The opportunity of direct seeding to mitigate greenhouse gas emission from paddy rice field

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Abstract. Direct seeded rice (DSR) is one of the options to reduce CH\textsubscript{4} emission because it uses less water during initial cropping but it sometimes has side effects such as increasing N\textsubscript{2}O emissions. The trade-off N\textsubscript{2}O and CH\textsubscript{4} production in rice soils makes a real challenge to reduce the gas production. Nonetheless, few studies have observed the effect of DSR to GHG emission. This study aims to investigate the option of agriculture strategy used to reduce GHG emission without any yield loss through DSR. The study was conducted during rainy season at experimental field of Indonesian Agricultural Environment Research Institute (IAERI), Central Java, Indonesia. We compared the emission of CH\textsubscript{4} and N\textsubscript{2}O, yield and yield components that affected by DSR and TPR practices. Total CH\textsubscript{4} emission in TPR was from 352 kg ha\textsuperscript{-1} season\textsuperscript{-1} and, it ranged from 187 kg ha\textsuperscript{-1} season\textsuperscript{-1} in the DSR. The CH\textsubscript{4} emissions were 47\% lower for DSR than for TPR during a rice growing season. No significant differences were observed among crop establishments on N\textsubscript{2}O emissions. GWP were reduced by 46.4\% under DSR compare to TPR. Crop-establishment did not influence grain yield, indicating the potential of DSR as alternative methods of establishing lowland rice with low GHG emissions.

1. Introduction

Paddy rice can be established either through transplanting or direct seeding. Transplanting is a common rice establishment in irrigated areas and consumes large amount of water during land preparation with wet puddling. The advantages of puddle transplanted rice (TPR) are controlling weeds, inhibiting water percolation and providing easy seedling establishment. While, direct seeding (DSR) is one method of rice establishments during early rainy season in mostly the rainfed lowlands of Indonesia. The crop may experience with less water or even drought at early growth stages. DSR offers benefits like saving irrigation water, reducing production cost and mitigating CH\textsubscript{4} production [1]. However, saving irrigation water in rice field should be applied appropriately. Enough water for rice growth would beneficial for increase percentage of filled grain as long as adequate nutrient supply and under favourable climate [2]. In contrast, another study found that submerged rice field showed low grain yield affected by limited rice growth due to detrimental root and chemical changes of paddy soil [3]. Different finding from Indonesian experience reported that continuous flooding was not essential factor for achieving high rice yields [4].

Rice field is one of the important anthropogenic sources of atmospheric CH\textsubscript{4}. Methane is produced by obligate anaerobic microorganism (methanogenic bacteria) under anaerobic conditions. TPR creates anaerobic conditions in the soil and contributes significantly to greenhouse gas (GHG)
emissions, particularly methane (CH$_4$) emission. Flooding rice field cuts off oxygen supply from the atmosphere to the rhizosphere that results anoxic decomposition and emit CH$_4$ from submerged soil to the atmosphere through aerenchyma of rice. N$_2$O is produced either by nitrification or by denitrification in soil, depending on the aerobic and anaerobic conditions of [5]. Continuous flooding of paddy field has less N$_2$O emissions but produce high amounts of CH$_4$ emission [6].

A trade-off between CH$_4$ and N$_2$O production is a challenge on reducing the production of one gas but the trade-off both of the emissions should be managed for a balanced set of mitigation options. Minimum cumulative radiative forcing of the two gases on global warming potential (GWP) is the possible option to minimize the trade-off and effect of GHG emissions. In 2014, GHG emission from agricultural sector in Indonesia including LULUCF and peat fire contributed 6% to national GHG emission which was estimated at about 113,440 Gg CO$_2$ and rice was calculated to contribute approximately 35,994 Gg CO$_2$e [7]. The mitigation of GHG emission from rice field is one of fundamental subsectors to decrease the contribution to global warming without any yield loss. The objectives of this study is to investigate crop establishment options to reduce GHG emission from rice field without any yield loss.

2. Materials and Methods

The location of the experimental field was at the experimental farm of Indonesian Agricultural Environment Research Institute (IAERI), Jakenan (06°46’42.1” S, 111°11’52.0” E), in the Pati district, Central Java, Indonesia. The soil type of the experimental field was included as Inceptisols (Aeric endoaquept).

The experiments were laid out in a randomized block design and comprised of transplanted rice (TPR) and direct seeded rice (DSR) with 3 replications. In the TPR plots, paddy rice was established by transplanting at fourteen-day-old seedlings. In the DSR plots, dry seeds were sown manually. There was no ponding of water in DSR during early growing season. Whereas in TPR soil was under continuous flooding. Both of the rice establishments were used Ciherang as a rice cultivar. Each of experimental plots received 60 kg P$_2$O$_5$ ha$^{-1}$ (super phosphate), 120 kg N ha$^{-1}$ (urea), and 90 kg K$_2$O ha$^{-1}$ (potassium chloride).

The CH$_4$ and N$_2$O fluxes were measured by closed chamber method and collected by 10 ml of syringe. Four hills of rice plants were covered by CH$_4$ chamber which measured 50 cm x 50 cm x 100 cm. Each experimental plot also had chamber for collection of N$_2$O, which measured 40 cm x 20 cm x 30 cm and no rice plants were covered. The concentrations of CH$_4$ and N$_2$O were directly analyzed with a gas chromatograph (GC), which was equipped with a flame ionization detector (FID) and an electron capture detector (ECD) for CH$_4$ and N$_2$O analysis, respectively.

3. Results

Cumulative of CH$_4$ fluxes under different rice establishments are shown in Figure 1a. The cumulative CH$_4$ flux of DSR was lower compare to cumulative CH$_4$ flux of TPR. The average of daily CH$_4$ fluxes from DSR and TPR were approximately 195 and 298 mg CH$_4$ m$^{-2}$ day$^{-1}$, respectively. The cumulative N$_2$O fluxes from paddy soils under DSR and TPR are given in Figure 1b. Since the early rice growing season, the cumulative N$_2$O flux from DSR was higher than TPR. The average of daily N$_2$O fluxes from DSR and TPR were approximately 393 and 331 µg N$_2$O m$^{-2}$ day$^{-1}$, respectively.
In general, applying water management through DSR and TPR did not statistically significance influence the rice yield (Table 1). The rice yield of DSR and TPR plots were 4.9 and 5.2 ton dry grains (14% mc) ha$^{-1}$. Statistics revealed that there is significant difference in global warming potential (GWP). Application DSR during the rainy season decreased GWP to 3.8 ton CO$_2$e ha$^{-1}$. This finding indicates that the total emission reduction using DSR was 46.4% compare to TPR. The lower value of the greenhouse gas intensity (GHGI) from DSR compared to control means that the treatments give more advantages to mitigate GHG emission and produce more rice.

Table 1. Yield, GWP and GHGI from direct seeded and transplanted rice during rainy season

| Treatments | Yield (t ha$^{-1}$) | GWP (t CO$_2$e ha$^{-1}$) | GHGI (ton CO$_2$e ton$^{-1}$ yield) |
|------------|---------------------|--------------------------|-----------------------------------|
| DSR        | 4.9a                | 4.4b                     | 0.9                               |
| TPR        | 5.2a                | 8.2a                     | 1.6                               |

The different letters vertically indicate significantly different between means at 0.05 level according to Tukey’s HSD-test.

Yield components in all parameter measured between DSR and TPR were not different except 1000 weight grain. The 1000 weight grain of DSR was significantly higher compare to TPR. The 1000 weight grain of DSR was 34.1 g and TPR was 33.5 g. No significant differences were observed among
the crop establishments on unfilled-filled grain, percentage of filled grain, shoot dry weight and grain per hill.

Table 2 Yield components from direct seeded and transplanted rice during rainy season

| Yield components                  | Treatments | DSR | TPR  |
|-----------------------------------|------------|-----|------|
| 1000 weight grain (g)             |            | 34.1a | 33.5 b |
| Unfilled grain                    |            | 305a | 310 a |
| Filled grain                      |            | 812a | 827 a |
| % filled grain                    |            | 72.3a | 72.9 a |
| Shoot dry weight (g hill⁻¹)       |            | 41.1a | 38.6 a |
| Grain (g hill⁻¹)                  |            | 30.1a | 30.8 a |

The different letters vertically indicate significantly different between means at 0.05 level according to Tukey’s HSD-test.

4. Discussions

The CH₄ emission in DSR was lower compared to TPR. It happens because there was no flooding condition of the DSR field and it results aerobic condition. While in TPR, the rice field was flooded throughout the growing season and it creates anaerobic condition. CH₄ is produced under anaerobic condition by metabolic activities of methanogens [9]. The standing water on rice soil surface inhibits oxygen transport from atmosphere into rhizosphere. The absence of oxygen, the activity of anaerobic bacterial and the presence of decomposable organic matter is the favourable condition to produce CH₄ [10]. As a result, CH₄ emission was high. Conversely, drain the water from soil surface results the higher redox potential (Eh) and decrease the amount of CH₄. The DSR fields were not continuously submerged with water, less anaerobic condition is created. As a result, less CH₄ is produced.

This study resulted higher N₂O concentration released from DSR compared to TPR. In TPR, less N₂O emission produced as nitrification process because it was inhibited by flooding water and N₂ was the main product of denitrification. In DSR, nitrification is the main process which takes place under aerobic condition [11]. One of the main factors regulating nitrification, denitrification and the release of N₂O is the availability of oxygen (O₂) in soil. Denitrification occurs in the anaerobic soil condition, whereas nitrification takes place under the aerobic condition [12]. The finding of this study was similar with the result that mentioned N₂O production in soils was produced by 93–96% during the drainage phase [11]. In general, DSR and TPR gave no difference on the yields most likely because there was adequate water supply in root zone of the rice to maintain the yield. One of the references shows that no yield penalty was observed when safe drainage was practiced in the field [13].

It is important to get the relative contribution of each gas to global warming because it can be used to evaluate the climate implication of the cultivation practices. DSR resulted 46% lower of GWP compare to TPR. This finding is similar with previous studies that stated less water in the field resulted 34 and 54% less GWP compare to traditional flooding, respectively [14,15]. Greenhouse gas index (GHGI) is the index for measure the comparability of GWP and grain yield. Thus, the lower value of the GHGI from DSR compared to TPR means that the DSR give more advantages to mitigate GHG emission and produce more rice.

5. Conclusions

A field experiment at IAERI research station during rainy season showed that the direct seeded reduced GHG emission approximately around 46.4% and without any yield loss compared to transplanted rice. The direct seeded could be a feasible option to transplanted rice for mitigating and adapting to climate change.
Acknowledgement
This study was a part of research collaboration between IAERI and International Rice Research Institute. The authors are thankful to all greenhouse gas laboratory members of Indonesian Agricultural and Environment Research Institute for the technical assistance in this work.

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