POST-HARVEST STRAW MANAGEMENT AND GREENHOUSE GAS EMISSIONS ESTIMATION IN RICE CULTIVATION IN PHU VANG COMMUNE, HUE CITY

Nguyen Trung Hai[1*], Nguyen Thi Hoai[1], Trinh Thi Sen[1], Tran Thanh Duc[1], Nguyen Thi Thanh[1], Nguyen Tran Sa Giang[2]

[1]University of Agriculture and Forestry, Hue University;

[2]Quoc hoc Hue High School for the Gifted, Hue city.

*Corresponding author: nguyentrunghai@huaf.edu.vn

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ABSTRACT

This study was investigated the current status of rice straw management and estimated greenhouse gas (GHG) emissions from post-harvest practices in Phu Vang commune, Hue City, Vietnam– during the 2024–2025 winter–spring season. Field surveys were conducted across multiple communes with 30 rice-farming households using randomised sampling to assess typical straw management practices such as open-field burning, incorporating into soil, composting, and reusing for mushroom cultivation or livestock feeding. Data were analysed to estimate straw production, burning rates, and corresponding GHG emissions using established emission factors. Survey data from local households indicated that livestock feed was the most common straw management method (83.33%), while open-field burning remained a significant concern, with 40% of households still engaging in this practice. The study found a strong correlation between straw biomass and greenhouse gas (GHG) emissions. The amount of straw generated varied from 7.8 to 12.2 t/ha/season across different study sites. Consequently, GHG emissions from straw burning also showed significant variation, with estimated emissions of CO_2 ranging from 4.1 to 6.7 t/ha/season. A positive correlation was observed between the quantity of straw burned and the level of emissions, confirming the environmental impact of current practices. This research contributed empirical data to the assessment of GHG emissions from rice cultivation in research sites and reinforced the need for sustainable straw management policies.

Keywords: Greenhouse gas emissions, Hue City, Rice cultivation, Rice straw management, Sustainable agriculture

QUẢN LÝ RƠM RẠ SAU THU HOẠCH VÀ ƯỚC TÍNH PHÁT THẢI KHÍ NHÀ KÍNH TRONG CANH TÁC LÚA Ở XÃ PHÚ VANG, THÀNH PHỐ HUẾ

Nguyễn Trung Hải[1*], Nguyễn Thị Hoài[1], Trịnh Thị Sen[1], Trần Thanh Đức[1], Nguyễn Thị Thanh[1], Nguyễn Trần Sa Giang[2]

[1]Trường Đại học Nông Lâm, Đại học Huế;

[2]Trường THPT chuyên Quốc học Huế, Thành phố Huế.

*Tác giả liên hệ: nguyentrunghai@huaf.edu.vn

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TÓM TẮT

Nghiên cứu này được thực hiện nhằm khảo sát hiện trạng quản lý rơm rạ và ước tính phát thải khí nhà kính (KNK) từ các hoạt động sau thu hoạch lúa tại huyện Phú Vang, thành phố Huế, Việt Nam trong vụ Đông Xuân 2024 - 2025. Các khảo sát thực địa được tiến hành trên 30 nông hộ trồng lúa được lựa chọn ngẫu nhiên nhằm đánh giá các phương thức quản lý rơm phổ biến, đồng thời thu thập mẫu để ước tính sản lượng rơm, tỷ lệ đốt và lượng phát thải KNK dựa trên các hệ số phát thải. Kết quả khảo sát từ các hộ gia đình cho thấy sử dụng rơm làm thức ăn chăn nuôi là phương thức phổ biến nhất (83,33%), trong khi đốt ngoài đồng vẫn là vấn đề đáng lo ngại, với 40% số hộ vẫn duy trì tập quán này. Nghiên cứu cũng phát hiện mối tương quan chặt chẽ giữa sinh khối rơm và phát thải KNK. Lượng rơm tạo ra

dao động từ 7,8 đến 12,2 tấn/ha/vụ tại các điểm nghiên cứu khác nhau. Do đó, lượng phát thải CO_2 từ hoạt động đốt rơm cũng biến động đáng kể, với ước tính từ 4,1 đến 6.7 tấn/ha/vụ. Mối tương quan dương được ghi nhận giữa lượng rơm bị đốt và mức độ phát thải, khẳng định tác động môi trường của các phương thức hiện tại. Nghiên cứu này đóng góp dữ liệu thực nghiệm cho việc đánh giá phát thải KNK từ sản xuất lúa ở khu vực miền Trung Việt Nam, đồng thời nhấn mạnh sự cần thiết của các chính sách quản lý rơm rạ bền vững sau thu hoạch.

Từ khóa: Canh tác lúa, Nông nghiệp bền vững, Phát thải khí nhà kính, Quản lý rơm rạ, Thành phố Huế

1. INTRODUCTION

Rice is a staple crop of paramount importance globally, providing a primary source of nutrition for more than half of the world's population. As a leading rice producer, Vietnam's agricultural sector plays a vital role in both national food security and international trade. However, the immense scale of rice cultivation generates a significant amount of agricultural by-products, particularly rice straw. The management of this post-harvest residue has become a critical challenge. In many regions of Vietnam, including provinces in the Mekong River Delta and the Red River Delta, the most common and expedient method for clearing fields is open-field burning (Tran Sy Nam et al., 2014; Hoang Anh Le et al., 2013). This practice, while quick, poses serious environmental and health risks.

Open-field burning of rice straw is a major source of atmospheric pollutants and greenhouse gas (GHG) emissions. The combustion process releases various harmful substances, including particulate matter ($PM_{2.5}$, PM_{10}), carbon monoxide (CO), nitrogen oxides (NOx), and polycyclic aromatic hydrocarbons (PAHs), which degrade local air quality and pose significant health hazards to surrounding communities (Gadde et al., 2009; Pham et al., 2019; Nguyen, 2021). Furthermore, this activity contributes substantially to global climate change by emitting GHGs such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The Intergovernmental Panel on Climate Change (IPCC) provides standardized methodologies for estimating these emissions, which are crucial for national GHG inventories (IPCC, 2019).

Despite growing awareness and numerous studies on straw management and emission factors in Vietnam (Tran Sy Nam et al., 2014; Tran Xuan Dung and Nguyen Huynh Thy, 2022), a detailed understanding of these issues at a local scale remains limited. While research has been conducted in neighbouring areas of Central Vietnam, such as in Quang Dien commune (Truong et al., 2023), there is a distinct lack of comprehensive data on straw management practices and GHG emission estimation specifically within the Phu Vang commune, Hue city. This information is essential for developing targeted and effective local-level strategies that promote sustainable straw management and support national climate change mitigation goals (Hou et al., 2023; Li et al., 2023).

Therefore, this study aims to address this research gap by achieving two primary objectives: (1) to assess the current state of post-harvest rice straw management practices and farmers' perceptions in Phu Vang commune, Hue city, and (2) to estimate the amount of greenhouse gas emissions resulting from rice straw burning in the area. The findings from this research are expected to provide a crucial foundation for policymakers and agricultural extension services to formulate and implement localized, sustainable straw management solutions, ultimately contributing to a greener and more resilient agricultural sector.

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2. MATERIALS AND METHODS

2.1. Study site area

The study was conducted in Phu Vang commune (16°26′23″ N, 107°42′56″ E), Hue city, a major two-season rice-producing area in Central Vietnam. The commune lies in a coastal plain with favourable conditions for wet rice cultivation, supported by a well-developed irrigation system. The research focused on the winter spring 2024 - 2025, covering major rice-growing areas, namely Phu Luong (1-3) and Phu Da (1-4).

2.2. Data collection methods

A mixed-methods approach was employed to collect both primary and secondary data, including:

Field survey: Direct interviews were conducted with 30 farming households using stratified randomised sampling by commune. The questionnaire covered production scale, straw management practices, environmental awareness, and constraints in straw handling.

Semi-structured interviews: Discussions were held with local authorities, commune-level agricultural officers, and representatives from agricultural service cooperatives to gain institutional and operational perspectives on straw management.

Secondary data: Supplementary information was obtained from the General Statistics Office of Vietnam, the provincial Department of Crop Production and Plant Protection, the Phu Vang People's Committee, and the commune Department of Agriculture and Rural Development.

Measurement and estimation methods:

Straw-to-grain ratio: The straw-to-grain ratio (R) was calculated following Tran Sy Nam et al. (2014):

$$R = Wr/Wh$$

Where:

R = straw – to - grain ratio

Wr = dry weight of straw at 14% moisture content (kg)

Wh = weight of rice grain yield at 14% moisture content (kg)

Quantity of straw generated after harvest: The amount of straw generated per season was estimated using the formula (Tran Sy Nam et al., 2014):

$$\text{Straw generated} = \text{rice grain yield (t/ha)} \times R$$

Quantity of straw burned in the field: The amount of straw burned in the field was estimated based on Gadde et al. (2009):

$$Qst = Qp \times R \times k$$

Where:

Qst = quantity of straw burned in the field (t)

Qp = rice grain yield production (t)

k = proportion of total straw burned in the field relative to total straw generated

Estimation of emissions from straw burning: GHG emissions from straw burning were calculated following Gadde et al. (2009):

$$E_i = Q_{st} \times EF_i \times F_{CO} / 1000$$

Where:

E_i = amount of gas *i* emitted into the atmosphere from open-field straw burning (t)

EF_i = emission factor of gas *i* from straw burning (g/kg), using Gadde et al. (2009) values as EF_{CO2} =1464 g/kg, EF_{CO} = 34.7 g/kg, EF_{Nox} = 3.1 g/kg.

Fco = combustion efficiency, assumed as 0.8 following IPCC (2019) and Gadde et al. (2009).

1000: converting from g/kg to kg/kg.

2.3. Data analysis

Data from household surveys were coded and entered into Microsoft Excel 2019, and subsequently analyzed using SPSS (version 20) for descriptive statistics (to summarize the main characteristics of the dataset), ANOVA (to determine whether significant differences existed among group means), and posthoc (Duncan) tests (to identify which specific groups differed from each other), with n ranging from 3 to 4.

3. RESULTS AND DISCUSSION

3.1. Post-harvest straw management practices in Phu Vang commune

Survey results (Table 1) indicate that farmers in Phu Vang employ multiple post-harvest straw management methods, often combining more than one practice within a single household. The most common practice is using straw as livestock feed (83.33%), reflecting the integrated crop–livestock farming systems prevalent in the commune. This is followed by mushroom cultivation (46.67%) and composting into farmyard manure (46.67%), as well as open-field burning (40.00%). Other practices are less common but still significant, including the use of straw for household fuel (36.67%), straw rolling machines (36.67%), and mulching around perennial crops (36.67%).

Table 1. Post-harvest rice straw management methods and adoption rates among surveyed households in Phu Vang commune, Hue city

Management method	Households (n)	Percentage (%)
Fuel at home	11	36.67
Open-field burning	12	40.00
Livestock feed	25	83.33
Mushroom cultivation	14	46.67
Composting (manure)	14	46.67
Straw rolling machine	11	36.67
Mulching	11	36.67

The findings indicated that 40% of households still resort to open-field burning, representing significant concern. While this method is quick and convenient for field clearing, it leads to severe negative environmental and health consequences. Prior studies have established that open burning is a major source of atmospheric pollutants, including particulate matter ($PM_{2.5}$, PM_{10}), carbon monoxide (CO), nitrogen oxides (NO_x), and toxic polycyclic aromatic hydrocarbons (PAHs), which degrade local air quality (Gadde et al., 2009; Pham et al., 2019). Furthermore, this practice contributes substantially to global climate change through greenhouse gases (GHGs) emission such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Studies conducted in Vietnam have confirmed these impacts, providing estimates of GHG emissions from straw burning in both the Red River and Mekong River Deltas (Hoang Anh Le et al., 2013; Tran Xuan Dung and Nguyen Huynh Thy, 2022). This high percentage underscores the need for more effective local interventions to curb this practice, in line with international guidelines for national GHG inventories (IPCC, 2019).

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The high percentage (83.33%) of households using straw for livestock feed highlights the significant economic benefits of this practice. It not only addresses the issue of excess straw but also provides an abundant and low-cost feed source, which can increase farmers' income. With 46.67% of households engaging in mushroom cultivation and another 46.67% in composting, these methods showcase a positive trend towards value addition and soil health improvement. Converting straw into compost enhances soil fertility and structure, which can lead to increase crop yields in subsequent seasons, as demonstrated by research (Tran et al., 2012; Li et al., 2023). These practices are vital for promoting a more circular and sustainable agricultural system. The adoption of straw rolling machines and mulching by 36.67% of households each indicates a growing awareness of methods that return organic matter to the soil. These techniques align with recommended sustainable straw management solutions (Dobermann & Fairhurst, 2002; Hou et al., 2023), helping to conserve soil moisture, control weeds, and naturally recycle nutrients.

The comparison of straw management methods in Phu Vang with those in the Mekong Delta and Red River Delta reveals both similarities and distinct differences (Figure 1). While our survey in Phu Vang shows that livestock feed is the most dominant method (over 80%), this is significantly higher than the reported rates for the Red River Delta and the Mekong Delta. This finding highlights a strong local tradition and economic reliance on livestock in the study area.

However, the practice of open-field burning remains a common challenge across all three regions. At 40%, the burning rate in Phu Vang is notably lower than that of the Mekong Delta (approximately 70%) (Nguyen Thi Hong Diep et al., 2024), but similar to the Red River Delta (around 60%; Hoang Thi Hue et al., 2024), indicating a nationwide issue that requires a concerted effort to address. The persistence of this practice in all major rice-producing areas confirms findings from Hoang Anh Le et al. (2013) and Tran Sy Nam et al. (2014) that farmers, in all regions, often resort to burning as a quick solution to prepare for the next crop cycle.

The findings data also showed that methods like composting and mushroom cultivation are more prevalent in Phu Vang compared to the other two regions. This may be attributed to successful local agricultural extension programs or specific market demands, suggesting a model that could be replicated elsewhere to promote more sustainable and circular agricultural practices. Conversely, the use of straw baling machines and mulching is practiced at a higher rate in the Mekong Delta and Red River Delta, potentially due to differences in farm size, mechanization, or policy incentives (Dobermann & Fairhurst, 2002). This comparative analysis underscores the need for localized policy interventions that are tailored to the specific socioeconomic and environmental context of each region while also recognizing shared challenges.

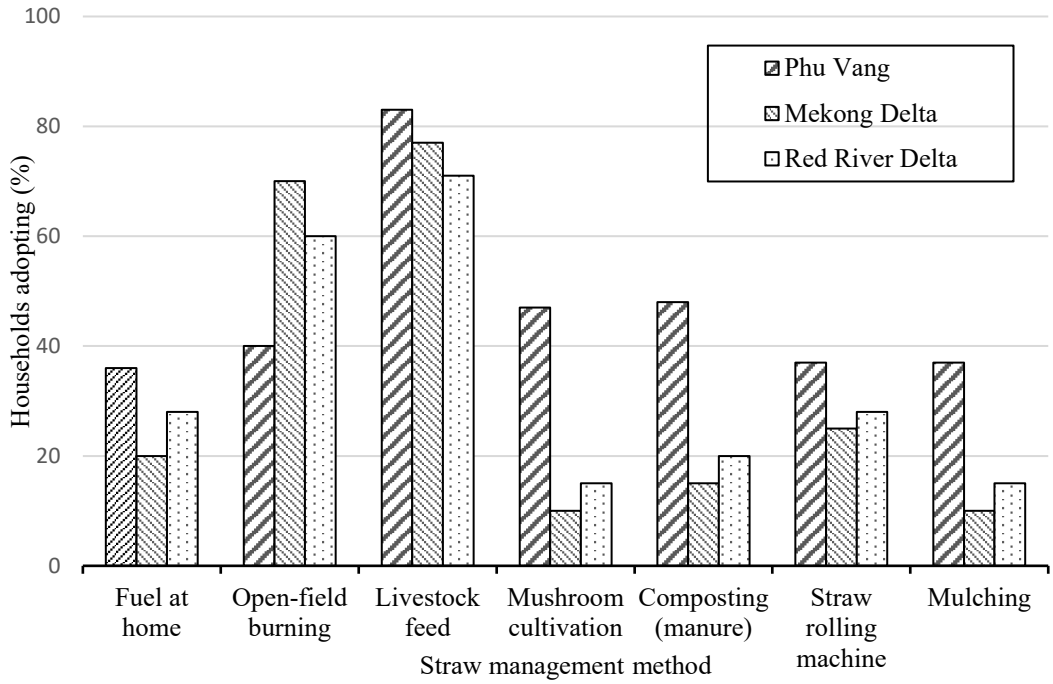

Figure 1. Comparison of post-harvest rice straw management practices among Phu Vang (2024), Mekong Delta (2024), and Red River Delta (2024) regions in Vietnam

3.2. Spatial variation in straw-to-grain ratios in Phu Vang commune

The analysis of straw-to-grain ratios across different experimental locations in Phu Vang commune reveals significant variability (Figure 2). The highest straw-to-grain ratio was observed in Phu Da 4, with a mean value significantly higher than the other locations. This suggested that the rice varieties or cultivation practices in Phu Da 4 resulted in a proportionally larger biomass of straw relative to the grain yield. In contrast, locations such as Phu Luong 1, Phu Luong 2, and Phu Luong 3 showed significantly lower straw-to-grain ratios. This indicated that a greater proportion of the crop's biomass was allocated to grain production, potentially due to different genetic traits of the rice varieties or specific local conditions such as soil fertility, water management, or fertilizer application.

The observed variations in straw-to-grain ratios were crucial for predicting greenhouse gas (GHG) emissions from rice cultivation. A higher straw-to-grain ratio, as seen in Phu Da 4, implied that a larger quantity of straw residue is left behind in the field for a given amount of grain harvested. This larger biomass directly contributes to a greater potential for GHG emissions, whether through open-field burning or natural decomposition (Justin Allenet al., 2020; Tran Xuan Dung & Nguyen Huynh Thy, 2022). The estimation of GHG emissions, therefore, must account for this variability in straw biomass production across different locations. For instance, the IPCC guidelines for national GHG inventories emphasized the importance of location-specific emission factors and biomass data for accurate reporting (IPCC, 2019).

These findings highlight the importance of developing location-specific management strategies. For areas with high straw-to-grain ratios, such as Phu Da 4, the need for effective straw utilization methods became even more critical. Conversely,

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locations with lower ratios might have a smaller straw management challenge, but sustainable practices were still essential. Understanding these localized differences is key to formulating targeted policies that promote efficient use of agricultural by-products and mitigate environmental impacts, aligning with the broader goals of sustainable agriculture (Li et al., 2023).

Furthermore, the variability in straw-to-grain ratios observed in our study was consistent with findings from other major rice-growing regions in Vietnam. For example, a study by Tran Sy Nam et al. (2014) in the Mekong River Delta also noted significant differences in straw biomass and management practices across various provinces. They found that factors such as rice variety, soil type, and cultivation intensity directly influenced the quantity of straw produced. The fact that a large portion of the straw was still openly burned in some areas of the Mekong Delta, similar to our findings in Phu Vang, underscored a nationwide challenge in transitioning farmers toward more sustainable straw management. This parallel suggested that the issues faced in Phu Vang were not isolated and that solutions developed here could be applicable to other regions in Vietnam with similar agricultural characteristics. This comparison reinforces the need for a comprehensive approach that considers regional variations and leverages successful alternative methods, such as those discussed in both studies.

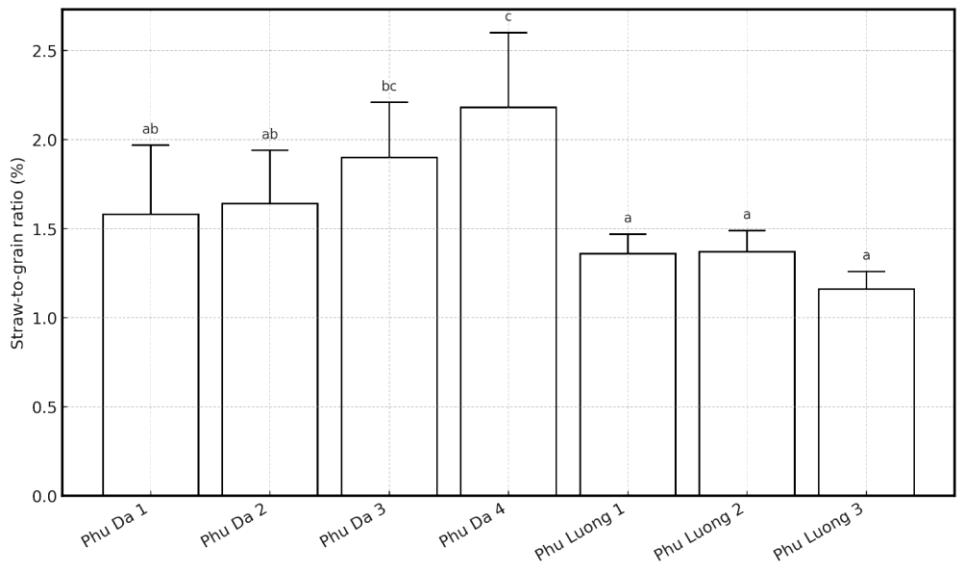

Figure 2. Comparison of straw-to-grain ratios across experimental locations in Phu Vang Commune. Different letters indicate significant differences at $p < 0.05$; error bars represent the SD of $n = 3$, except for Phu Luong 3 where $n = 4$; different letters ($^{a, b, c}$) indicate significant differences among regions at $p < 0.05$

3.3. Site-specific variations in rice straw generation, open-field burning, and associated emissions in Phu Vang Commune

The quantitative analysis of straw generation and associated emissions across the study sites provided a more detailed picture of the environmental impact of open-field burning in Phu Vang (Table 2). The amount of straw generated per hectare varied significantly, with Phu Da 3 producing the highest amount (12.2 ± 1.2

tonnes/ha/season) and Phu Luong 3 producing the lowest (7.8 ± 0.8 tonnes/ha/season). This finding aligns with the variability in straw-to-grain ratios previously discussed and underscores the need for location-specific emission estimations.

The estimated quantity of straw burned (Qst) followed a similar pattern to the total straw generated, with Phu Da 3 having the highest amount (5.73 ± 0.8 tonnes/ha/season). Based on this, the estimated emissions of CO_2, CO, and NO_x show significant differences across the study sites. The highest emissions of all three gases were recorded in Phu Da 3 (E_{CO2} = 6.7 ± 1.0 tonnes/ha/season; E_{CO} = 0.16 ± 0.02 tonnes/ha/season; E_{NOx} = 0.014 ± 0.0020 tonnes/ha/season). Conversely, Phu Luong 3, with the lowest straw generation, also had the lowest emissions for all three gases (E_{CO2} = 4.1 ± 0.2 tonnes/ha/season; E_{CO} = 0.10 ± 0.01 tonnes/ha/season; E_{NOx} = 0.009 ± 0.0005 tonnes/ha/season).

These results are consistent with the findings of other studies on GHG emissions from rice straw burning in Vietnam. For example, Tran Xuan Dung and Nguyen Huynh Thy (2022) and Hoang Anh Le et al. (2013) also reported substantial emissions of CO_2, CO, and NOx from open-field burning in the Mekong and Red River Deltas, respectively. While the absolute values may differ due to variations in rice varieties, biomass, and local emission factors, the overall pattern confirms that straw burning is a major source of air pollutants and GHGs. The high emission values from Phu Da 4, in particular, suggested that this area, with its higher biomass production, should be a priority for targeted interventions aimed at promoting alternative straw management practices. The data provides a quantitative basis for policymakers to focus their efforts on high-emission zones, thereby maximizing the impact of climate change mitigation strategies.

The quantitative data on straw generated and the resulting emissions offer a critical, evidence-based perspective on the environmental challenges posed by post-harvest straw management in Phu Vang. The significant differences in straw biomass, from 7.8 ± 0.8 tonnes/ha in Phu Luong 3 to 12.2 ± 1.2 tonnes/ha in Phu Da 3, directly correlated with the variability in GHG emissions. This correlation was not just a local phenomenon but is a fundamental principle of biomass-based emissions, as established by international bodies like the IPCC (IPCC, 2019). The IPCC guidelines provide the framework for converting biomass burned into GHG emissions, and our findings demonstrated the real-world application of these principles at a local scale.

Comparing our findings with regional studies, the estimated emissions of CO_2, CO, and NOx from Phu Vang were substantial. For instance, a study by Tran Xuan Dung & Nguyen Huynh Thy (2022) focusing on the Mekong River Delta similarly estimated large quantities of GHG emissions from straw burning. Their work, along with research by Hoang Anh et al. (2013) in Thai Binh (Hung Yen now) and Dinh Manh Cuong et al. (2016) in Ninh Binh, consistently highlighted open-field burning as a significant source of air pollution and GHG emissions across various regions in Vietnam. The consistency between our local data and these broader regional studies confirmed that the problem is widespread and not unique to Phu Vang. This strengthened the argument for a nationally coordinated strategy for sustainable straw management,

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while still allowing for localized implementation based on data like ours.

The data also provided a clear justification for targeted interventions. The high-emission zones like Phu Da 3, with emissions reaching over 6.7 tonnes of CO_2 per hectare per season, present an urgent case for action. These areas should be prioritized for programs that promote non-burning alternatives such as baling, composting, or using straw as livestock feed, as discussed in the study by Hou et al. (2023) and Li et al. (2023). By focusing resources on these hotspots, policymakers could achieve a greater impact in reducing air pollution and GHG emissions.

Table 2. Rice straw generation, open-field burning quantities, and associated greenhouse gas emissions across study sites in Phu Vang Commune

Unit: tonnes/ha/season

Study site	Straw generated	Qst	E_{CO2}	E_{CO}	E_{NOx}
Phu Da 1	9.7 ± 2.0	4.44 ± 1.2	5,2 ± 1,4	0.12 ± 0.03	0.011 ± 0.0031
Phu Da 2	10.1 ± 1.6	4.45 ± 1.0	5.2 ± 1.1	0.12 ± 0.03	0.011 ± 0.0024
Phu Da 3	12.2 ± 1.2	5.73 ± 0.8	6.7 ± 1.0	0.16 ± 0.02	0.014 ± 0.0020
Phu Da 4	11.0 ± 2.6	5.22 ± 1.5	6.1 ± 1.7	0.14 ± 0.04	0.013 ± 0.0036
Phu Luong 1	8.8 ± 0.8	3.96 ± 0.7	4.6 ± 0.9	0.11 ± 0.02	0.010 ± 0.0019
Phu Luong 2	9.1 ± 0.7	4.01 ± 0.4	4.7 ± 0.4	0.11 ± 0.02	0.010 ± 0.0009
Phu Luong 3	7.8 ± 0.8	3.53 ± 0.3	4.1 ± 0.2	0.10 ± 0.01	0.009 ± 0.0005

Values indicated mean ± SD with n = 3, except for Phu Luong 3 where n = 4.

4. CONCLUSION

Our research provided a comprehensive assessment of post-harvest rice straw management practices and their environmental impacts in Phu Vang Commune, Vietnam. The findings indicate that while some sustainable methods, particularly the use of straw for livestock feed, were widely adopted (83.3%), a significant portion (40%) of the farming community continues to rely on open-field burning. The adoption of non-burning alternatives such as composting and mushroom cultivation (46.7%), while showing promise, still faced barriers. This practice was a major source of atmospheric pollutants and GHG emissions, with quantitative data showing substantial variability in emissions across different study sites (varied from 4.1 to 6.7 tons CO_2/ha/season). The highest emissions were consistently found in areas with higher straw biomass production, highlighting specific hotspots for environmental concern. We recommend a focus on targeted programs that promote sustainable practices in high-emission zones and address the specific socioeconomic barriers preventing farmers from abandoning open-field burning.

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