Bulgarian Journal of Agricultural Science, 30 (No 5) 2024, 948–956

Potential greenhouse gas emissions and fertiliser material losses from rice straw management failure. Review

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Abstract

Muliarta, I. N. (2024). Potential greenhouse gas emissions and fertiliser material losses from rice straw management failure. Review. *Bulg. J. Agric. Sci., 30*(5), 948–956

Agriculture is one of the sectors that contribute to the increase in global emissions, starting from the land preparation process to the post-harvest process. The burning of rice straw is a form of failure in agricultural waste management and is one of the sources of global emissions in rice cultivation activities. Failure in the rice straw management process not only contributes to increased greenhouse area contributes to global warming by contributing gas emissions reaching 14,906.6 kg CO_2, 354.29 gas emissions but also loss of fertilizer materials. The activity of burning rice straw in a one-ha kg CO, 132.73 kg PM (particulate matter), 31.65 kg NO_x, 20.42 kg SO_2 and 12.25 kg CH_4. Failure to manage rice straw in the form of burning has also caused a loss of compost in a 1-ha area of 5.11 t. If rice straw is processed into compost, it can reduce the use of inorganic fertilizer, which is one form of application of the concept of low external input sustainable agriculture (LEISA). Rice straw management in principle is also a form of implementing a circular economy and efforts to realize sustainable agriculture.

Keywords: composting; fertilizers; greenhouse gases; rice straw; waste management

Inroduction

Agriculture contributes significantly to the increase in global emissions. Over 20 years the agricultural sector contributed about 20 percent of global greenhouse gas emissions (Ahmed et al., 2020). Other research suggests that agriculture accounts for up to 24 percent of global greenhouse gas emissions (Doğan & Karakaş, 2019). Most countries in the world that rely on imports of agricultural products currently emphasize agricultural production of environmentally friendly products and pay more attention to the carbon emissions of agricultural production in exporting countries (Zang et al., 2022). Based on scientific analyses, the adverse impacts of climate change can be avoided by keeping the global temperature rise no more than 1.5°C to 2°C (Minister of Environment and Forestry, 2022).

Rice has been one of the major food products economically in the world today (Bodie et al., 2019). The global rice production system faces two opposing challenges: the need to increase production to accommodate the growing world population while reducing greenhouse gas (GHG) emissions (Islam et al., 2018). Rice production is always followed by a by-product in the form of rice straw waste that should be properly managed during harvest (El-Dewany et al., 2018). Although some have been utilized, straw waste tends to be burned after harvest (Goodman, 2020). The burning of straw has the potential to harm human health in the form of respiratory problems and impact the environment in the form of contributing to increased emissions of exhaust emissions (El-Dewany et al., 2018). The Food and Agriculture Organisation (FAO) states that the rice production process and the management of the resulting by-products would be a more sustainable and beneficial step for many reasons (Bodie et al., 2019).

Research in India found that burning agricultural waste emits fine particles that cause air pollution and contribute to increasing the risk of lung cancer by 36% (Parmar, 2020).

A common reason for burning rice straw is to speed up tillage to catch up with the next planting season and avoid the spread of pests and diseases. The type of horticultural crops to be planted after rice harvest greatly influences farmers' decision to burn rice straw. There are two types of crops that tend to influence farmers' decision to burn rice straw, namely maize, and groundnuts (Muliarta, 2018).

Greenhouse gas emissions from open burning of straw can be avoided, as there are many methodologies to manage and utilize straw waste generated from crops. The problem is that farmers around the world prefer to burn straw waste and ignore its environmental impact (Singh et al., 2021). Open burning of straw, on the other hand, is not only a waste of fertilizer but also a source of carbon gas emissions that impact air quality (Muliarta, 2019).

Rice straw is a raw material that is difficult to decompose due to the presence of strong bonds in the form of cellulose, hemicellulose, and lignin (Zhang et al., 2022). The high cellulose content reaches 34.2% by dry weight, the hemicellulose content is 24.5% and lignin is up to 23.4%. Rice straw has potential as a raw material for bioethanol production due to its high lignocellulose content. The main component in lignocellulose is polysaccharides encased in lignin (Ana et al., 2021). Its utilisation based on the concept of circular economy has played an important role in achieving sustainable development goals (Harun et al., 2016).

Agricultural residues, one of which is rice straw, are an important energy feedstock for power generation (Bazaluk et al., 2021). Generation from renewable energy or bioenergy is a sustainable approach to waste management, especially in developing countries (Seglah et al., 2022). The utilisation of straw as bioenergy can reduce global warming potential compared to energy production from fossil fuels (Harun et al., 2016). Crop straw power generation not only promotes sustainable biomass management but also reduces anthropogenic greenhouse gas emissions that can cause several environmental problems (Seglah et al., 2022). Agricultural waste can be recycled in various ways. Cost-effectiveness is important information for enterprise investment decision-making and government policy-making to choose a favorable way to recycle agricultural waste (Hsu, 2021).

Straw waste biomass is an abundant renewable bioresource feedstock on Earth (Zhang et al., 2022). The potential production of rice straw waste at each harvest reaches 10.21 t ha^{-1}. If made in comparison, every production of 1 kg of grain also produces 1.3 kg of rice straw waste (Muliarta & Purba, 2020). The amount of rice straw waste is influenced by the variety, local rice varieties have the potential to produce higher rice straw biomass than superior rice varieties (Sumantri & Hadi, 2019).

Rice straw is a local raw material that can be used as a raw material for organic fertilizer. Its availability is quite abundant and becomes a source of nutrients if it can be processed into compost (Yuanita, 2020). The use of rice straw compost in rice plants can be an effort to reduce the use of inorganic fertilizers without reducing rice yield and quality (Kadoglidou et al., 2019).

Various alternatives to the use of straw in the future are expected to eliminate the habit of burning straw by farmers. This step must certainly be followed by political policy (Goodman, 2020). Many national and international institutions have called for an open ban on burning rice straws with the aim of preventing biomass loss and reducing CO_2 emissions (M. N. Nguyen, 2020). The country's commitment is also important in reducing emissions, such as Indonesia which is committed to reducing greenhouse gas emissions with an unconditional 29% target (Minister of Environment and Forestry, 2022).

A survey study in Klungkung Regency, Bali found that there were no farmers who processed rice straw into compost. Farmers reason that they do not know how to compost rice straws and have not received training on how to compost rice straws (Muliarta, 2019). Farmers in Subak Telun Ayah, Tegalalang, Gianyar-Bali also have not done rice straw composting because they do not know the method of composting rice straw. This reason causes farmers to prefer to burn the rice straw produced (Muliarta et al., 2022). A study in Egypt revealed that on average around 3 mln t of agricultural waste, especially rice straw is burned annually (El-Dewany et al., 2018).

The habit of disposing of straw waste by burning will contribute to further increasing greenhouse gas emissions. Burning rice straw on the other hand also means throwing away compost raw materials. Though the use of compost can reduce the use of inorganic fertilizers and reduce production costs due to fertilizer purchases.

Material and Methods

This research is a literature review. The first step taken is to formulate rice straw waste management problems that commonly occur in rice cultivation. Based on the existing problem formulation, it is then focused on the problem of the impact of failure to manage rice straw waste on increasing greenhouse gas emissions and wasted fertilizer raw materials in vain.

Based on the predetermined problem formulation, literature collection is carried out, either sourced from books or scientific articles online. An online search for scientific articles is done by accessing https://scholar.google.co.id/.

To facilitate the process of collecting literature using keywords, such as waste management of rice straw, rice straw, greenhouse gases, emissions from the agricultural sector, composting rice straw, and rice straw compost. The literature collected is articles published between 2018 and 2022.

Literature studies play an important role in providing clear studies and boundaries, finding theories or arguments that support claims, and defining and explaining key ideas for use in the empirical studies section (Nakano & Muniz, 2018). The study of literature serves as the basis for future research and theory. They can serve as a basis for knowledge development, create guidelines for policy and practice, provide evidence of effect, and, if done well, have the capacity to give birth to new ideas and the direction of specific fields (Snyder, 2019).

The collected literature is then selected with due regard to validity, reliability, and relevance to the issues discussed. For the analysis to be easier to complete, the theories and facts that have been collected are then compiled to do the mapping. The next stage is to combine related hypotheses to develop a research statement. The findings of this literature review are expected to contribute and offer more data to conduct research as well as serve as a basis for examining issues related to rice straw waste management. This study is expected to be a reference in the utilization and processing of rice straw waste, as well as a reference in mitigating global warming.

Results and Discussion

Potential of Rice Straw Waste

Rice is an important item, the demand for rice is still increasing every year due to population growth (Arsani, 2020). Rice production is associated with large amounts of rice straw, which have traditionally been eliminated by the practice of open-field burning (El-Dewany et al., 2018). Straw is the residue of rice harvest residue that has not been optimally utilized (Sumarno et al., 2020). The simple reason farmers burn rice straw is to speed up tillage to catch up with the next growing season and avoid the spread of pests and diseases. The type of crop to be planted after the rice harvest also greatly influences the decision of farmers to burn rice straw (Muliarta, 2018). The burning of rice straw pollutes the air, producing greenhouse gas emissions, particulate matter (2.5 and 10 μm) emissions, considerable losses on soil properties, soil nutrients, organic matter, productivity, and biodiversity, as well as humans and animals inside and outside health agriculture (Sharma et al., 2023).

Straw waste production is strongly influenced by the type or variety of rice plants (Sharma et al., 2023). The amount of rice straw waste production is also greatly influenced by the amount of fertilizer applied (Muliarta & Purba, 2020). Rice straw in India is mostly used as animal feed, but the rest is burned by local farmers (Kumar et al., 2021). Its total global production is estimated at 800 to 1000 mln t, of which about 91% is produced in Asia. Rice straw production is predicted to increase every year along with intensive rice planting (Harun et al., 2016).

Straw production in Indonesia as agricultural waste from rice crops reached 70.831 mln t in 2014 (Ana et al., 2021). Based on the results of calculations in Thailand, it was obtained that the amount of rice straw waste during the growing season of 2015/2016, was around 26 Mt. The net potential of rice straw, both burned and left in rice fields, is only about 15% or 3.85 Mt, which is used for heat and electricity production of 1331 kilotons (Cheewaphongphan et al., 2018). If you use the potential of broad unity straw waste, you can use the results of research by Muliarta & Purba (2020) which found that the amount of rice straw waste in each harvest reached 10.21 t ha^{-1}.

Potential greenhouse gas emissions from failure to manage rice straw waste

Rice cultivation accounts for 10% of greenhouse gases from the global agricultural sector due to the production of CH_4 from the anaerobic decomposition of organic matter. Straw management measures are a key factor in controlling global agricultural emissions (Allen et al., 2019). Increasing the utilization of straw is an effective way to turn waste into treasure, meet the needs of human society and reduce environmental pollution (Sun et al., 2022). Off-field practices such as composting, biochar, and bioenergy offer greater potential mitigation opportunities than on-the-ground practices. Composting, for example, can mitigate both emissions associated with the incorporation of fresh straw and others related to manure and fertilizer use (Allen et al., 2019).

The utilization of straw allows for a significant reduction in pollutant emissions: about one-hundredth of particulate matter formation compared to open combustion and one-tenth of ozone depletion (Bressan et al., 2022). Rice straw as an energy source can replace fossil fuels and reduce greenhouse gas emissions (Said et al., 2020). For example, the use of rice straw in China in 2020 was able to reduce carbon emissions from straw by 63.43×10^9 kg of CO_2. Disposal and incineration will only lead to a serious waste of biomass resources and environmental pollution (Sun et al., 2022).

The use of rice straw on the other hand to produce energy as an alternative to conventional fuels helps reduce global warming from rice cultivation (Bressan et al., 2022). Combining rice straw in flooded soil with a crimper roller increases off-season CH_4 emissions, and is used in combination with ryegrass, proving to be the most significant contributor to partial global warming potential (Grohs et al., 2020).

The practice of burning rice straw after harvesting seems to be common and common among farmers. The reason is simple to speed up tillage to catch up with the next growing season and avoid the spread of pests and diseases (Muliarta, 2018). Another reason is that burning is a fast, cheap, and efficient way to prepare the soil layer for the next growing season (Lakhvir & Brar, 2021). Sometimes the type of crop to be planted greatly influences the farmer's decision to burn rice straw (Muliarta, 2018).

Several studies have proven that open land burning and soil merging are unsustainable rice straw management practices, but remain common methods for cultivating and disposing of rice straw (Migo-Sumagang et al., 2020). The problem of open burning of rice straw is particularly severe in Asia, which is the world's largest producer as well as the world's largest rice consumer. Asian countries produce more than 70% of the world's rice production (Singh et al., 2021). About 150 mln t of rice straw are produced in Southeast Asian countries every year (Nguyen et al., 2016).

Burning 1 ton of rice straw can produce 1,460 kg CO_2, 34.70 kg CO, 3.10 kg NO_x, 2.00 kg SO_2, and 1.20 kg CH_4. Unlike when 1 ton of straw undergoes an aerobic decomposition process, it will produce 2.05 kg CO_2 (carbon dioxide), 0.67 kg CO (carbon monoxide), 0.01 kg H_2S (hydrogen sulfide), 0.04 kg NO_x (oxides of nitrogen) and 1.07 kg CH_4 (methane) (Kumar et al., 2021). When using data on the amount of rice straw waste of 10.21 t ha^{-1} (Muliarta & Purba, 2020), it can be estimated that greenhouse gas emissions per unit area (Figure 1).

The burning of rice straw in one hectare contributes directly by producing 14,906.6 kg CO_2, 354.29 kg CO, 132.73 kg PM (particulate matter), 31.65 kg NO_x, 20.42 kg SO_2, and 12.25 kg CH_4. The increase in the area of rice harvested whose straw is burned will cause an increase in greenhouse gas emissions produced. This analysis is the same as the statement of Arai et al. (2015) which states that increasing rice production through the expansion of rice planting has an impact on increasing the total biomass of plant residues burned, which ultimately has a significant impact on greenhouse gas emissions. Straw management is a key factor in controlling rice emissions and mitigation potential, especially by affecting methane (CH_4) from anaerobic decomposition and carbon loss due to combustion (Allen et al., 2019).

Immersion of rice straw into the ground which causes decomposition to take place anaerobically or the process of anaerobic decomposition contributes greatly to the increase in greenhouse gas emissions, both CO_2 and CH_4 gases. If rice straw from the harvest area reaches one hectare, if decomposed anaerobically it will produce 20.93 kg CO_2, 6.84 kg CO, 0.10 kg H_2S, 0.40 kg NO_x, and 10.92 kg CH_4. This condition is in line with the statement of Grohs et al. (2020) which states that methane emissions arise when the rice straw is included immediately after harvest with flooded soil conditions. The incorporation of straw is highly recommended in rice paddy fields to improve soil quality and mitigate atmospheric carbon dioxide (CO_2), through increasing soil organic carbon (SOC) stocks. However, immersion of rice straw into the ground significantly increases methane (CH_4) emissions during rice planting (Song et al., 2019).

Potential loss of organic fertilizer

Rice straw is a resource that can be used as organic fertilizer. Burning rice straw commonly carried out by farmers is a detrimental action because it is equivalent to disposing of fertilizer raw materials (Muliarta & Purba, 2020). The burning of straw has caused the soil to experience a continuous decrease in organic matter and organic carbon content because the biomass from rice plants is not returned to the land adequately. Farmers prefer to return rice straw after burning, but this will not improve conditions (Aminah et al., 2022). Burning straws will cause losses of 5–8 kg N, 2–3 kg P, and 15–20 kg K per ton of straw burned (IRRI, 2020). Long-term return of straw to the soil, accompanied by reducing chemical fertilizers, not only improves nutrient stocks and soil fertility but also increases nitrogen supply capacity in the soil (Chen et al., 2022).

Globally only about 20% of rice straw is used for purposes such as ethanol, paper, fertilizer, and animal feed and the

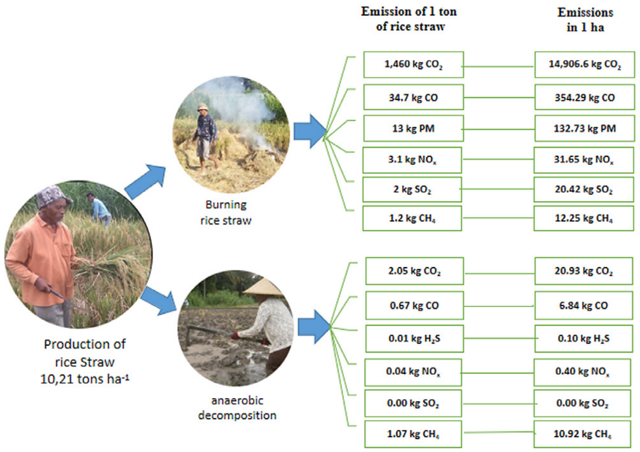

Fig. 1. Comparison of emissions from open burning and anaerobic decomposition of rice straw

remaining amount is removed from the field, burned on the spot, stacked or spread on the land, put into the soil, or used as mulch for subsequent crops (Hanafi et al., 2012). Rice straw as organic matter contains about 80, 40, and 30% potassium (K), nitrogen (N), and phosphorus (P), respectively, which are taken up by rice and thus their combination can reduce the need for subsequent crop fertilizers (Chivenge et al., 2019). Another study states that about 40% of nitrogen (N), 30 to 35% of phosphorus (P), 80 to 85% of potassium (K), and 40 to 50% of sulfur (S) taken up by rice remains in vegetative plant parts at the time of mature harvest (Singh & Brar, 2021). But keep in mind that different cultivars affect variations in the nutrient content and fiber of rice straw (Wahyono et al., 2021).

Composting is one way to use rice straws effectively (Nghi et al., 2020). The problem is that there are no farmers who compost rice straw, and it was found that 97.75% of farmers admitted that they did not make rice straw compost because of their ignorance about how and how to compost rice straw (Muliarta, 2019). The difficulty of making rice straw compost seems to be the root of the problem because the procedure for making compost rice straw is complex and labor-intensive (Supaporn et al., 2013). Organic fertilizers such as compost, in addition to providing nutrients for plants, can also improve the physical, chemical, and biological properties of the soil and maintain environmental balance (Kadir & Harsani, 2023). Rice straw when it has become compost, on average contains C-organic around 16.37–20.02%, N-total 0.66–0.73%, P-total 0.11–0.12%, and K reaches 0.40–0.69% (Barus, 2019).

The average rice straw production is quite large, reaching around 10.21 t ha^{-1} (Muliarta & Purba, 2020). Some studies on the other hand say that when 1 ton of straw is composted, it will produce 0.5 t to 0.75 t of compost (Kadir & Harsani, 2023). If you use the lowest estimate, where 1 ton of straw when decomposed produces 0.5 t of compost, then the amount of compost that can be produced from harvesting rice from one hectare of land area is around 5.11 t of compost. This means that if in managing rice straw, farmers burn, it means disposing of compost reaching 5.11 t ha^{-1}. If converted into clean energy, the rice straw supply chain can produce biogas through anaerobic digestion of 3,500 MJ per ton (Nguyen et al., 2016). This means that if straw production in an area of 1 ha is used as biogas, it will produce biogas of as much as 35,745 MJ ha^{-1} (Figure 2).

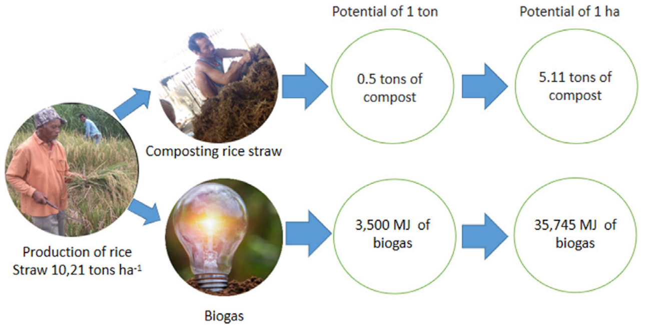

Fig. 2. Conversion of rice straw waste into compost and biogas

The use of rice straw compost can be one way to streamline the use of inorganic fertilizers (Muliarta & Suanda, 2021). The combination of organic and inorganic fertilizers is the best way to increase rice yields (Lenin et al., 2021). Rice straw compost can reduce the use of inorganic fertilizers ranging from 20–80% without reducing yield. The use of rice straw compost can also be a way to reduce exhaust gas emissions from burning straw and realize environmentally-friendly rice cultivation (Muliarta & Suanda, 2021). The application of a combination of organic and inorganic fertilizers in rice cultivation can increase yields by about 10-12% (Lenin et al., 2021).

The use of rice straw in compost to reduce the use of inorganic fertilizers is one form of application of the concept of low external input sustainable agriculture (LEISA) (Tangkesalu et al., 2021). LEISA is a term that refers to agricultural practices carried out with three main objectives; environmental conservation, economic profitability, and social equality (Tiwari et al., 2020). LEISA can improve soil porosity from 35% to more than 50% or at ideal conditions of potato cultivation. As a result, the water content in the soil especially in the root zone is available for potatoes to grow for 13-17 days (Setiyo et al., 2017). Long-term application of LEISA's unique rice farming system can reduce the need for synthetic fertilizer applications by more than 13% while increasing soil organic carbon (Firth et al., 2020). The implementation of LEISA can be one of the enabling answers nationally and internationally to issues such as (1) food security and nutrition, (2) sustainable agriculture, and (3) environmentally friendly agriculture (Setiyo et al., 2017). Efficient utilization of crop straw is a decisive factor for clean production and sustainable development in the agricultural sector (Seglah et al., 2022).

Rice straw management and circular economy

Previously, rice straw was considered a renewable resource and of economic value, but today straw is still burned in the fields because it is no longer needed for cooking, roofing, and animal feed as before the 1990s (Nguyen, 2019). Agricultural waste management in the future is time to be directed to the development of multifunctional products by utilizing all by-products into products of economic value ((Illankoon et al., 2023). If managed effectively, rice straw has the potential to preserve agricultural ecosystems and increase the economic resilience of populations dependent on rice farming (Kumar et al., 2023).

Waste management should direct its efforts on reduction, recycling, and treatment techniques, which view waste as a resource (Guman & Wegner-Kozlova, 2020). The processing of waste into compost is a win-win option that allows not only reduces environmental pollution coming from open waste disposal but also recovers essential nutrients for crop production, consequently increasing crop yields and reducing the use of expensive chemical fertilizers (Bekchanov & Mirzabaev, 2018). The use of compost in agriculture will be beneficial both for increasing soil organic matter and reducing GHG. The results show how high-quality compost can represent the true driving force of these changes being able to link food, waste, economics, and the environment (Razza et al., 2018).

Policy development for integrated rice straw management is needed to increase value in the supply chain and consumption of straw products, to increase the effective use of this resource and minimize environmental pollution (Nguyen, 2019). The conversion of rice straw into biofertilizer formulations presents an encouraging solution for rice straw management, which can have positive economic and ecological outcomes (Sharma et al., 2023). Placing by-products from the rice cultivation process into new raw materials is a form of implementation of the circular economy concept (Belc et al., 2019). Biotransformation of rice straw into biofertilizer formulation is a technically feasible and cost-effective method. Rice straw management following the basic principles of a circular economy is economically feasible and is a sustainable solution (Sharma et al., 2023).

The circular economy is a priority goal today, especially at the European level. Waste management is just one of the relevant fields to improve the circular economy (Moustakas & Loizidou, 2023). The concept of circular economy (CE) can contribute to a paradigm shift in the transformation of traditional linear approaches that do not like the concepts of reuse, recycling, and recovery (Khatiwada & Golzar, 2021). The idea of a circular economy reinforces the sustainable development approach. The implementation of the circular economy concept can be considered a panacea for existing problems related to waste management (Mandpe et al., 2023). The application of circular economy principles is more often considered a key driver for achieving sustainable development goals. Economic activities in terms of a circular economy target conservation by maximizing the value of products, materials, and resources, as well as minimizing the amount of pollution or waste produced, at the same time (Guman & Wegner-Kozlova, 2020)).

Rice straw waste management when viewed from a circular economy side, each ton of rice straw compost has a nutritional content equivalent to Urea 41 kg of, SP36 6 kg of, and KCl 89 kg or equivalent to a total of 136 kg NPK (Wahyuni & Hoesain, 2017). If one hectare of rice harvest area produces 5.11 t of compost, there will be around 694.96 kg of NPK that can be returned to the ground. According to Surdianto & Sutrisna (2015), so far rice farmers generally use fertilizers with doses of 200–250 kg ha^{-1} Urea, 150 kg ha^{-1} SP36, and 100 kg ha^{-1} KCl. The problem is that the release of nutrients from compost or organic fertilizer when implemented into the soil is very slow (Adugna, 2016). This is what causes the use of organic fertilizers in plants not to replace inorganic fertilizers, but as a complement to increase soil and plant productivity in a sustainable manner (Murnita & Taher, 2021).

Conclusions

Burning rice straw by farmers is one form of failure in agricultural waste management that contributes to greenhouse gas emissions. Rice straw waste in an area of one hectare, if burned will contribute to global warming by contributing to gas emissions reaching 14,906.6 kg CO_2, 354.29 kg CO, 132.73 kg PM (particulate matter), 31.65 kg NO_x, 20.42 kg SO_2 and 12.25 kg CH_4.

Failure in the management of rice straw in the form of burning also causes organic fertilizer loss in an area of 1 ha reaching 5.11 tons. Processing rice straw into compost can reduce the use of inorganic fertilizers, which is one form of application of the concept of low external input sustainable agriculture (LEISA).

Acknowledgements

We would like to express our gratitude to Made Sumariani who has helped in collecting journals and books related to rice straw management, and the impact of burning rice straw. We convey the same greeting to I Wayan Raditya Mahendranata who has helped in grouping literature and helping to analyze the collected data so that it makes it easier to write articles.

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Received: **July, 13, 2023**; *Approved*: **November, 05, 2023;** *Published:* **October, 2024**