emissions from rice fields (Hussain et al., 2020).

Globally, rice farming practices are linked to numerous environmental challenges. The lethal greenhouse gas emissions caused by different rice production steps and techniques and their connection to global warming is one of the main worries (Singh et al., 2021). Rice straw is one of the agricultural wastes, and it must be managed properly in paddy fields to preserve soil productivity and lower greenhouse gas emissions (Zhang et al., 2013). This precious biomass is frequently burned as waste in the open, harming the environment, causing air pollution, global warming, and the loss of plant nutrients. Approximately 60 % of the rice straw produced in India and throughout Asia is burned outdoors (Bhattacharyya et al., 2020). One way to prevent burning straw is to use straw to produce bio-energy instead of burning it (Soam et al., 2017). For the environment, the primary benefit of using rice straw is preventing the harm that comes from burning straw on land (Silalertruksa and Gheewala, 2013). As millions of tons of rice straw are burned, potent greenhouse gasses are released into the sky, causing localized chemical disruptions. The generation of bio-methane and bio-ethanol, which provide energy equivalents of 8.0 GJ tonne^{-1} and 5.6 GJ tonne^{-1}, respectively, can be successfully achieved using rice straw if it is not burned (Trivedi et al., 2017).

Reducing greenhouse gas emissions globally ought to continue to be of utmost importance. Furthermore, it is advisable to develop and execute limitations and strategies for adaptability (Kumar and Pooja, 2020). People need to get involved in this issue and actively contribute in order to lessen the effects of climate change. Rahman, (2018) asserts that it is critical to motivate every member of the community to take part in mitigation measures related to climate change adaptation. Impacts of climate change should be mitigated globally and with the utmost importance. A worldwide commitment is required to confront the issue and mitigate its detrimental effects in order to secure the existence of the planet (Abbass et al., 2022). In light of the current climate emergency, workable mitigation and adaptation strategies are required. Given the current climate emergency, workable strategies for both mitigation and adaptation are required (Fawzy et al., 2020). Addressing the effects of climate change on food security is more difficult than altering agricultural techniques to be more ecologically friendly. Politics and the economy have a role in this (Islam and Wong, 2017). Furthermore, Menhas et al. (2016) assert that greenhouse gas emissions are the result of the food and agriculture systems taken as a whole.

The agricultural sector is responsible for greenhouse gas (GHG) emissions and impacts climate change (Islam et al., 2022). The use of appropriate rice varieties and water-efficient irrigation methods can reduce greenhouse gas emissions from wetland rice cultivation. Compared to flood irrigation systems, the application of intermittent irrigation in rice cultivation can significantly reduce cumulative CH_4 emissions by about 35 %. (Habib et al., 2023). Efficient fertilizer management practices also play an important role in increasing crop yields and promoting low-carbon agriculture (Islam et al., 2022). Compared to traditional nitrogen fertilizer management, the use of improved fertilizer methods to increase nitrogen utilization efficiency can reduce environmental pollution, including reducing greenhouse gas emissions (Islam et al., 2022; Sun et al., 2020). The management of agricultural waste, such as rice straw, should also be done by considering its impact on global warming. Incorporating rice straw into waterlogged soil can increase CH_4 emissions (Grohs et al., 2020). The strategy of selecting new rice varieties, non-continuous flooding, and removing thatch reduces GHG emissions by 24 %, 44 %, and 46 % respectively (Qian et al., 2023). Adaptation to drainage systems is one of the most promising options for mitigating methane gas in rice production (Islam et al., 2018).

Composting is one of the best uses for rice straw. Additionally, composting reduces burning, which contributes to global warming (Nghi et al., 2020). Straw is the only adequate organic matter used by the majority of rice farmers. The vegetative plant parts still contain 40–50 % sulfur (S), 30–35 % phosphorus (P), 80–85 % potassium (K), and 40 % nitrogen (N) when the harvest is mature. Compost and other value-added products can be made from rice straw, which mostly consists of lignin, cellulose, and hemicellulose (Kaur et al., 2019). The process of turning rice straw into compost will increase crop productivity. Due to open burning, it will also lessen pollutants in the area and the ecosystem (Zakarya et al., 2018).

There are variations in the decomposition time, stability, maturity, and sanitation potential of composting techniques (Mengistu et al., 2018). Global warming is caused by greenhouse gas (GHG) emissions that are directly released during the composting process as opposed to auxiliary emissions. Mitigation methods are needed to lessen climate change's harmful effects. These tactics ought to serve as a foundation for the creation and application of greener technology (Awasthi et al., 2018). In addition, offering individualized composting choices to lessen the effects of climate change. Compost is currently produced in a fast, simple, and high-quality manner using composting techniques. Making composting techniques that are safe for the environment and don't have any long-term repercussions is the next obstacle, though. The purpose of writing this article is to offer composting method options that are more adaptive to global warming mitigation efforts. Choosing a method for composting rice straw waste that is adaptive to mitigating global warming will be a form of contribution from the agricultural sector, especially from rice cultivation, in reducing greenhouse gas emissions related to efforts to process the agricultural waste produced

Materials and method

This article was written and prepared using a literature study approach. Identifying the overall issues surrounding the handling of rice straw waste in rice farming and its relationship with global warming was the first step. Finding the impact of global warming and strategies to mitigate its impact is the next step.

Literature searches for both journals and books are carried out online via the pages Google Scholar, PubMed, and Web of Science. The literature collection process was aided by keywords such as rice straw waste management, greenhouse gases, global warming, agricultural sector emissions, rice straw composting, and mitigation. The collected coverage includes papers published from 2013 to 2023.

Literature studies are essential for defining research boundaries, finding theories and arguments that support claims, and defining and explaining important ideas for empirical research (Nakano and Muniz, 2018) . The literature study serves as the basis for future research and theory. It is expected to have the ability to develop new ideas, serve as a basis for knowledge development, set standards of practice and policy, and provide evidence of impact (Snyder, 2019).

The selected literature was chosen based on its pertinence, legitimacy, and connection to the subject matter under discussion. Unqualified goods were removed following the screening. The gathered information and theories were arranged for mapping to facilitate analysis. Literature reviews, according to Helmericks et al. (1991), may consist solely of a summary of the sources, although they are typically organized to include synthesis and summary. A literature review's primary goal is to compile and summarize other people's viewpoints without providing new material.

Relevant theories were then compiled to create the article's draft. It is anticipated that the findings of this evaluation of the literature will support and supplement existing data for further studies, as well as serve as a foundation for examining problems in the management of rice straw waste. Additionally, the results of this study can be used as a guide for managing and processing rice straw waste, developing composting strategies, and reducing the effects of global warming.

Results and discussion

Because cellulose, hemicellulose, and lignin create strong linkages, rice straw is a raw material that is difficult to decompose (Zhang et al., 2022). A high percentage of cellulose (34.2 %), hemicellulose (24.5 %), and lignin (up to 23.4%) are present. Rice straw's high lignocellulose content makes it a promising feed-stock for bio-ethanol. Polysaccharide wrapped in lignin are the primary constituents of lignocellulose (Ana et al., 2021). After harvest, the leftover straw is typically burned even when it is only half used (Goodman, 2020).

The open burning of straw releases greenhouse gases that contribute to global warming, yet there are numerous ways to treat and use straw waste in crop production. The issue is that farmers disregard the effects straw waste has on the environment in favor of burning it (Singh et al., 2021). Burning straw in principle not only wastes raw materials for fertilizer, but also becomes a source of carbon dioxide that affects air quality (Muliarta, 2018). A study in India found that burning agricultural waste releases fine particles that pollute the air and increase the risk of lung cancer by 36 % (Parmar, 2020).

One raw material that can be utilized to make organic fertilizer is rice straw. If it can be turned into compost, it is readily available and a source of nutrients (Yuanita, 2020). One efficient usage for rice straws is composting (Nghi et al., 2020). The situation on the ground has changed significantly because farmers have not composted rice straw, and 96.75 % of farmers said they had not done so because they were unsure of how to proceed (Muliarta, 2019). The labor-intensive and intricate procedure of creating rice straw compost is the reason rice straw composting is challenging (Supaporn et al., 2013).

Burning rice straw and possible emissions of greenhouse gases

An additional organic resource that can be used as compost feed-stock is rice straw. On Earth, biomass from straw waste is a plentiful renewable bio-resource feed-stock (Zhang et al., 2022). Each harvest has the potential to produce 10.21 tons ha^{-1} of rice straw waste. In contrast, each kilogram of grain produced yields 1.3 kilograms of waste rice straw (Muliarta and Purba, 2020). The type of rice affects how much waste is generated from rice straw; inferior rice cultivars may not yield as much biomass from rice straw as local rice varieties (Sumantri and Nugroho, 2019).

Farmers' inability to use the rice straw generated can be attributed to two factors: their long-standing practice of burning the straw and their ignorance of rice straw management (Kadarsah et al., 2023). Another reason why farmers burn the straw is the kind of crop they plant after the rice is harvested. Farmers' decisions to burn rice straw are influenced by crops such as corn and groundnuts (Muliarta, 2018). Due to the short time between harvest and the following planting season, farmers also frequently burn rice straw; therefore, an efficient method of handling the trash produced is required. Although many approaches have been proposed to address the issue of rice straw waste, there hasn't been much use of these alternatives (Nikam and Singh, 2020). The practice of open burning will persist unless technical advancements are made that will lower the expense of treating rice straw trash (Ahmed et al., 2015). Technology that can handle rice straw quickly and farmer aid programs that take the shape of incentives are two ways to start encouraging farmers to return rice straw to the soil (Aminah et al., 2022).

Crop production intensity and country of origin have little bearing on overall greenhouse gas emissions. It is time to target areas with high emissions and high intensity of agricultural production with climate mitigation measures (Carlson et al., 2017). According to Kumar et al. (2021), burning one tonne of rice straw can produce the following greenhouse gases: 1460.00 kg CO_2, 34.70 kg CO, 3.10 kg NO_x, 2.00 kg SO_2, and 1.20 kg CH_4. Table 1 illustrates an estimate of the greenhouse gas emissions per unit area based on the 10.21 tons ha^{-1} of rice straw waste (Muliarta and Purba, 2020).

Table 1. Amount of greenhouse gases generated from rice straw waste combustion activities

Types of Greenhouse Gases	Amount of greenhouse gas from burning 1 tonne of rice straw *	Amount of greenhouse gases from burning 1 ha of rice straw
CO_2	1460.00 kg	14906.6 kg
CO	34.70 kg	354.29 kg
NOx	3.10 kg	31.65 kg
SO_2	2.00 kg	20.42 kg
CH_4	1.20 kg	12.25 kg

*Kumar et al., 2021

Emissions of greenhouse gases will rise if straw waste is burned to expand the harvested area. This study supports the findings of Arai et al., (2015), who contended that expanded rice fields will boost rice yields by adding to the overall biomass of burned crop residues, which will have a major effect on greenhouse gas emissions. For example, by affecting the production of methane (CH_4) from anaerobic decomposition and the loss of carbon from combustion, straw management is a crucial component of emission control and has the potential to lower emissions from rice (Allen et al., 2019).

Choosing a composting method

Composting techniques have improved in recent years to create high-quality compost and expedite the composting process. Fermi-composting, which uses worms as organic matter degrades, Berkeley composting, which uses cellulose- and nitrogen-rich organic matter, Bangalore composting, which uses fecal waste and municipal solid waste as raw materials, and heap composting, which uses a variety of compost materials, are just a few of the techniques that have been developed. The creation of composting methods is an effort to control variables that have the potential to quicken the composting process. The kind of material to be composted, labor availability, equipment availability, and supplementary materials will all have a greater impact on the technology selected and how it is modified (Soam et al., 2017).

One way of composting that doesn't need an outside oxygen source is the anaerobic method. Large volumes of organic waste, including food waste, animal feces, and agricultural waste, are treated using this enclosed method. Anaerobic composting is done by placing organic matter in a closed reactor or treatment system that can be broken down biologically by microorganisms. Anaerobic composting differs from aerobic composting in that it does not require aeration and therefore takes longer (Mckenzie et al., 2022). Meena et al. (2021) reported that composting that occurs without oxygen intervention involves several types of anaerobic microorganisms. Like aerobic microorganisms, anaerobic microorganisms also use N, P, K, and other nutrients for organism development. Anaerobic microorganisms also use nitrogen, phosphorus, and other nutrients to develop cell protoplasm (Mehta and Sirari, 2018).

Methane and carbon dioxide are produced during oxygen-free digestion, leaving behind sediment that can be utilized as organic fertilizer. Methane (CH_4) and carbon dioxide (CO_2) are the principal byproducts of anaerobic digestion of organic materials. The majority of the chemical energy in the primary substrate is liberated as methane gas during anaerobic decomposition (Mckenzie et al., 2022). Elevated carbon dioxide emissions carry consequences for global climate change. Considering that methane gas is 20–30 times more dangerous than carbon dioxide (Arai et al., 2015).

When one tonne of rice straw is turned into compost by anaerobic decomposition, the following gases are produced: 2.05 kg of carbon dioxide, 0.67 kg of carbon monoxide, 0.04 kg of nitrogen oxides, 1.07 kg of methane, and 0.01 kg of hydrogen sulfide (Kumar et al., 2021). Table 2 can be used to determine the greenhouse gas emissions per unit, as the vegetation area of rice straw is 10.21 tons ha^{-1} (Muliarta and Purba, 2020).

Table 2. Greenhouse gas production from rice straw composting by anaerobic method

Types of greenhouse gases from anaerobic composting	Greenhouse gas production resulting from anaerobic composting of 1 tonne of rice straw waste*	Greenhouse gas production from anaerobic composting of 1 ha of rice straw
CO_2	2.05 kg	20.93 kg
CO	0.67 kg	6.84 kg
H_2S	0.01 kg	0.10 kg
NO_x	0.04 kg	0.41 kg
CH_4	1.07 kg	10.92 kg

*Kumar et al., 2021

Anaerobic decomposition produces some positive emissions of greenhouse gases. If the methane released during the anaerobic breakdown of rice straw can be converted into biogas, it will be beneficial. 3,500 MJ tonnes^{-1} of net energy can be produced by anaerobic digestion of rice straw to produce biogas (Nguyen et al., 2016). A hectare of straw output can produce 35,745 MJ ha^{-1} if it is used to produce biogas (Fig. 1).

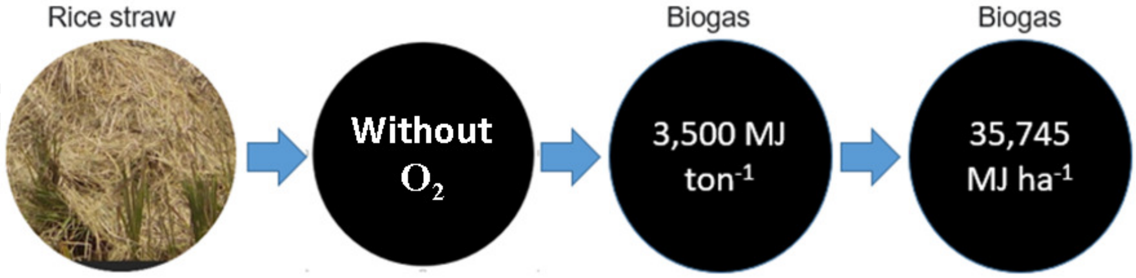

Figure 1. Biogas potential from rice straw waste treatment

Due to the lack of methane gas production, aerobic composting is more effective and environmentally benign than anaerobic composting. Composting, or the breakdown of organic materials by microbes that need oxygen to survive, is known as aerobic composting. Anaerobic composting needs an oxygen-free atmosphere, whereas aerobic composting is quicker and more effective. Because of its superior and shorter decomposition period, aerobic degradation happens more quickly than anaerobic digestion (Christy et al., 2013). The slow growth of methanogenic bacteria is the cause of the poor rate of anaerobic breakdown (Aslanzadeh, 2014).

Aerobic composting works quickly but requires a lot of care as moisture and temperature must be carefully controlled and aeration must be done regularly (Mckenzie et al., 2022). The presence of oxygen accelerates the composting process in aerobic composting compared to anaerobic methods (Meena et al., 2021). In aerobic composting, oxygen enters the compost pile thereby reducing the production of harmful gases, but in anaerobic composting, the closed system produces unpleasant odors (Mehta and Sirari, 2018).

Compared to anaerobic methods, aerobic composting can reduce organic waste by 40–50 %, and the heat produced during the thermophilic phase kills pathogens (Mckenzie et al., 2022). Among the benefits of aerobic composting over anaerobic composting are the following: a) faster raw material decomposition; b) raising the pile temperature to a level where pathogens are present, which prevents weeds from growing; c) the ability to decrease the intensity and volume of gas delivery; and d) the ability to produce the compost quickly (Heydarpour and Farhangi, 2022).

Many studies have shown that aerobic composting produces the lowest greenhouse gas emissions. The atmospheric CH_4 concentration from aerobic composting is estimated to be lower than the atmospheric CO_2 concentration value (Faundry et al., 2015). Aerobic digestion is the most effective way to reduce CH_4 gas production from anaerobic waste storage in sediment tanks (Allen et al., 2019). During aerobic composting, liquid N_2O production is very low due to the low N value of the compost. In addition, the presence of N_2O gas during composting is rare and most studies consider N_2O gas undetectable (Faundry et al., 2015).

Composting as a strategy for sustainable rice cultivation

Owing to the anaerobic breakdown of organic matter in rice, 10 % of greenhouse gas emissions from the worldwide agricultural sector are attributable to this crop. Managing straw is essential to reducing agricultural emissions worldwide. One method of mitigating emissions from rice straw waste management operations is composting. Thanks to improved methods, agriculture may have a significant potential for sequestering carbon. But how to lessen the effects of global warming on crop production—particularly in agricultural systems—is still unknown. (Uusitalo and Leino, 2019).

Composting organic matter into the soil can boost plant growth, protect the environment, and make chemical fertilizer use more efficient. The quantity of empty grains per tiller will decrease as a result of rice straw composting (Barus, 2019). Rice straw conversion into value-added compost will boost agricultural output, lessen environmental pollution, and lessen local pollution from open burning (Zakarya et al., 2018). Because they don't know how to compost rice straw, 97.75 % of farmers typically acknowledge that they don't compost their rice straw (Muliarta, 2019). Conversely, farmers that compost their rice straw considerably contribute to a 54 % reduction in carbon dioxide emissions (De Vera, 2013).

Composting waste from animals and crops on the farm is one of the major issues that on-farm composting addresses and resolves for the sustainability of agricultural practices. When compared to conventional agricultural waste disposal techniques, composting is a sustainable approach from an environmental and economic standpoint (Pergola et al., 2018). Composting offers many advantages when done properly and sustainably. These include creating fertilizer, lowering air and water pollution, cutting expenses associated with operations, and generating money. Errors in execution may result in the generation of methane, the emission of odors, etc. (Nainari et al., 2022). As stabilized organic matter, compost can help improve the fertility and condition of deteriorated soil. Composting is consistent with sustainable agriculture as it is a sustainable process that converts potential trash into organic fertilizer (Pergola et al., 2018).

Organic debris can be transformed into soil-building components for agriculture through the process of composting (Shukla, 2016). Composting has been a popular method for addressing important issues such as the disposal of livestock waste and crop leftovers on agricultural land, thereby contributing to the sustainability of agricultural activities (Hashim et al., 2022). Composting is a useful substitute for conventional waste disposal techniques, which have negative effects on both the environment and people (Pillala and Arrabelli, 2021). Composting has the power to reduce climate change while boosting food system sustainability and productivity (Zhao et al., 2021).

Composting rice straw is a method of implementing the LEISA (low external input sustainable agriculture) concept as well as a strategy for reducing global warming. LEISA uses little outside input and is a sustainable system. To maximize productive resources, this system was created (Djuwendah et al., 2018). The LEISA concept may also be seen as an attempt to use trash as fertilizer to balance and lessen the amount of synthetic fertilizers that farmers typically use. This would lower the cost of synthetic fertilizer purchases for farmers. By balancing fertilizer use, LEISA is anticipated to be able to boost farmers' rice yield (Melinda et al., 2013).

Environmental enhancement and agricultural development are positively impacted by agriculture that uses the LEISA approach. Nonetheless, the majority of small farmers lack the knowledge necessary to properly and efficiently arrange concepts and integrate agricultural commodities in their specific region (Franjaya et al., 2015). One potential solution to address both domestic and global concerns related to food and nutrition security, sustainable agriculture, and environmentally friendly agriculture is the adoption of the Low External Input Sustainable Agriculture (LEISA) system (Setiyo et al., 2017). Long-term usage of the LEISA concept in rice cultivation can increase soil organic carbon while reducing the need for synthetic fertilizer use by more than 13% (Firth et al., 2020).

Composting and circular economy implementation

Composting rice straw waste to produce organic fertilizer which can be used in efforts to increase rice production is part of circular economic activities. Rice straw waste must be used at all costs with technology to ensure zero waste and no harm to the environment. This strategy is part of building sustainable agriculture so that rice straw waste management must be carried out periodically to form an economic cycle or circular economy. The idea of the circular economy views trash or rejected materials as the primary component. It is anticipated that as agricultural waste management advances, all by-products will be recycled back into the economy to create multipurpose goods (Illankoon et al., 2023). Rice straw has calories and nutritional value. For the majority of rice growers, straw is the only organic material that they can obtain in large amounts. It is not only the farmer's duty to use rice straw properly; the government should enact appropriate laws and regulations to prevent stubble burning. Both required training for farmers and public awareness campaigns on rice straw management are necessary (Singh and Brar, 2021).

To achieve sustainable development by reducing resource consumption, it is imperative that attempts to establish a circular economy model prioritize increasing public knowledge (Sulewski et al., 2021). The circular economy idea will raise the value of byproducts and offer more ways to treat garbage for waste management (Li et al., 2016). To promote economic growth, the circular economy concept can reduce the annual use of natural resources by up to four times. This idea confirms that a systematic approach that takes waste management, manufacturing, and consumption into account is necessary to address the circularity of the economic system (Bianchi and Cordella, 2023).

When considering the circular economy (CE) in the current context of resource scarcity, global climate change, environmental degradation, and rising food demand, it appears to be a promising approach to promoting restorative, regenerative, and sustainable agriculture (Gallego-Schmid et al., 2021). By suggesting activities and solutions to recover waste and by-products in the production chain, the circular economy can be a better way to become involved and lessen the impacts created in the agri-food sector (Chiaraluce et al., 2021). One sustainable development approach that has been suggested to address the urgent issues of resource shortages and environmental degradation is the circular economy (Heshmati, 2017).

Reducing greenhouse gas emissions and altering the extraction, processing, design, use, and return of materials to manufacturing systems are two benefits of a circular economy strategy. Currently underway sector-specific initiatives to mitigate carbon dioxide emissions include those aimed at black carbon, methane, nitrous oxide, and fluorinated hydrocarbons. The key to reducing greenhouse gas emissions is, according to Gallego-Schmid et al. (2020), boosting resource efficiency by delaying, closing, and decreasing the material and energy loop. Reducing CO2 emissions is one way to advance the circular economy, which is important for enhancing environmental quality. Business initiatives that encourage circular economies and recycling practices contribute significantly to environmental sustainability by lowering emissions (Hailemariam and Erdiaw-Kwasie, 2023).

Composting as an effort towards resilient fertilizer availability

Reducing the usage of chemical fertilizers, lowering leach-ate levels, and safeguarding both renewable and non-renewable resources are just a few ways that effective agricultural waste management helps conserve the environment (Kavvadias et al., 2023). Composting is a process that helps reduce pollution and produce bio-fertilizers that are safer for both people and the environment. One of the easiest and most efficient ways to make natural fertilizer for plant development is by composting. For effective waste management, this technique is equally crucial (Parihar and Sharma, 2021).

Rather than being burned on the field, as farmers often do, which can lead to pollution, rice straw can be used as a soil conditioner through the composting process (Khalib et al., 2019). Additionally, studies demonstrate the benefits of using rice straw compost over manure treatment. This has to do with the high nutritional content of straw, particularly potassium (Salamba et al., 2021). The most effective strategy to boost lowland rice production is to use both organic and inorganic fertilizers (Lenin et al., 2021). Composting can boost microbial diversity and replace 10 % of artificial fertilizers. Thus, rice yields can be raised by using compost in place of 10 % of artificial fertilizer (Huang et al., 2023).

Typically, 10.21 tons ha^{-1} of rice straw waste are produced (Muliarta and Purba, 2020). Every ton of straw waste converted into compost will yield 0.5–0.75 tons of compost (Kadir and Harsani, 2023). Accordingly, 5.11 to 7.66 tonnes of organic fertilizer can be produced from one hectare of rice harvest if the rice straw is composted.

Concurrently, 8–10 tons of organic fertilizer are needed per hectare for organic rice production (Sutrisno, 2014). This condition means that composting rice straw, apart from being an effort to mitigate global warming, also helps provide fertilizer availability of around half the dose required for organic rice cultivation. Meanwhile, specifically local upland rice varieties usually requires a dose of organic fertilizer reaching 15 tons ha^{-1} (Gusmiatun et al., 2019).

Conclusion

Composting is a responsible rice straw waste management method and one of the approaches to reducing greenhouse gas emissions from rice straw waste management, which helps mitigate global warming. Rather than burning straw waste in the open after harvest, composting is the most effective way to add organic matter to the soil. Besides reducing the need for inorganic fertilizer, composting also helps farmers produce fertilizer.

The aerobic method of composting rice straw waste produces relatively little greenhouse gas emissions and does not produce methane gas, making it a composting technique that is adaptive to attempts to mitigate global warming. The aerobic approach is quick, simple, and practical, making it ideal for in situ composting in rice fields. Because it doesn't need a unique location that is airtight or oxygen-free, aerobic composting is thought to be more practical and simpler.

The anaerobic composting method is considered less environmentally friendly because it produces methane gas during composting. The methane gas generated during composting will exacerbate greenhouse gas emissions if it is not used, but it will have more positive effects if it is used as alternative energy in the form of biogas. Reducing the usage of fossil fuel energy, which increases greenhouse gas emissions, can be achieved by utilizing renewable energy.

This article is still limited to discussing the selection of composting methods for rice straw waste and is not able to provide a discussion of composting agricultural waste as a whole. It is hoped that the direction of future development will include research and development of composting technology that is more efficient, faster, and environmentally friendly. The next hope is the integration of rice straw composting technology with broader agricultural systems, such as organic farming and integrated farming.

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