Combined compost with biochar application to mitigate greenhouse gas emission in paddy field

A Pramono¹, T A Adriany¹, E Yulianingsih¹, T Sopiawati¹ and A Hervani²

¹ Indonesian Agricultural Environment Research Institute, Indonesian Agency for Agricultural Research and Development, Pati, Indonesia
² Indonesian Agroclimate and Hydrology Research Institute, Bogor, Indonesia

Corresponding author: ali_pramono@yahoo.com

Abstract. Crop production and environmental sustainability were threatened by environmental issues such as global warming, climate change and land degradation. Rice is a staple food of more than half of the world’s population and the most important source of greenhouse gas (GHG) emissions. Rice production accounted for 36% of total emissions from agriculture. The use of organic material management in paddy fields is a potential to support sustainable agriculture. Biochar is reported to enhance soil carbon sequestration and soil productivity. This study aimed to know the effect of combined compost with biochar application on rice yields and greenhouse gas emissions in rainfed rice fields. The research was conducted for 3 years at research station of Indonesian Agricultural Environment Research Institute, Pati-Central Java. CH₄ and N₂O emissions were measured using close chamber method. We used combined compost with rice husk biochar for organic fertilizer, namely Biocompost. The results of this study indicated that the application of combined compost with biochar in each planting season improved the grain yield by 17% and reduced global warming potential (GWP) by 5% compared to conventional practice. The combined compost with biochar application in paddy fields has the opportunity as GHG mitigation efforts on rice production.

1. Introduction

Through green revolution, Indonesia has been achieved self-sufficiency and improved national rice production over four past decades [1]. However, some of negative impacts of its implementation that more attention focused and highly dependent on irrigated rice fields as a medium for rice production, while suboptimal land received less attention. Moreover, environmental issues such as climate change, land conversion and degradation have increased with food safety demand [2].

The environmentally friendly technology is needed to support the sustainability of rice production. The use of both organic and chemical fertilizers is one component that plays an important role in the rice cultivation. The use of organic matter as a source of nutrition is an alternative to increasing rice production. On the other hand, applying fertilizers also has the potential to contribute to greenhouse gases [3], where the increasing of greenhouse gases is the cause global warming. Applying organic fertilizers to paddy soil tends to produce lower greenhouse gases. To reduce greenhouse gas emissions in paddy field farming, agriculturists should add organic fertilizer instead of chemical fertilizer [4].

Biochar is produced by pyrolysis from agricultural waste can reduce greenhouse gas emissions and increase land productivity which when composted requires a long period of time. Biochar is the result of burning carbonaceous biomass in anaerobic conditions or with less oxygen. Biochar is very useful
in soil management, carbon sequestration, and can immobilize pollutants [5]. Biochar could reduce the rate of N₂O production through improving soil physical properties (diffusion, aggregation, water holding power), soil chemical properties (degree of acidity, available nitrogen nutrients from minerals and organic, dissolved organic carbon), soil biology (number of microorganisms, macrofauna activity) [6, 7]. Also, CO₂ emissions from paddy fields under water-saving irrigation decreased by 2.22% compared with flood irrigation under the same amount of biochar application. Biochar amendment increased rice yield and water use efficiency by 6.30-9.35% and 15.1-42.5%, respectively, when combined with water-saving irrigation [8]. Biochar has been described as a possible material for soil fertility improvement, potential hazardous element adsorption, and climate change mitigation [9]. Biochar contained in organic fertilizer has potential to support environmental agriculture. This study aimed to know the effect of combined compost with biochar application on rice yields and greenhouse gas emissions in rainfed rice fields.

2. Methods

This study was carried out at experiment field in Agricultural Environment Research Institute, Pati-Central Java (6 ° 46’39.7 "S and 111 ° 11’53.0" E) during 3 years (2013-2016). The first rice growing season started on October until January and the second was February to May. Based on the soil classification, the research location was Aeric Endoaquents soil type, with the characteristics of the top layer having a pH of 5.7, a sand texture of 34%, 56% dust, 10% clay, 0.18% organic C, 0.05% total N, Ca 0.51% and Mg 0.04%.

This experiment was laid out in a randomized completely block design and consisted of Bio compost application (B) and farmer practice (FP) as a control with 3 replications. The experimental plot size was 25 m x 25 m. The difference of the treatments can be seen at Table 1. In this study, has a C-organic composition of 14.6%; N total 1.9%; Total P 1.85 and K total 0.77% and 13% moisture content. Bio compost is organic fertilizer which containing farmyard manure and biochar with comparison 4:1. The Bio compost treatment and farmer practice applied 3-ton ha⁻¹ of organic fertilizer. Both treatments are integrated with integrated crop management (ICM) which applied the high quality of seeds, minimum tillage, legowo 2:1 spacing method, integrated nutrient management (N fertilizer based on LCC, P and K fertilizers based on soil nutrient status). In dry season, rice was planted by transplanting 2 seeds per hole, while in wet season, rice was planted by direct seeding of 5-10 seeds per hole. The rice variety were used IR64. Organic fertilizer was given at a rate of 3 tons ha⁻¹ applied during or after soil preparation. The rates of inorganic fertilizers used were 92 kg N ha⁻¹, 45 kg P₂O₅ ha⁻¹, and 90 kg K₂O ha⁻¹. Fertilization was carried out 3 times, first at 21 DAS (⅓ N, all P, and ⅓ K), second fertilization at 41 DAS (⅓ N and ⅓ K), and the third at 56 DAS (⅓ N). Integrated pest and disease control which is carried out by spraying pesticides when there is a massive pest and plant disease attack.

### Table 1. Organic management for Bio compost treatment and farmer practice during six consecutive rice growing seasons

| Season               | Site 1      | Site 2     | Site 3     |
|----------------------|-------------|------------|------------|
|                      | Site 1 | Site 2 | Site 3 |
| Walik Jerami 2013    | Bio compost | Bio compost | Bio compost |
| Gogo Rancah 2013/2014| Bio compost | FYM | Bio compost | FYM | Bio compost |
| Walik Jerami 2014    | Bio compost | - | Bio compost | - | Bio compost |
| Gogo Rancah 2014/2015| Bio compost | FYM | Bio compost | FYM | Bio compost |
| Walik Jerami 2015    | Bio compost | - | Bio compost | - | Bio compost |
| Gogo Rancah 2015/2016| Bio compost | FYM | Bio compost | FYM | Bio compost |

Remarks: B = Bio compost; FP = Farmer practice/conventional; FYM = farm yard manure

The parameters observed were GHG flux (CH₄ and N₂O) and rice yield. Measurement of GHG flux in paddy fields was carried out at 2 and 5 days after fertilization. CH₄ and N₂O gas samples were taken...
manually using the closed chamber method (Figure 1). Gas samples were taken using a syringe with a volume of 20 ml with a time interval of every 5, 10, 15, 20 and 25 minutes for CH$_4$ gas and 10, 20, 30, 40 and 50 minutes for N$_2$O gas. The concentrations of gases analysis are calculated to be flux or GHG emissions using the formula [10].

$$E = \frac{dc}{dt} \times \frac{V_{ch}}{A_{ch}} \times \frac{m_{W}}{m_{V}} \times \frac{273.2}{273.2+T}$$

where $E$ is flux of CH$_4$ or N$_2$O (mg m$^{-2}$ day$^{-1}$), $\frac{dc}{dt}$ is delta concentration of CH$_4$/N$_2$O (ppm minute$^{-1}$), $V_{ch}$ is volume of chamber (m$^3$), $A_{ch}$ is area of box (m$^2$), $m_{W}$ is molecular weight of CH$_4$ or N$_2$O (g), $m_{V}$ is molecular volume of CH$_4$ or N$_2$O, and T is average temperature at sampling time (°C). The flux of CH$_4$ and N$_2$O was then converted as global warming potential (GWP) into kg CO$_2$-equivalent ha$^{-1}$ season$^{-1}$.

3. Results and discussion

3.1 Effects of bio compost application on rice yields and GHG emission

The results showed that the Bio compost treatment gave higher grain yields than farmer practice for 6 consecutive seasons (Figure 2). The Bio compost treatment gave an average grain yields of 5.90 ton ha$^{-1}$, while the conventional treatment yielded an average grain yields of 5.03 ton ha$^{-1}$ (Table 2). In this study, Bio compost technology which integrated with the integrated crop management (ICM) approach could increase grain yields by 17% compared to farmer practice/conventional methods.
There was seasonal variation in CH₄ emissions during the three-year study (Figure 3). The CH₄ emissions in the Bio compost treatment ranged from 112-292 kg ha⁻¹ season⁻¹, while the farmer practice/conventional method was 112-356 kg ha⁻¹ season⁻¹. Variations in the amount of CH₄ emission are highly dependent on water factors and rice varieties. The average CH₄ emissions in the Bio compost treatment were 218 ± 25.9 kg ha⁻¹ season⁻¹, lower than CH₄ emissions from farmer practice by 228 ± 41.6 kg ha⁻¹ season⁻¹. The formation of CH₄ gas is caused by the availability of an organic substrate in flooded conditions, thereby increasing the electron donor reduction process which then creates anaerobic conditions [13]. The addition of organic matter causes an increasing of carbon substrate, and the large amount of root exudates and decomposed dead plant would increase CH₄ emissions [14]. However, in this study, Bio compost provided lower average CH₄ emission than the farmer practice (Table 2).

The higher N₂O emissions were observed in the farmer practice at first season as compared to the Bio compost treatment. The N₂O emissions of Bio compost treatment ranged from 0.41-0.89 kg ha⁻¹ season⁻¹, while the farmer practice ranged 0.43-1.38 kg ha⁻¹ season⁻¹ (Figure 4). We presumed that high N₂O fluxes occurred of intensively fertilization. The results of this study on a field scale (2013-2016) showed that the application of Bio compost at a rate of 3-ton ha⁻¹ in each planting season increased the grain yield of rainfed lowland, as well as reduced greenhouse gas production. Bio compost application increased dry grain yields of IR64 rice variety by an average of 17% and decreased CH₄ emission rate by 4% and N₂O emission rate by 23% compared to manure application (Table 2). The addition of biochar to organic fertilizers has a direct effect on soil carbon content, increases nutrient and water holding capacity and improves soil characteristics and plant growth [11]. Based on these chemical properties in this experiment, biochar was effective in improving and maintaining soil quality. Another advantage of applying biochar to organic fertilizers is that it increases the carbon content in the soil which will play a significant role in the formation of soil aggregate stability because it will bind soil particles tightly to minimize soil erosion [12].

**Table 2.** The average of grain yields and GHG emission under Bio compost treatment and farmer practice/conventional during six consecutive rice growing seasons

| Parameter                        | Treatments¹/²          |
|----------------------------------|------------------------|
|                                  | Bio compost            | Farmer practice       |
| Grain yield (ton ha⁻¹)           | 5.90 ± 0.22            | 5.03 ± 0.18           |
| CH₄ emission (kg ha⁻¹ season⁻¹)  | 218 ± 25.9             | 228 ± 41.6            |
| N₂O emission (kg ha⁻¹ season⁻¹) | 0.58 ± 0.06            | 0.74 ± 0.07           |

Note: ¹/² Average from six rice growing season (2013-2016). Data average 3 sites and 3 replications

Bio compost containing biochar which is useful for improving soil fertility and increasing plant growth. Biochar has specific properties, its incorporation into the soil will increase soil pH and nutrient holding and make fertilization efficient [15]. On agricultural soils, there may be a reduction of CH₄ sources with the addition of biochar when CH₄ production increases and or CH₄ oxidation occurs by methanotrophs [16]. The use of biochar in agricultural soils affects soil organic carbon sequestration by changing the carbon balance directly due to the use of biochar through (i) reducing the amount of inorganic fertilizers due to increased fertilization efficiency, (ii) preventing conversion of natural ecosystems to agriculture as higher crop yields than biochar added to the soil, (iii) reducing the need for irrigation water due to increased water storage capacity, and (iv) reducing soil processing energy through improved soil physical properties [11]. The interaction of biochar with N₂O emissions can vary depending on soil type, land use, climate and biochar characteristics [16]. The effect of wood biochar applications on N₂O emissions is still strong for up to 2 years [18]. Conversely, the addition of wheat straw biochar to agricultural land planted with rice and maize can reduce emissions [19]. Biochar facilitates the transfer of electrons from the soil to denitrifying microorganisms, and simultaneously with the effect of liming it will support the reduction of N₂O to N₂ [20].
Figure 3. The CH$_4$ emission under Bio compost treatment and farmer practice/conventional during six consecutive rice growing season. Error bars represent standard deviation. Data average 3 sites and 3 replications.

Figure 4. The N$_2$O emission under Bio compost treatment and farmer practice/conventional during six consecutive rice growing season. Error bars represent standard deviation. Data average 3 sites and 3 replications.

3.2 Implication in GHG mitigation

GHG emissions and crop yield are two interrelated things in GHG adaptation and mitigation efforts. It is important to reduce CH$_4$ emissions while maintaining an increase in rice production [21]. Moreover, rice is the main food for 50% of the world's population and is considered a source of CH$_4$ emissions.
Based on Table 3, Bio compost treatment produces the highest grain but provides lower GHG emissions (expressed as global warming potential / GWP). Emission index is a value that describes the comparison between GHG emissions and grain yield, the lower the emission index, the better. We found that Bio compost treatment resulted lower the GHG index than conventional treatment by 0.96 and 1.23, respectively. This means that the using of Bio compost has the opportunity to adapt and mitigate GHG, especially CH₄ in paddy fields. This result indicated that compost with biochar addition, improves the soil nutrient status and hence, rice productivity in nutrient poor agriculture soils. It is also suggested that rice husk biochar could be a sustainable crop residues waste management option.

**Table 3.** Global warming potential, rice yields, GHG intensity under Bio compost treatment and conventional during six consecutive rice growing season

| Season | GWP (kg CO₂-e ha⁻¹)* | Grain yield (kg ha⁻¹)* | GHG intensity |
|--------|-----------------------|------------------------|---------------|
|        | Bio compost | Conventional | Bio compost | Conventional | Bio compost | Conventional |
| I      | 7,570      | 6,739       | 5,573       | 4,560       | 1.36       | 1.48         |
| II     | 3,051      | 4,862       | 5,753       | 5,320       | 0.53       | 0.91         |
| III    | 3,695      | 4,471       | 4,960       | 4,180       | 0.74       | 1.07         |
| IV     | 5,512      | 2,962       | 7,777       | 6,617       | 0.71       | 0.45         |
| V      | 6,760      | 9,042       | 5,447       | 4,527       | 1.24       | 2.00         |
| VI     | 7,160      | 7,470       | 5,937       | 5,043       | 1.21       | 1.48         |
| Average| 5,625      | 5,924       | 5,908       | 5,041       | 0.96       | 1.23         |

Note: *) Average from six rice growing season (2013-2016). Data average 3 sites and 3 replications

4. Conclusions

The application of combined compost with biochar (Bio compost) in each planting season improved the grain yield in average by 17% and reduced global warming potential (GWP) by 5% compared to conventional practice. The combined compost with biochar (Bio compost) application in paddy fields has the opportunity as GHG mitigation efforts on rice production.

Acknowledgment

The authors thanks to Titi Sopiawati, Sri Wahyuni, Hilda AR, Yono, Jumari A, Jumari B, Susanto, and Suryanto for helping in the field and GHG laboratory

References

[1] Timmer C P 2004 *Food Security in Indonesia: Current Challenges and the Long-Run Outlook* Center for Global Development Working Paper No. 48 (Washington: Center for Global Development)
[2] Las I 2009 *Tabloid Sinar Tani* (Jakarta: Duta Karya Swasta)
[3] Kindred D, Berry P, Burch O and Sylvester-Bradley R 2008 *Aspects of Applied Biology* 88 1–4
[4] Sampanpanish P 2012 *Science Asia* 38 323–330
[5] Kajitani S, Tay L H, Zhang S and Li Z C 2013 *Fuel* 103 7–13
[6] Lehmann J, Gaunt J and Rondon M 2006 *Mitigation and Adaptation Strategies For Global Change* (Switzerland: Springer) pp 403–427
[7] Lorenz K and Lal R 2014 JSSPN 177 651–670
[8] Yang S, Jiang Z, Sun X, Ding J and Xu J 2018 *Int. J. Environ. Res. Public Health* 15 1–17
[9] Stewart C E, Zheng J, Botte J and Cotrufo M F 2013 *GCB Bioenergy*, 5 153–164
[10] Minamikawa K, Tokida T, Sudo S, Padre A and Yagi K 2015 *Guidelines for measuring CH₄ and N₂O emissions from rice paddies by a manually operated closed chamber method.* (Japan: NIAES) p 76
[11] Sohi SP, Krull E, Lopez-Cappel E and Bol R 2010 *Advances in Agronomy* 105 47–82
[12] Khademalrasoul A, Naveed M, Heckrath G, Kumari K G I D, de Jonge L W, Elsgaard L,
Vogeland H J and Iversen B V 2014 Soil Science 179 1–11

[13] Wassmann R and Aulakh M S 2000 Biol. Fertil. Soils, 31 20–29
[14] Watanabe I, Hashimoto T and Shimoyama A 1997 Biol Fertil Soils, 24 261–265
[15] Wang T W, Tu A Y, Tsung L C and Juang K W 2017 13th International Conference of the East and Southeast Asia Federation of Soil Sciences Societies (13th ESAFS) 12-15 December 2017 (Pattaya, Pattaya, Thailand: Nong Nooch Tropical Garden)
[16] Mukherjee A and Lal R 2013 Agronomy 3 313–339
[17] Karhu K, Mattila T, Bergström I and Regina K 2011 Agric. Ecosyst. Environ. 140 309–313
[18] Case S D C, McNamara N P, Reay D S and Whitaker J 2013 GCB Bioenergy 6 76–89
[19] Zhang A, Liu Y, Pan G, Hussain Q, Li L, Zheng J and Zhang X 2012 Plant Soil 351 263–275
[20] Cayuela ML, Sánchez-Monedero MA, Roig A, Hanley K, Enders A and Lehmann J 2013 Nature Sci. Rep. 3 1–7
[21] Van der Gon D H A, Kroff M J, van Bremmen N, Wassmann R, Lantin R S, Aduna E, Corton T M and van Laar H H 2002 PNAS 99 12021–12024
[22] Sass R L and Cicerone R J 2002 PNAS 99 11993-11995
[23] Sohi S, Lopez-Capel E, Krull E and Bol R 2009 Biochar, climate change and soil: A review to guide future research CSIRO Land and Water Science Report 09 pp 56