Open Access
J. Glob. Innov. Agric. Sci., 2024, 12(3):555-561
ISSN (Online): 2788-4546; ISSN (Print):2788-4538
DOI: https://doi.org/10.22194/JGIAS/24.1320
http://www.jgiass.com

Assessing and enhancing sustainable rice straw management for environmental conservation in Yen Thanh District, Nghe An Province, Vietnam

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This study assessed the current management of rice straw in Yen Thanh District, Nghe An Province, and propose solutions for sustainable agricultural development. A survey was conducted with 120 households in four communes to determine straw use and management practices. The findings revealed six common methods of using and managing rice straw in Yen Thanh District: open burning, burying, mushroom plantation, using it for husbandry feeding, selling, and giving it to others. These practices vary based on the crop season. Open burning is the most prevalent practice, accounting for 98.15% and 89.52% during the winter-spring and summer-autumn harvests, respectively. A crucial step in establishing a pollution control and management database is a comprehensive inventory of emissions. Consequently, authorities and environmental scientists are currently focusing on the emission inventory, particularly emissions resulting from open-burning rice straws. The estimated total amount of rice straw produced annually is 159,732 tons, with 151,384 tons being directly burned in the fields. This burning releases significant emissions, including 1,005.18 tons of $PM_{2.5}$, 1,102.08 tons of PM_{10}, 21.80 tons of SO_2, 142,543.18 tons of CO_2, and more, negatively impacting the environment, human health, and agriculture. Additionally, it was observed that most farmers are inclined to continue burning rice straw out of habit in the upcoming years. The study suggests promoting alternative straw management practices such as mushroom cultivation, biochar production, and organic fertilizer production to reduce burning and its associated negative consequences. This information would be invaluable for managers to effectively plan for the future management of rice straw.

Keywords: Nghe An Province, waste management, rice straw, agricultural residue, Yen Thanh District.

INTRODUCTION

Rice is the primary food crop in Vietnam and many other countries. Rice straw, the stems and leaves of the rice plant remaining after harvesting, is an agricultural waste product. Every kilogram of grain harvested produces of 1-1.5 kg of straw (Maiorella, 1985). At harvest time, the moisture content of rice straw is as high as 60% (Le *et al.*, 2017). However, in dry weather conditions, rice straw can dry quickly, reaching an equilibrium moisture state of about 10-12% (Le *et al.*, 2017). Rice straw usually has high ash content (over 22%) and low protein content (Ta *et al.*, 2010). The main carbohydrate components of rice straw include lignocellulose (37.4%), hemicelluloses (semi-cellulose - 44.9%), lignin (4.9%), and high silica ash (silicon dioxide) content (9 - 14%) (Ta *et al.*, 2010). Rice straw is also considered an essential nutrient source that can increase rice yield and improve soil fertility over time (Ponnamperuma, 1984). In Vietnam, the annual amount of rice straw produced is approximately 67.6 million tons, but most of it is not used effectively (Cassou *et al.*, 2017). Common methods for managing rice straw after harvest include collecting it for cooking fuel, spreading it in the field, plowing it into the soil, or using it as mulch for crops. However, with improved living standards in rural areas, farmers are increasingly using commercialized fuels and less reliant on agricultural by-products for cooking (Ta *et al.*, 2010). Furthermore, the utilization of rice straw are still very limited due to two main reasons: technical obstacles and economic feasibility, especially concerning issues of harvesting, transportation, and storage. Consequently, the practice of burning rice straw directly in the field after harvest has become more common, leading to air pollution and a waste of organic carbon energy (VMONRE, 2014). Incomplete combustion of straw generates thick smoke that

Tiep, N.V., N.V.D. Thinh and L.Q. Tuan. 2024. Assessing and enhancing sustainable rice straw management for environmental conservation in Yen Thanh District, Nghe An Province, Vietnam. Journal of Global Innovations in Agricultural Sciences 12:555-561.
[Received 29Feb 2024; Accepted 30 Jun 2024; Published 13 Aug 2024]

covers large areas, affecting the health of nearby residents and posing a risk to traffic safety (Nguyen, 2012). Additionally, air pollutants emitted from open burning, such as CO_2, CO, CH_4, NO_x, SO_x, $PM_{2.5}$, PM_{10}, PAHs, PCDDs, and PCDFs, have been linked to respiratory problems (Gadde *et al.*, 2009). Furthermore, burning contributes to regional and global climate change (Le *et al.*, 2013). Exhaust gases, such as SO_x and NO_x, can accumulate in the atmosphere, leading to the formation of acid rain. Despite these negative impacts, air pollution from agricultural waste burning is often neglected in air quality management programs in many countries. Quantifying emissions from burning agricultural residues is crucial for developing appropriate national air quality policies and fostering international cooperation to control these emissions effectively (Kanabkaew and Oanh, 2010). Studies on emissions from open burning of agricultural wastes, including rice straw, have been conducted in many Asian countries such as Thailand, India, Indonesia, Philippines, China, and Vietnam (Kanabkaew and Oanh, 2010). However, limited research has focused on rice straw burning in Nghe An Province, particularly Yen Thanh District.

This study investigated rice production, straw use and management practices, and open-burning activities in Yen Thanh District, Nghe An Province (Figure 1). The study also estimated greenhouse gas emissions from rice straw burning in the area and proposed solutions to promote sustainable rice straw management for environmental protection and community health.

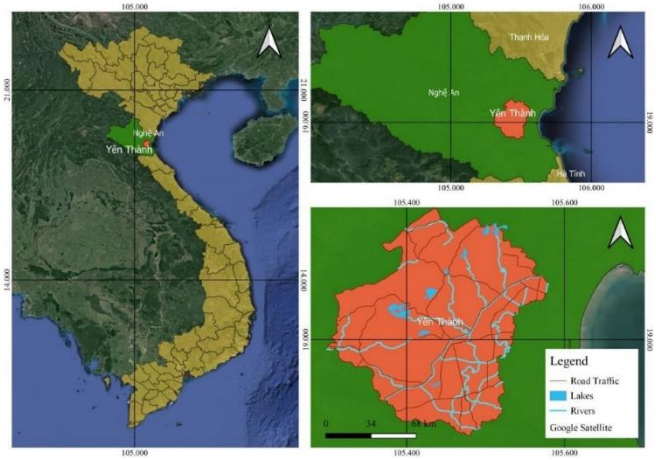

Figure 1. Map of Yen Thanh District, Nghe An Province

MATERIALS AND METHODS

***Data collection*:** Secondary data (rice area, rice production in Yen Thanh District) were collected from the General Statistics Office of Vietnam, the statistical yearbook of Nghe An Province, and the Department of Agriculture and Rural Development of Yen Thanh District. A survey using pre-prepared questionnaires was conducted in four communes (Hop Thanh, Phuc Thanh, Nhan Thanh, and Vinh Thanh) with the highest rice cultivation areas in the district, from October to November 2020. The questionnaire comprises three parts: Part I covers demographics of the interviewee (full name, gender, education, main income sources, age, address), Part II addresses the rice farming situation (area, number of crops/year, rice varieties, productivity, harvesting methods), and Part III focuses on straw management practices (amount of straw for each purpose of use in each crop). Sample size formula is determined and followed by Yamane (1967):

$$\boldsymbol{n} = \frac{\boldsymbol{N}}{\boldsymbol{1+N(e)^2}} \qquad (1)$$

With N as the Yen Thanh's population (which was 302,500 in 2019), and e representing the level of precision (set at 0.1), the required sample size, denoted as n, is 100. To enhance the confidence level and ensure representation of typical characteristics, the survey was conducted with 120 farmers. The list of rice farming households was provided by the People's Committees of the communes. Based on this list, the author randomly selected 30 farmer households for interviews in each commune.

***Emission estimation of open-burning rice straw*:** Emissions from biomass burning are estimated based on the amount of biomass combustion and emission factor. The data is calculated based on the study by Kanabkaew and Oanh (2010). In each commune, 5 random fields were selected; At each field, 5 plots (1 m x 1 m) was chosen to harvest (collect all straw and grain, straw in this study is the biomass of the rice plant, not including the roots). After determining the weight of fresh biomass, all samples were taken to the laboratory of the Department of Environment and Natural Resources, Nong Lam University, to determine the weight of dry biomass.The ratio of straw-to-grain was estimated using the following equation:

$$\mathrm{SGR} = \frac{\mathrm{W_s}}{\mathrm{W_g}} \qquad (2)$$

where in SGR = Straw-to-Grain Ratio, W_s = Dry weight of straw (kg), and W_g = weight of grain (humidity = 14%) (kg).

The amount of rice straw produced could be derived using the following equation:

$$\mathrm{Q_{RS}} = \mathrm{P_{RR}} \times \mathrm{SGR} \qquad (3)$$

where in Q_{RS} = quatity of rice straw (tons), P_{RR} = rough rice production (tons), and SGR = straw-to-grain ratio.

The amount of rice straw burned in the fields was estimated using the following equation:

$$\mathrm{Q_{BS}} = \mathrm{Q_{RS}} \times \mathrm{k} \qquad (4)$$

where in Q_{BS} = quatity of rice straw burned in the fields (tons), Q_{RS} = quatity of rice straw (tons), and k = percentage of rice straw burned in the fields (%).

Emissions from burning rice straw were estimated using the following formula:

$$\mathrm{E_i} = \mathrm{EF_i} \times \mathrm{f_{co}} \times \mathrm{Q_{BS}} \qquad (5)$$

where in E_i = emission amount of i, EF_i = emission factor (gram of pollutant per kg of dry straw) of i ($EF_{PM2.5}$ = 8.3,

EF_{PM10} = 9.1, EF_{CO2} = 1,177, EF_{CO} = 93, EF_{NOx} = 2.28, EF_{EC} = 0.51, EF_{OC} = 2.99 (Oanh *et al.*, 2011), EF_{SO2} = 0.18 (Cao *et al.*, 2008), EF_{NH3} = 4.1, EF_{CH4} = 9.59 (Christian *et al.*, 2003), EF_{NMVOC} = 7 (Andreae and Merlet, 2001), f_{co} = combusion factor (0.8, fraction of the mass combusted during the coarse of a fire, default value as per IPCC 2006 guideline, vol 4, Table 2.6 (Aalde *et al.*, 2006)), Q_{BS} = amount of rice straw subjected to open-field burning (tons), and i = type of emission ($PM_{2.5}$, PM_{10}, SO_2, CO_2, CO, NO_x, NH_3, CH_4, NMVOC, EC, and OC).

Data analysis: The yield and straw-to-grain ratio data were statistically analyzed using one-way analysis of variance (ANOVA) and Tukey's post hoc ANOVA test for individual comparisons ($P < 0.05$, level of significance). SPSS 13.0 (SPSS Inc., Chicago, IL, USA) was used for all statistical analyses.

RESULTS AND DISCUSSION

***The situation of rice production in Yen Thanh District, Nghe An Province*:** Nghe An is the province with the 8th most extensive area of rice cultivation in the country, with an average rice land of 0.036 ha/person. Yen Thanh District has the largest area for rice cultivation in the province, accounting for 13.24% of the province's rice area. In the two main production seasons of the district, the yield of the winter-spring crop brings higher value (Table 1); the same study results in Ninh Binh Province (Cuong *et al.*, 2016). Thus, in addition to rice varieties and care, rice production in Yen Thanh District is greatly affected by seasonal and weather factors. In Yen Thanh District, farmers were prompted to cultivate rice varieties with growth cycles under 100 days, like VT-NA2, VT-NA6, Thien Uu 8, Khang Dan 18, HT1, and BT09, for the summer-autumn cropping period. This cycle involved early planting to ensure harvest completion by late August, before the onset of the rainy season. During the winter-spring season, characterized by more favorable weather, rice varieties such as VT 505, VT 404, Nhi Uu 986, Thai Xuyen 111, and G97 were chosen for cultivation, resulting in higher yields. The rice yield of the Winter-Spring crop of Yen Thanh District, Nghe An Province, is equivalent to that of Thai Binh Province (7.035 tons/ha) (Le *et al.*, 2013). However, the Summer-Autumn rice yield in Yen Thanh District is much lower than that of Thai Binh Province (6.029 tons/ha) (Le *et al.*, 2013).

The farmers who took part in the survey were predominantly middle-aged, with 93% being over 35 years old. The primary source of income for these farming households is reliant on rice cultivation, constituting 85%. A significant portion of the farmers has a low level of education, with 46% having completed elementary school, 48% secondary school, and only 6% having completed high school. In terms of the rice cultivation area, farmers in Yen Thanh district typically manage relatively small plots, ranging from 500 to 7,500 m^2, with an average of 2,500 m^2.

***The situation of rice straw use and management in Yen Thanh District, Nghe An Province*:** The findings show that there are 6 common ways to use and manage rice straw in Yen Thanh District: open burning, burying, mushroom plantation, husbandry feeding, selling, and giving to others (Table 2); the same findings in Mekong River Delta (Tran *et al.*, 2014). Open burning is the most common practice (98.15% in the Winter-Spring season and 89.52% in the Summer-Autumn season). Famers burn more straw in the Winter-Spring season because the time of harvesting the Winter-Spring crop is favorable (the weather is dry, often hot), so the rate of wholly burned straw is higher, and the burning time is also faster. Summer-Autumn crop, due to unfavorable weather like Winter-Spring crop often has a lot of rain, so the percentage of households burning straw decreases; farmers often burn straw when it is sunny and burying plow the straw when it rains. Additionally, the gap between the Winter-Spring crop

Table 1. Rice area, yield, and production in Yen Thanh District, Nghe An Province.

	2018		2019		2020
	Winter-Spring	**Summer-Autumn**	**Winter-Spring**	**Summer-Autumn**	**Winter-Spring**
Area (ha)	12.853	12.298	12.881	11.875	12.834
Yield (tons/ha)	7.186	4.558	7.155	4.576	7.148
Production (tons)	92.362	56.054	92.171	54.340	91.737

Table 2. Typical ways of using rice straw through the cropping of 2019-2020.

Ways of using rice straw	**2019 Summer-Autumn**		**2020 Winter-Spring**	
	Area (m^2)	**Share (%)**	**Area (m^2)**	**Share (%)**
Selling	4084.27	1.31	2431.85	0.78
Open burning	279114.24	89.52	306008.14	98.15
Mushroom cultivation	3678.96	1.18	2774.81	0.89
Burying	20136.04	6.46	-	-
Giving to others	4188.36	1.34	561.20	0.18
Husbandry feed	574.13	0.18	-	-

and the Summer-Autumn crop is very short, approximately 2-3 weeks. Consequently, farmers choose to burn straw in the fields to clear the land quickly for the Summer-Autumn crop. According to the farming practice, farmers burn straw to clean the field to prepare for the next cropping, and the ash after burning is used as fertilizer. In recent years, combine harvesters have been used more and more in Yen Thanh District, leading to the widespread scattering of straw across the fields. This scattering makes straw collection difficult. Therefore, farmers burn them directly if the weather is sunny, dry, or buried them if there is adverse weather, such as rain or flooding. Besides, the Summer-Autumn crop is the main rice crop providing straw for mushroom growers, which explains the high percentage of straw sold in some surveyed areas. For the hand-harvested fields, due to the rainy weather and inconvenient transportation, it is not possible to sell straw or bring it home for other purposes, so farmers leave the straw in the field for the straw to decompose or wait for the straw to dry (when it is sunny) to burn the fields. Fortunately, the hand-harvested was chosen by some farmers, mainly for some small fields where the harvester can not access.

The findings also show that most of the measures used by farmers to treat rice straw after harvest are traditional methods that have been applied for a long time, and no new scientific measures have been applied. However, there is only the mushroom cultivation method applied with a shallow rate of 1.18% in the 2019 Summer-Autumn crop and 0.89% in the 2020 Winter-Spring crop (Table 2). Thus, it could be seen that farmers' access to the new scientific methods for managing and using rice straws after harvest is limited. Farmers mainly focus on cleaning the field surface for the next crop but do not pay much attention to the value of straw by-products after harvest, as well as the environmental impact of burning rice straw in the field. The survey results also show that farmers no longer use rice straw much to feed livestock in Yen Thanh District (only 0.18% of the straw in the 2019 Summer-Autumn crop is used for raising livestock). The reason is that the total number of cattle in the district is not much, as well as more diverse food sources for cattle such as residues from winter vegetable crops, grown elephant grass, etc. The same results also were found in Thai Binh Province (Le *et al.*, 2013), Ninh Binh Province (Cuong *et al.*, 2016) and the Mekong River Delta (Tran *et al.*, 2014).

The results also show that 98.33% (Winter-Spring crop) and 95.83% (Summer-Autumn crop) households will still burn straw in the field to treat this biomass source in the following years. This result shows that farmers' awareness of the impact of straw burning on the environment and public health is still limited. Open burning rice straw in large areas of Yen Thanh District would significantly affect the soil, air environment, and human health and contribute to climate change (Gadde *et al.*, 2009), wasting a considerable biomass resource.

***The amount of rice straw generated after harvest in Yen Thanh District, Nghe An Province*:** The findings show that the ratio of straw-to-grain ranged from 0.91 to 1.28, of which the lowest was in Nhan Thanh commune in the Winter-Spring crop at the rate of 0.91 ± 0.12 and the highest in Phuc Thanh commune in the Summer-Autumn crop with the rate of 1.28 ± 0.03. The ratio of straw-to-grain is closely related to rice variety and rice yield in each season. Research results show that the amount of rice straw in the Winter-Spring crop is usually lower than in the Summer-Autumn crop. The average ratio of straw-to-grain in the 4 surveyed communes in the 2019 Summer-Autumn crop is 1.15 ± 0.13 higher than 1.06 ± 0.17 in the 2020 Winter-Spring crop. Because rice yield in the Winter-Spring crop is higher than in the Summer-Autumn crop. The ratio of straw-to-grain in Yen Thanh District, Nghe An Province, is equivalent to that in Thai Binh Province (1.19) (Le *et al.*, 2013). The amount of rice straw generated and rice straw burned in the fields in Yen Thanh District is estimated according to formulas (3) and (4) shown in Table 3.

Table 3. The estimated amount of generated and field burned rice straw in Yen Thanh District, Nghe An Province.

Crop	Production (tons)	Rice straw (tons)	Rice straw burned in the field (tons)
2019 Summer-Autumn	54,340	62,491	55,942
2020 Winter-Spring	91,737	97,241	95,442
Total	146,077	159,732	151,384

***The estimated emissions of rice straw burned in the fields in Yen Thanh District, Nghe An Province*:** According to research by scientists worldwide, burning rice straw in the field would create many harmful emissions into the environment (Oanh *et al.*, 2011; Cao *et al.*, 2008; Christian *et al.*, 2003; Andreae and Merlet, 2001). Emissions from burning straw calculated by the formula (5) have a proportional relationship with the amount of straw burned (Table 4). Among the emissions from burning rice straw in the field, CO_2 and CO have the highest total emissions, at 142,543.18 and 11,262.96 tons/year respectively. This has also resulted in a significant increase in the concentration of anthropogenic greenhouse gases in the global atmosphere, resulting in global warming and climate change. Climate change reduces global agricultural production due to low rainfall, seasonal fluctuations, and temperature increase (Sekoai and Yoro, 2016). Due to climate change, many parts of the world are experiencing drought and are no longer suitable for commercial farming. Changes in temperature and precipitation are also likely to exacerbate soil and water degradation. Therefore, burning rice straw in the field would impact rice yield. Besides, the activity of burning rice straw in the field in Yen Thanh District, Nghe An Province, has generated 1,161.42 tons/year of CH_4. CH_4 is a greenhouse gas

estimated to have 28-36 times the global warming power of CO_2 over the last 100 years, making it the second most anthropogenic greenhouse gas emitted into the atmosphere (Riddick *et al*., 2019). Although SO_2 is generated at least during the burning of rice straw in Yen Thanh District, 21.80 tons/year, according to a report by the US Environmental Protection Agency, short-term contact with SO_2 in the air can lead to several adverse health effects (USEPA, 2023). In addition, open-burning rice straw in the Yen Thanh District, Nghe An Province, has generated 1,005.18 tons/year of $PM_{2.5}$ and 1,102.08 tons/year of PM_{10}. Particulate matter (PM) pollution has been most strongly linked to adverse health effects (Pope and Dockery, 2006). Especially, there is increasing evidence of the impact of PM with aerodynamic diameters less than 10 and 2.5 µm (PM_{10} and $PM_{2.5}$) on cardiovascular and respiratory disease (Samoli *et al*., 2005). Therefore, burning rice straw in the field in Yen Thanh District, Nghe An Province, could harm the environment and the community's health.

Table 4. The estimated emissions of rice straw burned in the fields (tons).

	2019 Summer-Autumn	2020 Winter-Spring	Total
$PM_{2.5}$	371.45	633.73	1,005.18
PM_{10}	407.26	694.82	1,102.08
SO_2	8.06	13.74	21.80
CO_2	52,674.99	89,868.19	142,543.18
CO	4,162.08	7,100.88	11,262.96
NO_x	102.04	174.09	276.13
NH_3	183.49	313.05	496.54
CH_4	429.19	732.23	1,161.42
NMVOC	313.28	534.48	847.76
EC	22.82	38.94	61.76
OC	133.81	228.30	362.11

***Proposing some solutions to reduce emissions from burning rice straw in the field*:** Some practical solutions to reduce emissions from burning rice straw in the field are: (1) *Increasing the use of straw as the substrate for growing mushrooms:* Currently, the ratio of using straw to grow mushrooms in Yen Thanh District is very low, only 0.89-1.18%. According to Arai *et al*. (2015), the cultivation of straw mushrooms demonstrated a 12.5% reduction in overall global warming potential compared to the practice of burning straw. Mushrooms are a very popular food in Asian countries and are widely grown in tropical and subtropical regions. Straw mushroom is a nutrient-rich food with high protein content (2.66-5.05%) and 19 amino acids (including 8 non-replaceable amino acids), which does not increase cholesterol in the blood (Dung, 2006). This mushroom thrives in both outdoor and indoor environments. Nevertheless, cultivating it outdoors comes with potential drawbacks, such as rain, wind, or high temperatures, all of which can diminish the yield. The net profit obtained from producing 1 kilogram of mushrooms remained consistent for both indoor and outdoor cultivation methods, ranging from 0.5 to 0.6 US dollars per kilogram (Thuc *et al*., 2020). It offers economical production expenses and a growth cycle of around 45 days (Thuc *et al*., 2020), thus proving to be a viable strategy for lifting farmers out of poverty; (2*) Production of biochar derived from rice straw:* Rice straw–derived biochar can be used in many applications, ranging from heat and power production to soil amendment and wastewater treatment (Lap *et al*., 2021). Although coal is priced at approximately 0.36 USD per kilogram (equivalent to 8,000 VND/kg), the expense for producing biochar amounts to around 0.05 USD (or 1,000 VND/kg) (Hung *et al*., 2018). Moreover, the thermal energy content of biochar derived from rice straw is notably elevated at about 4,030 kcal/kg, surpassing that of comparable materials like chaff and sawdust (Hung *et al*., 2018). The proposed biochar production method is well-suited for household-scale applications due to its quick combustion process, impressive output, and straightforward execution; and (3) *Using rice straw to produce microbial organic fertilizers:* Every year, farmers pour large amounts of chemical fertilizers and pesticides into the fields to make the fields gradually lose their fertility, pollute the environment, and affect human health. The study conducted by Son *et al*. (2008) has clearly demonstrated the impact of incorporating composted paddy straw treated with *Trichoderma* sp., along with nitrogen-fixing bacteria (*Gluconacetobacter diazotrophicus*, *Bradyrhizobium japonicum*, *Bradyrhizobium* spp.) and phosphate-solubilizing bacteria (*Pseudomonas syringae*), across various soil types within the Mekong Delta region. The application of the recommended models for rice-soybean/groundnut-rice rotations resulted in improved yield components and grain production compared to the conventional farmer's fertilizer approach. Implementing these recommended models led to notable savings in fertilizer costs for all three crops across three seasons, amounting to VND 953,640 per hectare, equivalent to 45.74% less than the farmers' conventional practice. Additionally, the recommended model led to a decrease of VND 1,092,277 per hectare, equivalent to 14.48% of gross input. Therefore, the use of straw as the organic fertilizer has great economic and social significance for the people of Yen Thanh District in particular and farmers in Nghe An Province in general.

Furthermore, the open-burning of rice straw leads to the almost complete loss of vital soil nutrients: nitrogen (N) is entirely lost, while phosphorus (P) sees losses of around 25%, potassium (K) diminishes by 20%, and sulfur (S) is depleted by 5-60% (Dobermann and Fairhurst, 2002). Conversely, the complete extraction of stubbles and rice straw residues, which presents the lowest overall global warming potential, might not be advantageous for soil health over the long term. The elimination of straw from the field can result in the depletion of potassium (K) and silicon (Si) reserves in the paddy

(Dobermann and Fairhurst, 2002). However, extensive research at IRRI demonstrates that, with careful and efficient crop and soil management, it is possible to remove all straw from flooded rice fields after harvest without reducing soil organic matter or fertility levels (Pampolino *et al.*, 2008; Singh *et al.*, 2008).

***Conclusion*:** In Yen Thanh District, Nghe An Province, rice cultivation generates approximately 160,000 tons of rice straw annually. There are six common ways to use and manage rice straw in Yen Thanh district: open burning, burying, mushroom plantation, husbandry feeding, selling, and giving to others. But open burning is the most common practice (98.15% in the Winter-Spring crop and 89.52% in the Summer-Autumn crop). This led to waste a huge amount of biomass energy source, but rice straw collection efficiency or capacity and its trans-portation are challenging. Calculations based on previous studies indicate that open burning in Yen Thanh District results in the annual release of substantial emissions, including 1,005.18 tons of $PM_{2.5}$, 1,102.08 tons of PM_{10}, 21.80 tons of SO_2, 142,543.18 tons of CO_2, and more. These emissions have detrimental effects on the environment, human health, and agricultural practices. To mitigate these emissions, future strategies in Yen Thanh District should focus on developing straw mushroom farming, increasing rice straw biochar production, researching its applications, and promoting the production of microbial organic fertilizers from straw.

***Authors contributions statement*:**Conceptualization and Methodology, N.V.T. and L.Q.T; Investigation, N.V.T.; Data Curation, N.V.T. and N.V.D.T.; Writing – Original Draft Preparation, N.V.D.T and N.V.T.; Writing – Review & Editing, N.V.D.T and L.Q.T.

***Conflict of interest*:** The authors declare no conflict of interest.

***Acknowledgment*:** We are thankful to Dr. Nguyen Nhat Huynh Mai for her recommendation.

***Funding*:** No.

***Ethical statement*:** All interviewees clearly understood the content and purpose of the survey and participated voluntarily.

***Availability of data and material*:** Available

***Code Availability*:** Not applicable

***Consent to participate*:** All authors participated in this research study.

***Consent for publication*:** All authors submitted consent to publish this research article in JGIAS.

***SDG's Addressed*:** Responsible Consumption and Production.

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