Opportunities to mitigate greenhouse gas emission from paddy rice fields in Indonesia

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Abstract. Human activities including modern agriculture have increased the concentration of atmospheric greenhouse gas (GHG) since the industrial age. The agricultural sector is a source for three primary GHG emissions: methane (CH₄), nitrous oxide (N₂O) and carbon dioxide (CO₂). Numerous management practices can potentially mitigate GHG emissions from rice fields. Before implementing the practices, it is critical to evaluate its impact on GHG emissions and rice production. The aim of this study is to explore the management practices from paddy fields in Indonesia as mitigation of GHG emission without any yield loss. There were some trade-offs between CH₄ and N₂O emissions. Continuous flooding triggered largely CH₄ emissions and reduced N₂O emissions. Organic fertilizer tended to decrease N₂O emissions. Nevertheless, inorganic fertilizer e.g. urea application led to an increase of N₂O emissions. Promising mitigation options of GHG emission from rice cultivation are the application of water management, a nitrification inhibitor, iron supplement, rice cultivars selection, nutrient (organic-inorganic) management, cultivation method. The effectiveness of the GHG mitigation options varied while acceptability of mitigation options will depend on the extent to which sustainable production will be achieved or maintained.

1. Introduction

Indonesia is third-highest rice producer in the world with rice – harvested area approximately 12,250,000 ha in 2017 [1]. Indonesia is the world’s biggest rice consumers; thus rice consumption is higher than rice production (Figure 1). Rice cultivation is one of the main sources of global greenhouse gases (GHG) emissions including methane (CH₄) and nitrous oxide (N₂O). Paddy fields contribute about 5 – 19% of CH₄ emissions to the anthropogenic global CH₄ budget [2]. While fertilized agricultural soils contribute about 13 – 24% of global N₂O emission annually [3]. Due to the wide agricultural areas, nowadays developing countries contribute for three-quarters of GHG emissions and are predicted to be the most rapid sources of GHG emissions in the future [4]. GHG emissions from agriculture in Indonesia accounted for 7.8% to national GHG emissions or estimated approximately 112.727 Gg CO₂e [5]. Indonesia government has declared to achieve 29% emission reduction using national resources compare to usual practice in 2030 and up to 41% with international support. Agricultural sector could be a sector that can reduce GHG emissions through CH₄ and N₂O mitigation, as well as soil carbon sequestration [6]. The agricultural sector in Indonesia should reach the target of emission reduction of about 0.008 Gt CO₂e in 2030 [5].

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The major sources of CH$_4$ from agriculture are paddy fields, livestock, landfills, natural wetlands and sediments [7]. CH$_4$ is produced by methanogenic bacteria when organic materials decomposed in anaerobic conditions [8]. CH$_4$ productions in the soil were influenced by organic matter content, redox potential, temperature and pH [7]. N$_2$O emission is by-product of biological transformation of nitrogen, i.e., nitrification and denitrification. The soil is one of the main sources of N$_2$O emission and an estimated 65% of total N$_2$O emission [9]. N$_2$O emission from soil is affected by moisture regime, soil pH, oxygen content, soil texture, temperature, fertilizer application, organic amendment and plants [10]. Carbon dioxide (CO$_2$) emission is emitted by microbial decomposition and plant litter burning. Management practices and soil environmental characteristics influence microbial activities and decomposition processes that release CO$_2$. Photosynthesis absorbs CO$_2$ from the atmosphere during the daytime, while respiration release CO$_2$ to the atmosphere during the night [11]. So, if there is a plant, there would be a sink of CO$_2$. GHG emissions from agriculture are complex processes because trade-off could happen between each gas and agricultural production. Balance set of mitigation options should be prepared to minimize GHG emissions trade-off.

Climate change significantly affects agricultural productivity. Several aspects of best management practices in the paddy field have been studied to boost its production. Thus, the aim of this paper is to evaluate the impact of rice management practices that could be implemented as technologies for increasing its production as well as reducing GHG from agriculture.

2. Material and method
The data collected from published papers which studied about technology to reduce GHG emissions from paddy fields in Indonesia, including water management, selection of rice cultivars, nutrient management (organic-inorganic, application of nitrification inhibitor and iron supplement) and cultivation method.

3. Results and discussion
The mitigation options of GHG emissions from paddy fields that investigated in Indonesia were listed in Table 1. Water management, selection of rice varieties, cultivation methods and nutrient management are the proposed options that could be used to reduce GHG emission from rice fields. The options of GHG mitigation cannot give a negative effect to rice production.
Table 1. A list of mitigation options of GHG emissions from rice fields in Indonesia as estimated by different authors

| Mitigation options       | Location                      | Range (min-max) of | Rice yield | Details                                                                 | References |
|--------------------------|-------------------------------|--------------------|------------|-------------------------------------------------------------------------|------------|
|                          |                               | CO₂ mg C m⁻² hour⁻¹ | CH₄ µg N m⁻² hour⁻¹ | N₂O ton ha⁻¹ |                                                                  |            |
|                          |                               | 8.04 to 49.63      | 44.38 to 16.09 | 1233 to 1108 | intermittent drainage could reduce GHG emission around 14.7 to 68.5% compared to CF | [12]       |
| Water management         | Sungai Rangas, South Kalimantan Pati, Central Java | - 7.53 to 9.15 | 14.98 to 4.96 | 6.87 | Alternate wetting and drying (AWD) reduce 33 - 39 % GHG emissions compared to CF and no difference on yield | [13]       |
|                          | Sukamandi, West Java           | - 2.18 to 15.15    | -          | - | intermittent irrigation and saturated soil have less CH₄ emission around 53-67% than CF | [14]       |
| Rice Cultivars           | Taman Bogo, Southern Sumatera Pati, Central Java | - 13.3 to 2.96     | -          | - | Atomita-4, IR-64, and Bengawan Solo were high yielding cultivars with low CH₄ emission | [15]       |
|                          | Pati, Central Java             | - 10.22 to 13.69   | 9.07 to 7.12 | 5.0 to 5.3  | IR-64 has the lowest CH₄ emission with no difference in yield compare to Memberamo, Way Apoburu and Cisadane | [16]       |
| Cultivation methods      | Pati, Central Java             | - 0.11 to 13.96    | 0.53 to 1.92 | 4.09 to 9.21 | zero tillage resulted less GHG emissions than conventional tillage | [17]       |
| Nutrient management      | Pati, Central Java             | - 3.14 to 6.43     | 6.86 to 7.80 |                          | steel slag applications decreased the CH₄ and N₂O emissions compared without steel slag application | [18]       |
|                          | Pati, Central Java             | - 2.39 to 4.7      | 7.80       |                          | Applications of fresh and decomposed straw could reduce N₂O emission around 33 and 28% compare without straw application | [19]       |

3.1. Water management

The effects of different water regimes on CH₄ and N₂O emission from rice fields have been well studied. In Indonesia, intermittent irrigation or alternate wetting and drying (AWD) was better than the
continuous flooding (CF) treatment in term of GHG emission (Table 1). CH$_4$ was produced by methanogenic bacteria in the soil exclusively in anaerobic conditions that resulted from flooding the field. Drainage could improve the aeration and minimize the production of CH$_4$ in the soil. Some studies showed drainage rice fields could reduce CH$_4$ emission: multi-aeration decreased by 12%, without any decreases in rice yield [21], intermittent irrigation decreased to 45% [22] and AWD has the potential to reduce by 73% compared with traditional flooded rice [23]. Somehow water managements show a trade-off between CH$_4$ and N$_2$O emission. Generally, low N$_2$O emission is found during flooded condition. Different water regimes in rice fields caused a sensitive change in N$_2$O emissions due to nitrification and denitrification processes [24]. Alternate anaerobic and aerobic cycling considerably increased N$_2$O emission relative to constant aerobic and anaerobic conditions [25]. However, N$_2$O emission from rice fields could be neglected because N$_2$O emission from rice fields was very low [26].

3.2. Selection of rice varieties
During flooded condition, CH$_4$ is produced in the anaerobic layer of soil and mainly transported to the atmosphere through rice plants through intercellular air spaces (aerenchyma) that connected rhizosphere to the atmosphere. Each of cultivars has different ability to release CH$_4$ based on their morphological and physiological properties, i.e. number of plant tiller, biomass, root exudate that released by the plants [18]. Table 1 shows that IR-64 has the lowest CH$_4$ emission because it has a relatively short growth period, the lowest dry matter weight of biomass and plant tiller [18]. Rice plants are one of the promising strategies to reduce CH$_4$ emission from rice fields through the approach of high yielding rice cultivars with low CH$_4$ emission. High yielding rice cultivars with low CH$_4$ emission will give more benefit to the farmers. Adoption of GHG mitigation option by the farmers depends on the advantages for the farmers and the easiness to be implemented [27].

3.3. Cultivation methods
Table 1 mention that conventional tillage resulted in higher GHG emissions than zero tillage, this likely because conventional tillage causes higher aeration and then results in increasing of N$_2$O emission [28]. Moreover, the intensive soil tillage resulted in rapid decline of soil C content [29]. Conversely, increased soil tillage reduces CH$_4$ emissions, because CH$_4$-oxidising bacteria are negatively affected by soil disturbance [30]. However, some study showed contradictory results that intensification of soil tillage inhibited N$_2$O emission [31].

3.4. Nutrient management
Addition of nutrient in a rice field to achieve sustain rice production affect GHG emission. Chemical fertilizer, i.e., nitrogen fertilizer generally stimulates CH$_4$ and N$_2$O production in soil due to losses of N through nitrification and denitrification. Increasing N uptake and reducing N losses can be achieved using nitrification inhibitors [19]. Application of organic fertilizers for improving soil fertility and enhancing crop productivity release CO$_2$, CH$_4$, and N$_2$O through processes of priming effect, methanogenesis, nitrification, and denitrification because easily decomposable organic substances affect to microbial activity to utilize C and N in soil [32]. Steel slag contains active iron and it could be used as an electron acceptor to decrease methanogenic activity and to suppress CH$_4$ production.

4. Conclusion
Water management, selection of rice cultivars, nutrient management (organic-inorganic, application of nitrification inhibitor and iron supplement) and cultivation method are the promising approach to achieve sustain rice production as well as to reduce GHG emissions from paddy fields. The effectiveness of the GHG mitigation options varied.

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