

RESEARCH ON EMISSIONS INVENTORY FOR RICE STRAW OPEN BURNING IN AN GIANG PROVINCE

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Abstract

Rice straw open burning is the most common form of agricultural by-product treatment in developing countries. Contaminated pollutants pollute the environment, badly affect human's health and contribute to the increase of greenhouse gases that impact climate change. This research was carried out to estimate the amount of rice straw produced, a seasonal burning rate and the modified combustion efficiency (MCE) from field-based rice straw open burning by field sampling method, field survey and quick measurement; the inventory is based on emission factors. The results show that 62% of respondents use rice straw for different purposes such as cattle feed, selling, composting... 38% respondents do not use for any purposes. The main disposal method is open burning. Open burning rate is different in each cultivative season. It was 36.36%, in winter-spring crop, 49.32% in summer-autumn crop and 40% in winter-autumn crop. In 2017, total CO₂ emissions from open burning were the highest compared with two other pollutants. It was nearly 5.7 million tons and followed by CO with 135.1 thousand tons. The other pollutants emitted from open burning were PM_{2.5} (50.4 thousand tons), PM₁₀ (14.4 thousand tons), SO₂ (7.78 thousand tons), NO₂ (0.27 thousand tons) per year. The inventory results show that rice straw open burning in An Giang has been affecting on the quality of the air environment, landscape and reducing the traffic vision; especially fine dust (PM_{2.5}) greatly affects to local people's health. If all surplus rice straw is used for energy production, it can help not only reduce fossil fuel use, but also reduce the amount of pollutants generated by open burning. This is a win-win solution that should be paid attention by the local authorities to come up with appropriate incentives.

Keywords: emission inventory; rice straw; open burning; emissions.

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1. Introduction

Rice straw is byproduct from rice production. Rice straw is often used for cooking, cattle feed, roofing, bedding, fertilizer... However, the utilization rate of rice straw is very small compared to the generated amount, farmers have to treat it before the beginning of the new season. The most popular treatment method is to burn directly in the field and then plow into the soil. Uncontrolled burning of rice straw generates smoke, dust and pollutants including CO₂, CO, CH₄, NO_x, and SO₂... which affect not only on the air environment, but also on traffic vision. They also contribute to increase the greenhouse effect and climate change [1–4]. Currently, there are a number of in-country studies related to exhaust emissions from rice straw open burning. In 2013, Le et al. [5] carried out emissions inventory from rice straw open burning in the field in Thai Binh province. The results showed that CO₂ emission was the largest (738.8 thousand tons/year), accounting for 89.6% of total gas emission;

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followed by CO emission of 58.4 thousand tons/year accounting for 7.08% of total gas emissions. The remaining emissions (3.35%) were PM_{2.5}, PM₁₀, SO₂, NO_x, NH₃, CH₄, NMVOC, EC, VOC [5]. While in the Red River Delta, the maximum amount of CO₂ emission from rice straw in the field was from 1.2 to 4.7 million tons / year with the open burning rate was in the range from 20 - 80%. The emission of other pollutants such as CH₄ was from 1.0 to 3.9 thousand tons/year, CO 28.3 to 113.2 thousand tons/year [6]. According to Cuong et al. [7], in Ninh Binh province, the CO₂ emission in the period of 2010 - 2015 was always the highest, in particular: low emissions were about 448.7 ± 1.2 thousand tons/year, accounting for 91.5%; average emissions: about 667.7 ± 1.8 thousand tons/year, accounting for 91.2%; high emission: about 949.6 ± 2.5 thousand tons/year, accounting for 98.3% of total GHG emissions from rice straw open burning, while PM_{2.5} and carbon black (BC), respectively, were 1.8 ± 0.005 to 4.7 ± 0.02 thousand tons; 0.28 to 0.3 thousand tons. In Taiwan, Chang's emissions inventory showed that CO₂ emissions was 511931 tons/year, CO was 32,609 tons/year, CH₄ was 421 tons/year, N₂O was 25 tons/year, NO_x was 799 tons/year. SO₂ was 63 tons/year, PM₁₀ was 3919 tons/year and PM_{2.5} was 2910 tons/year [8]. An Giang province is the leading province in terms of rice production, in 2017 it reached nearly 4 million tons [9]. Rice production has generated a large amount of rice straw, which needs to be treated. However, the most common treatment method is open burning directly in the field. In addition, few studies have been conducted to determine the amount of rice straw generated, disposed annually, and to assess impacts on the air environment and human health living near the field sites especially in An Giang province and in the Mekong Delta in particular. Therefore, the study was conducted with the objective to estimate the amount of rice straw generated, the rate of use for different purposes, the rate of disposal by open burning in the locality and inventory of emitted gases and dust including PM₁₀, PM_{2.5}, CO, CO₂, NO₂, SO₂ which cause air pollution from open burning.

2. Research methodologies

2.1. Secondary data collection

Secondary data on paddy area and rice yield of districts in An Giang province were collected from An Giang Statistical Yearbook published by An Giang Statistical Office from 2011-2016 [10].

2.2. Determination of rice straw amount generated by area

Average harvest index values and average yield values of rice can be used for the computation of total rice straw generated for each crop. However, the production levels of rice straw depend on the variety cultivated, level of fertilization, soil type, climate, irrigating condition and seasons... In this research, the sample was taken including rice straw and the paddy soil with the rice straw root in the soil about 4 - 5 cm depth. Each sample is collected from three 1-m² plots. These plots were selected randomly but were chosen to represent the real biomass distribution. There are three samples (VT1-3) collected in which VT1 is outside the flood protection dike and VT2, 3 are inside the dike. The sampling was repeated 3 times according to 3 main seasons (e.g. Winter-Spring, Summer-Autumn and Autumn-Winter) in An Giang. Rice straw content in three 1-m² plots are collected to weight the average rice straw amount (kg) per 1 m².

2.3. Determination of rice straw utilization and burnt rates

Assessment of utilization rate and surplus rice straw (burn rate) is based on the field surveys using respondent's answers of six categories of the farmers (Table 1) regarding the paddy area owned

based upon the pre-designed questioner. The locations for interview survey was selected according to the proposal of the Extension officers, Cultivation Agency, Department of Agriculture and Rural Development in An Giang province. In which Chau Thanh District was chosen due to the largest paddy cultivation area in the province [10]. This district represents for two different types of cultivation, including the area inside flood protection dike (triple rice crops) and outside the dike (double rice crops). Within the district the sample villages were identified based on zonation, productivity status and paddy area. Five villages were selected as sample villages for field data collection (6 respondents per village). Using the survey data surplus biomass was computed as follows: Surplus Biomass = (Total generation) – (Domestic Use + Selling as fodder).

Table 1. Number of households interviewed and the area of respective paddy land

No.	Number of households interviewed (households)	Area of paddy land owned (m ²) [11]
1	5	1000–2000
2	5	3000–6000
3	5	7000–12000
4	5	12000–20000
5	5	20000–30000
6	5	> 30000

2.4. Determination of modified combustion efficiency (MCE)

Under natural conditions, rice straw can not be completely burned, the products of the burning consist of CO, CO₂, CH₄ and some other gases. Assuming 90% carbon in rice straw after conversion to CO and CO₂. The MCE is calculated through the emission of CO₂ and CO as follows [12]:

$$MCE = \frac{CO_2}{CO_2 + CO} \quad (1)$$

where *MCE* is Modified combustion efficiency, CO and CO₂ are the average concentrations of CO and CO₂ emissions identified in each experiment, (mg/m³).

If *MCE* > 0.9, the fire process is mainly flame. If *MCE* < 0.9, the fire process is mainly smoldering [12]. The CO and CO₂ concentration is measured by conducting random open burning in 3 areas (VT1, 2, 3) with areas of 500 m² in each location. Burning experiments at each location were repeated 3 times in 3 different cultivation crops. CO and CO₂ were quickly measured by the Testo 350XL Portable Emissions Analyser at three times including before burning (ambient air), during burning (from starting to the end of the fire) and the end of burning. The sample receiver of the Testo is placed in a fixed position at a height of 1.5 m above the ground and in the same local wind direction. The measurements are done continuously until the CO and CO₂ concentrations to close to that in the ambient air before burning.

2.5. Calculation method and data processing

a. Determination of amount of straw to be burned

The amount of burnt rice straw (*M*) is estimated according to (2).

$$M = P \times N \times B \times MCE \quad (2)$$

where P is paddy production area (ha/year), N is rice straw generated by area (kg/m^2 , ton/ha), B is open burning rate (%), MCE is modified combustion efficiency (%).

b. Inventory calculation

The pollutant emissions (PM_{10} , $\text{PM}_{2.5}$, CO , CO_2 , NO_2 , SO_2) from rice straw open burning are inventoried based on burnt rice straw amount and emission factors of pollutants (3).

$$EA_i = M \times EF_i \quad (3)$$

where i is pollutant i , EA is emission of pollutant i from rice straw open burning, M is burnt rice straw amount (kg/year), EF_i is emission factor of pollutant i (g/kg).

3. Results and discussion

3.1. Rice straw amount produced by area

The average amount of rice straw per square meter in three pilot sites in three cultivative crops in An Giang is $1.7 \text{ kg}/\text{m}^2$ (Table 2). Differences in results at different locations and crops were not significant. Thus, the total amount of rice straw produced in An Giang is 17 tons/ha. This is a biomass source with significant energy value. If it is not to be used, disposal will have significant environmental impacts.

Table 2. Rice straw amount produced by area

No	Sample symbol	Amount per 1 m^2 (kg)
1	VT1	1.7
2	VT2	1.6
3	VT3	1.7
4	Average	1.7

3.2. Modified combustion efficiency (MCE)

The average CO and CO_2 concentration measured in VT1, VT2, VT3 is presented in Table 3. In comparison with QCVN 05:2013/BTNMT – National Technical Regulation on Ambient Air Quality, the limitation of CO is $30 \text{ mg}/\text{m}^3$ in 1 hour, the CO concentrations in the rice straw open dumping sites are higher from 2.3 to 3 times. By applying (1), the results show that $MCE < 0.9$, it means that the burning process is mainly smoldering.

Table 3. Modified combustion efficiency (MCE) in An Giang

Sample symbol	CO concentration (mg/m^3)	CO_2 concentration (mg/m^3)	MCE	Fire process
VT1	90.2	410.9	0.82	Smoldering
VT2	70.3	431.8	0.86	Smoldering
VT3	72.9	274.2	0.79	Smoldering
Average	77.8	372.3	0.82	Smoldering

3.3. Rice straw utilization and burnt rates

The results from the field surveys on the rice straw utilization and burnt rates show that 62% of the respondents use rice straw for different purposes such as cattle feed, selling, composting (Fig. 1). After each harvest season, the rice straw is rolled and sold with the highest rate (42.9%) in comparison with other use ways. Other use ways are included cattle feeding, land cover, composting accounted for 19%; 9.5%, and 4.8%, respectively. It means that local households can earn money from the residue of rice production. However, non households use all parts of rice straw after each season. The utilization amount is very small compared to the total amount generated. In An Giang province, the rice straw utilization rate of households for cooking, mushrooming and animal husbandry is very low because, currently, local people's living standards have been improved significantly, they choose other fuels such as gas and electricity instead of rice straw for domestic uses.

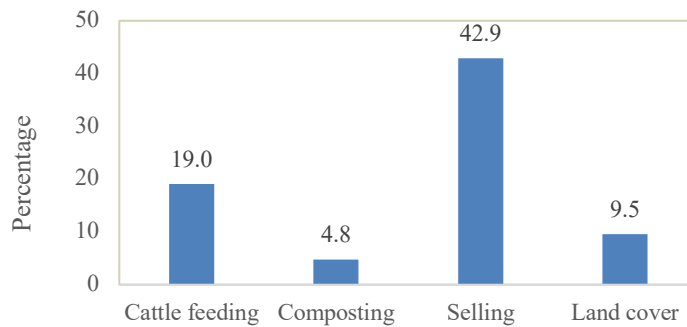


Figure 1. Current rice straw using methods

3.4. Open burning rate of rice straw

The results of the survey on the utilization and burning rates of rice straw in different seasons (Fig. 2) show that the highest open burning rate was 49.32% in the summer-autumn crop, followed by the autumn-winter crop (40%), the lowest is winter-spring (36.36%) in An Giang province. Because the main season is winter-spring and it is harvested in dry season, rice straw have good quality, so that

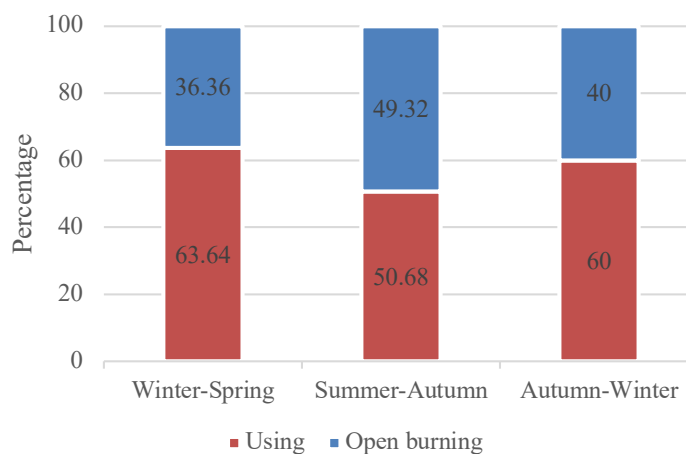


Figure 2. Open burning rate of rice straw in An Giang

it is used maximum for many purposes. In additional, climatic conditions in this season are favorable for mushroom cultivation, so rice straw is often bought to mushroom growers. In summer-autumn crop, the open burning rate was the highest in 3 seasons. This crop is usually harvested in rainy season, rice straw has high moisture content, it is not suitable for stocking, therefore, open burning is the best method to clean residues for new season. In the case of mulche, it will be dried in the field after harvesting for four to six days, farmers will burn it directly in the field with rice straw, then burying, plowing in the soil to prepare surface for next crop. The open burning will generate a lot of dust, smoke and pollutants to the surrounding areas, the emissions will affect the environment, landscape, transportation and especially on local people's health.

Applying (2) and the open burning rate were synthesized from the interview survey, estimated results of the amount of rice straw burnt in different crops in An Giang is shown in Fig. 3.

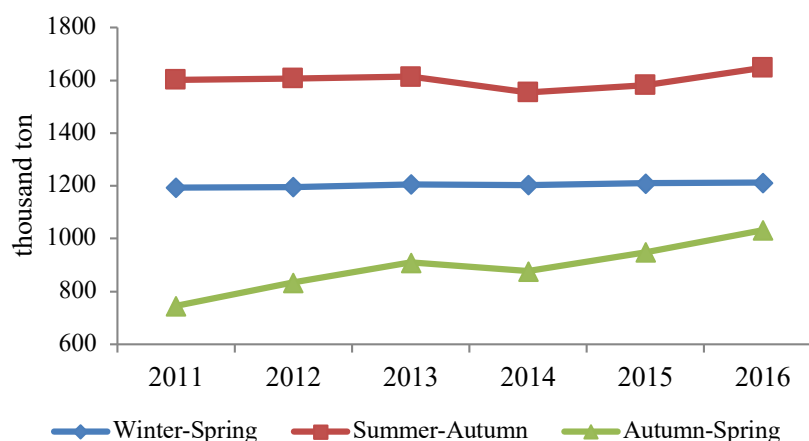


Figure 3. The amount of rice straw burnt in An Giang from 2011-2016

The research results show that in the summer-autumn crop, the amount of rice straw has being burnt about over 1600 thousand tons/crop, the highest in compared with two other ones, it was 1647 thousand tons in 2017. Due to the short time from summer-autumn to autumn-winter crop, farmers choose mainly open burning for quick soil preparation. The amount of rice straw produced in winter-spring crop is always highest, but because of the low burning rate, the amount burnt is only ranked in the second with an average of 1200 thousand tons/crop, it was 1213 thousand tons in 2017. The autumn-winter crop has the lowest open burning amount, as households outside the dyke can only cultivate two crops, these land areas are planted vegetable or leave blank. The average rice straw burnt in this crop is about 800 thousand tons/crop. In the year 2017, it was 1032 thousand tons. The amount of rice straw harvested in this crop fluctuates from year to year and depends on the cultivated area.

3.5. Emission inventory results from rice straw open burning in An Giang

The parameters are chosen to inventory in this study include PM_{10} , $PM_{2.5}$, CO, CO_2 , NO_2 , SO_2 . Inventory is done based on other studies on emission factors of pollutants from open burning of rice straw in the field [13–16]. The emission factors (mg/kg) chosen to use are PM_{10} : 3,7; $PM_{2.5}$: 12,95; CO: 34,7; CO_2 : 1460; NO_2 : 0,07; SO_2 : 2. Inventory results for 2017 are shown in Table 4.

Table 4 shows that CO_2 emissions from rice straw open burning are highest with nearly 5.7 million tons/year in An Giang province. In which 1.7 million tons was from winter-spring crop, 2.4 million tons in summer-autumn crop, 1.5 million tons in autumn-winter. It is followed by CO with 135.1

Table 4. Emission inventory results from rice straw open burning in An Giang 2017 (unit: thousand ton)

Parameters	PM ₁₀	PM _{2.5}	CO	CO ₂	NO ₂	SO ₂
Winter-Spring	4.5	15.7	42.1	1770.6	0.09	2.4
Summer-Autumn	6.1	21.3	57.2	2405.2	0.12	3.3
Autumn-Winter	3.8	13.4	35.8	1507.0	0.07	2.1
Total	14.4	50.4	135.1	5682.8	0.28	7.8

thousand tons/year (42.1 thousand tons in winter-spring crop, 57.2 thousand tons in summer-autumn crop, 33.8 thousand tons in autumn-winter crop). The remaining parameters are PM_{2.5} (50.4 thousand tons/year), PM₁₀ (14.4 thousand tons/year), SO₂ (7.8 thousand tons/year) and the lowest are NO₂ (0.28 thousand tons/year). As the inventory result depends on the amount of rice straw burnt and the emission factor for each parameter, the emission amount of generated in summer-autumn crop is always the highest, followed by winter-spring and the lowest season is autumn-winter. Comparative results of different emission between three seasons are shown in Figs. 4 to 9.

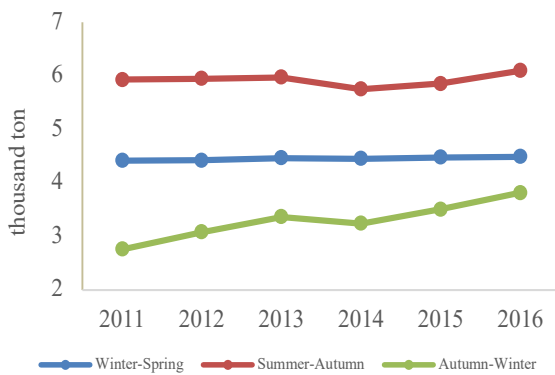
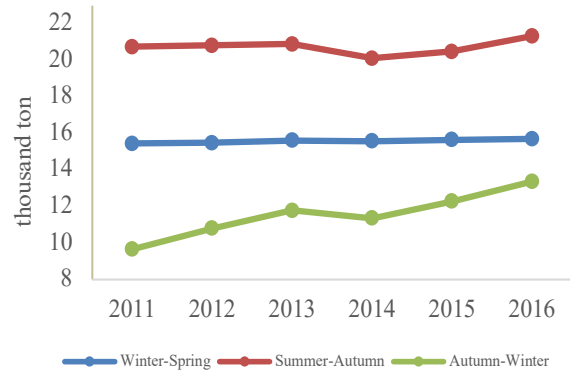
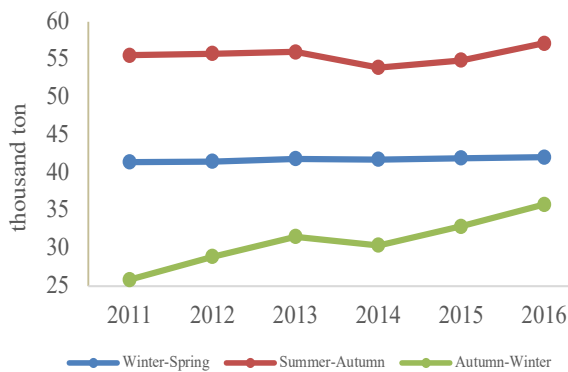
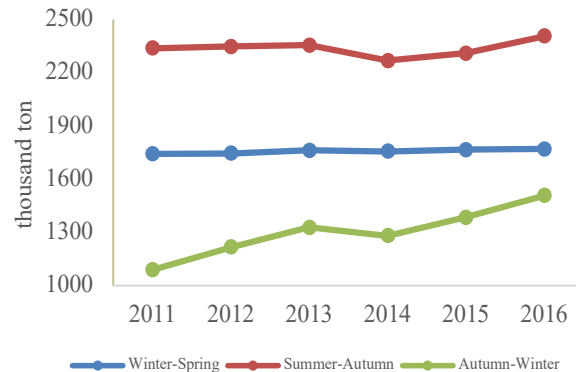
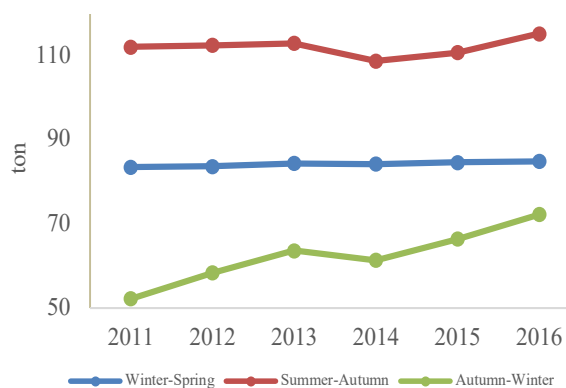
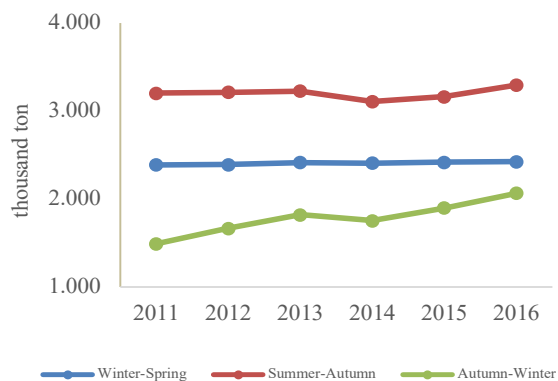

Figure 4. PM₁₀ emission

Figure 5. PM_{2.5} emission


Figure 6. CO emission


Figure 7. CO₂ emission

The above results show that rice straw open burning in An Giang in particular and in the Mekong River Delta in general has been affecting on the quality of the regional air environment. Burning rice

Figure 8. NO₂ emissionFigure 9. SO₂ emission

straw does not occur in whole year, the peak is concentrated in the harvest season (about 3 months of the season), when all the fields in the area are harvested and burnt, the emission of dust and air pollutants to reduce the visibility of traffic participants, affect on the landscape of the area and especially fine dust (PM_{2.5}) greatly affects to health of local people. Rice straw can be used as a fuel to generate electricity. If all surplus rice straw is used for energy production, it can help not only reduce fossil fuel use, but also reduce the amount of pollutants generated by open burning. This is a win-win solution that should be paid attention by the local authorities to come up with appropriate incentives.

4. Conclusions

In An Giang, averagely, 62% of households use rice straw for different purposes such as cattle feed, selling, composting... 38% of the remaining households do not use rice straw, the main disposal method is open burning in the field. Open burning rate of rice straw in winter-spring crop is 36.36%, summer-autumn crop is 49.32% and winter-autumn crop is 40%. The rice straw harvested in 2017 winter-spring was 1213 thousand tons, the summer-autumn was 1647 thousand tons, the autumn-winter was 1031 thousand tons. The amount of CO₂ emission from rice straw open burning is highest with nearly 5.7 million tons followed by CO with 135.1 thousand tons. The remaining parameters are PM_{2.5} (50.4 thousand tons), PM₁₀ (14.4 thousand tons), SO₂ (7.78 thousand tons) and the lowest are NO₂ (0.28 thousand tons). Research results show that if rice straw is used for variety purposes, it will greatly reduce the amount of air pollutants emitted by open burning. Especially if the surplus rice straw is used for energy production, it also help not only reduce environmental impacts by replacing fossil fuels, but also reduce local people's health.

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