Response of planting methods to rice productivity and greenhouse gas emissions

H L Susilawati¹, R Kartikawati¹ and P Setyanto²

¹ Indonesian Agricultural Environment Research Institute, Pati, Indonesia
² Directorate General of Horticulture, Ministry of Agriculture, Jakarta, Indonesia
E-mail: helenalina_s@yahoo.com

Abstract. Intensively cultivated rice field is one of Greenhouse Gases (GHG) contributors to the atmosphere. Soil cultivation of Gogorancah or Direct-Seeded Rice (DSR) has been introduced to save water and reduce GHG emissions from rice field because rice plants grow under aerobic condition after seed germination. This study aims to evaluate GHG emissions, yield component and rice yield to different planting methods: Transplanted Rice (TPR) and DSR. The study was carried out at farmer’s field namely D. Waru, Adiwerna and K. Banteng Sub District in Tegal District, Central Java. The closed chamber method with the unit consisted of a cubic chamber (50 × 50 × 100 cm) and a frame base (50 × 50 × 15 cm), and gas chromatography (GC) was used to determine the nitrous oxide (N₂O) and CH₄ fluxes. The results showed that the DSR increased yield components and reduced CH₄ emissions. The DSR could significantly increase grain yield than TPR at D. Waru and K. Banteng approximately 26 and 49%, respectively. The DSR could be an option for reducing global warming potential (GWP) and maintaining rice yield. However, further studies are needed to identify suitable management practices for reducing both CH₄ and N₂O emissions without any trade-off.

1. Introduction
Rice (Oryza sativa L.) is the staple food for more than 50% of the global population, mostly in Asian and African countries [1]. Generally, rice is produced by smallholder farmers more or less around 0.5-3 ha in both Asia and Africa [2]. The demand of it is expected increased by 24% for the next 20 years due to the overpopulation [3]. It needs to enhance food production sustainably to feed a growing world population. Nowadays, many cultivation concepts are emerging to increase rice production.

There are two rice establishments, namely Direct-Seeded Rice (DSR) and Transplanted Rice (TPR). The primary rice establishment in the world is TPR and it account for nearly 77% of global the total rice cultivation area [4]. TPR is a method to establish rice after the rice seedling was grown in the nursery. While DSR is a process of rice establishment from seeds directly sown in the field. DSR is consider as a more efficient and cheaper rice cultivation method because it requires less sources i.e., labor, water and less greenhouse gas (GHG) emission compare to TPR [5]. Some studies have reported that DSR resulted higher yield and conserved water than TPR [6]. On the other hand, there are some contradict result of studies that showed DSR caused lower yield due to plant sensitivity to water stress at different rice growth stages [7-8].

Rice cultivation, through flooded rice field and nitrogen fertilizer used, is one of the most significant sources of agricultural GHG emission. Higher demand of rice result higher GHG emissions. Generally, rice is grown under anaerobic condition. However, this condition become a
trigger of methanogen to produce greater amount of GHG emissions (primarily CH₄) compare to aerobic condition [9]. The information of N₂O emission measurements have become available from transplanted rice fields, but information from DSR is still scarce. Therefore, responses of grain yield, yield components, and GHG emissions from DSR application in the rice field need to be observed in this study to ensure GHG reduction without any yield loss.

2. Materials and methods

2.1 Study site
The experimental sites were at farmer’s fields of Dukuh Waru, Adiwerna and Kedung Banteng Sub District in Tegal District, Central Java, Indonesia during dry season. According to meteorological data, the region has an average temperature of 27.35°C, and the rainfall was 54.37 mm during 4-month experiment. The soil samples of the three sites were collected from the upper 20 cm of soil surface before the experiment was started. Physicochemical characteristics of soil from the three experimental sites is shown at table 1.

| Soil Analysis     | Location-Treatment | D. Waru | Adiwerna | K. Banteng |
|-------------------|--------------------|---------|----------|------------|
|                   | DSR | TPR | DSR | TPR | DSR | TPR |
| Sand (%)          | 15  | 18  | 19  | 22  | 2   | 3   |
| Texture           | 54  | 32  | 57  | 1   | 10  | 15  |
| Silt (%)          | 31  | 50  | 24  | 78  | 87  | 82  |
| Clay (%)          | 1.62| 2.07| 1.65| 1.87| 1.65| 1.93|
| Walkley & Black C (%) | 0.11 | 0.11 | 0.08 | 0.12 | 0.13 | 0.14 |
| Kjeldahl N (%)    | 14.7| 18.8| 20.6| 15.6| 12.7| 13.8|
| C/N               | 0.94| 0.94| 0.96| 0.94| 0.94| 0.94|
| Destruction, P-Total (%) | 440.26 | 1.068.83 | 674.03 | 677.92 | 922.08 | 902.6|
| Spectrophotometer Fe (mg kg⁻¹) | 0.27 | 0.28 | 0.75 | 0.37 | 2.95 | 0.45 |
| Destruction, extract K-Total (%) | 0.63 | 0.15 | 0.51 | 0.39 | 0.14 | 0.41 |
| HClO₂:HNO₃ = 1:5, Ca (mg kg⁻¹) | 0.65 | 1.68 | 0.71 | 0.66 | 1.76 | 1.44 |
| AAS Mg (mg kg⁻¹) | 0.65 | 1.68 | 0.71 | 0.66 | 1.76 | 1.44 |

2.2 Experimental design and cultivation methods
The study was arranged by a randomized block design and adopted two establishments DSR and TPR. The treatments were replicated 3 times at three sites: D. Waru, Adiwerna and K. Banteng. Each site used different rice cultivars but both treatments used same rice cultivar. The rice that used at D. Waru was Inpari 13, while at Adiwerna and K. Banteng were Situbagendit. No water puddling at DSR plots when the plots were ploughed and harrowed. Dry seeds were sown manually at DSR plots. TPR plots were ploughed and puddled before transplanting. The seed were sown at nursery and the seeds were transplanted into the TPR plots after 21 days old at nursery. The DSR plots were not irrigated until several days. From then, 5-10 cm of standing water were kept in the plot until 2 weeks before harvest. While TPR plots was under continuous flooding until 2 weeks before harvest.

The rates of fertilizers were 60 kg P₂O₅ ha⁻¹ (super phosphate), 120 kg N ha⁻¹ (urea), and 90 kg K₂O ha⁻¹ (potassium chloride) and the fertilizers were applied equally to all the treatments. All of the P₂O₅, one third of the N and K₂O were applied as a basal starter dose, while the rest of N and K₂O was equally split at tillering stage and panicle initiation stage. Weeds, diseases, and insects were intensively controlled during rice growing season.

2.3 Data collection
Gas samples were measured using the closed-chamber technique with two different-sized chambers (0.5 m length × 0.5 m width × 1 m height to determine CH₄ gas and 0.4 m length × 0.2 m width × 0.3 m height to determine N₂O gas). The chamber base in each plot was permanently installed during
entire rice growing season. Gas sampling were conducted once a week and began 1 day after transplanting.

The sampling time was started at 6:00 a.m. on each sampling day. The gases were taken from inside the chambers using 10-mL plastic syringes fitted with three-way stopcocks after chamber closure at 3, 6, 9, 12, 15, 18, 21 and 24 min for CH₄ and 5, 10, 15, 20, 25, 30 and 35 min for N₂O. The gas samples were analyzed by gas chromatography on the same day. The concentrations of CH₄ and N₂O were analyzed simultaneously with a gas chromatograph equipped with an Electron Capture Detector (ECD) for N₂O concentration and a Flame Ionization Detector (FID) for CH₄ concentration.

Global warming potential (kg CO₂e ha⁻¹) is based on a 100-year time frame and was calculated using the following equation [10]:

$$\text{Global Warming Potential (GWP)} = (CH_4 \times 21) + (N_2O \times 310)$$

Yield-scaled global warming potential/ greenhouse gas intensity (GHGI) was calculated as following formula [11]:

$$\text{GHGI (ton CO₂e ton grain}^{-1}) = \frac{GWP}{\text{yield}}$$

3. Results and discussion

3.1. CH₄ and N₂O emission

Total CH₄ emission during rice growing period from DSR at D. Waru, Adiwerna and K. Banteng were 26.73, -0.24, and 0.29 kg ha⁻¹ season⁻¹, respectively (figure 1a). While CH₄ emission from TPR approximately ranged 24.53, 1.53 and 11.61 kg ha⁻¹ season⁻¹, respectively. The negative value of CH₄ from DSR at Adiwerna most likely because the leakage or the role of the soil for CH₄ sink. Soil can be a sink for CH₄, when low water content, high air-filled porosity and therefore CH₄ diffusivity increases, favouring methanotrophy and hence CH₄ consumption [12-13]. The hypothesis that DSR decrease methane emissions of a rice paddy is not supported at D.Waru. Increased CH₄ emissions in the DSR system are most likely due to greater gross ecosystem production (GEP) associated with higher rice plant density [14]. DSR at Adiwerna and K. Banteng resulted lower CH₄ than TPR because DSR keep aerobic conditions at the early of the season, resulting limiting anaerobic CH₄ production in the rice paddy [15].

![Figure 1. CH₄ (a) and N₂O (b) emissions from DSR and TPR during rice growing season.](image)
The total of N\textsubscript{2}O emissions during the rice growing seasons DSR and TPR are presented in figure 1b. The highest emission rate was observed in DSR at K. Banteng (1.55 kg ha\textsuperscript{-1} season\textsuperscript{-1}) followed by TPR at K. Banteng, DSR at Adiwerna, DSR at D. Waru, TPR at D. Waru and TPR at Adiwerna were around 0.47, 0.39, 0.19, -0.03 and -0.26 kg ha\textsuperscript{-1} season\textsuperscript{-1} respectively. DSR emitted higher N\textsubscript{2}O emission compare to TPR. N\textsubscript{2}O emission is a by-product of microbial nitrification and denitrification in the soil, which mostly affected by water management and application of N fertilizer. Therefore, changes of soil water content directly affect nitrification and denitrification rate and govern N\textsubscript{2}O production in the soil.

3.2 Yield-scaled global warming potential/greenhouse gas intensity (GHGI)
GHGI from DSR and TPR at D. Waru, Adiwerna and K. Banteng are shown in figure 2. GHGI is a method to measure the efficiency of cropping systems that produce high grain yields with low global warming potential (GWP) values. GWP is an index to measure the radiative forcing of a unit mass of the specific gas, accumulated over a specific time period and using carbon dioxide as a reference [16].

In this study, GHGI from TPR at Adiwerna resulted negative value most likely because the negative value of GWP was contributed from N\textsubscript{2}O emission. The negative value of N\textsubscript{2}O most likely because the fluctuations of water in the field. The contribution of CH\textsubscript{4} and N\textsubscript{2}O emission to GWP in this study were around 71% and 29%, respectively. It means that CH\textsubscript{4} is the main contributor of GWP from rice field. DSR at D. Waru and K. Banteng showed lower GHGI around 10 and 37% than TPR, respectively. It means that DSR ensure high yields with low GHG emissions.

![Figure 2. GHGI from DSR and TPR during rice growing season.](image)

3.3 Yield and yield component
Yield components in all parameter measured between DSR and TPR at the three sites were not different, included 1000 weight grain, % filled grain, root and shoot weight and total biomass (Table 2). The highest grain yield was found at DSR-D. Waru and followed by TPR-D. Waru, DSR-K. Banteng, DSR-Adiwerna, TPR-Adiwerna, and TPR-K. Banteng were approximately 9.53; 7.04; 6.22; 5.10; 5.09 and 3.15 ton ha\textsuperscript{-1}, respectively. DSR resulted higher grain yield compare to TPR. The DSR could significantly increase grain yield than TPR at D. Waru and K. Banteng approximately 26 and 49%, respectively. Providing enough water for rice growth would promote percentage of filled grain as long as nutrient supply is sufficient and climate is favourable for rice plant growth [17]. Continuous submergence of rice field in Indonesia was not essential for achieving high rice yields [18]. Rice yields under continuously flooded condition tend to be very low due to detrimental to rice root growth, limited rice growth during the vegetative phase of rice and the chemical changes of paddy soil that affect the transformation of nutrient [19].
Table 2. Yield and yield components from DSR and TPR during rice growing season.

| Parameters                  | D. Waru | Adiwerna | K. Banteng |
|-----------------------------|---------|----------|------------|
| 1000 grain weight (g)       | 24.8    | 24.4     | 24.7       | 24.0     | 26.5     | 26.3     |
| % Filled Grain              | 62.8    | 62.4     | 53.4       | 81.7     | 57.3     | 78.7     |
| Root Weight (g hill⁻¹)      | 5.75    | 2.50     | 2.40       | 3.20     | 4.10     | 2.05     |
| Shoot Weight (g hill⁻¹)     | 111.35  | 42.30    | 43.65      | 40.05    | 35.05    | 32.55    |
| Total biomass (g hill⁻¹)    | 117.10  | 44.80    | 46.05      | 43.25    | 39.15    | 34.60    |
| Grain yield (t ha⁻¹)        | 9.53    | 7.04     | 5.10       | 5.09     | 6.22     | 3.15     |

Most of rice produced on the Java Island, Indonesia is under irrigation and the farmers are using TPR in this area. However, DSR is applied in the first planting season in some areas in rainfed lowland. Mostly, the seeds experience with the drought and the vigour of the seed are dependent on the intensity and frequency of rains received after sowing. Aerobic soil in the early planting season will reduce GHG emissions and save the water. Based on the advantages, DSR should be applied not only in rainfed area but also in irrigated area. DSR is a chance to change production practices to gain higher yield and reduce GHG emissions.

4. Conclusions
In summary, despite the relatively higher N₂O emissions in DSR, the GWP of DSR is lower than that of transplanted rice because of substantially low CH₄ emissions in DSR. Furthermore, DSR showed higher grain yield. DSR is an appropriate GHG emission reduction strategies that maintain or even enhance high yields. DSR has been considered the best option of rice planting system for rice production. Further studies are needed to identify suitable management practices for reducing both CH₄ and N₂O emissions without any trade-off.

Acknowledgments
The authors would like to thank all greenhouse gas laboratory members of Indonesian Agricultural and Environment Research Institute for the technical assistance in this study. The three authors of this paper were contributed equally as the main contributors.

References
[1] FAO 2016 *Save and grow in practice: maize, rice and wheat, a guide to sustainable cereal production*. FAO, Rome, p. 124
[2] Sepat S and Rana D S 2013 Effect of double no-till and permanent raised beds on productivity and profitability of maize (Zea mays l.) – wheat (Triticum aestivum (l.) emend. Flori & paol) cropping system under Indo-gangetic plains of India *Int. J. Agr. Food Sci. Tech.* 4 787–790
[3] Van Nguyen N and Ferrero A 2006 Meeting the challenges of global rice production *Paddy Water Environ.* 4 1–9
[4] Rao A N, Johnson D E, Sivaprasad B, Ladha J K and Mortimer A M 2007 Weed management in direct-seeded rice *Adv. Agron.* 93 155–255
[5] Gaihre Y K, Singh U, Bible W D, Fugice Jr J and Sanabria J 2020 Mitigating N₂O and NO emissions from direct-seeded rice with nitrification inhibitor and urea deep placement *Rice Sci.* 27 434–444
[6] Totin E, Stroosnijder L and Agbossou E 2013 Mulching upland rice for efficient water management: a collaborative approach in Benin *Agric. Water Manage.* 125 71–80
[7] Katsura K and Nakaide Y 2011 Factors that determine grain weight in rice under high-yielding aerobic culture: the importance of husk size *Field Crop Res.* 123 266–272
[8] Johnson D, Mortimer M, Orr A and Riches C 2003 *Weeds, rice and poor people in South Asia.* Natural Resources Institute, Chatham (UK)

[9] Linquist B, van Groenigen K J, Adviento-Borbe M A, Pittelkow C and Kessel C 2012 An agronomic assessment of greenhouse gas emission from major cereal crops *Global Change Biol.* 18 194–209

[10] IPCC 2007 *Changes in atmospheric constituents and in radiative forcing.* In: Solomon S, Qin D, Manning M, et al. (Eds.), Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK/New York, pp. 498–540.

[11] Shang Q Y, Yang X X, Gao C M, Wu P P, Liu J J, Xu Y C, Shen Q R, Zou J W and Guo S W 2010 Net annual global warming potential and greenhouse gas intensity in Chinese double rice-cropping systems: a 3-year field measurement in long-term fertilizer experiments *Global Change Biol.* 17 2196–2210

[12] Epron D, Plain C, Ndiaye F K, Bonnau P, Pasquier C and Ranger J 2016 Effects of compaction by heavy machine traffic on soil fluxes of methane and carbon dioxide in a temperate broadleaved forest *For. Ecol. Manage.* 382 1–9

[13] Fest B, Wardlaw T, Livesley S J, Duff T J and Arndt S K 2015 Changes in soil moisture drive soil methane uptake along a fire regeneration chronosequence in a eucalypt forest landscape *Global Change Biol.* 21 4250–4264

[14] Lia H, Guoa H Q, Helbig M, Daia S Q, Zhang M Z, Zhao M, Pengb CH, Xiaog X M and Zhaoa B 2019 Does direct-seeded rice decrease ecosystem-scale methane emissions?—A case study from a rice paddy in southeast China *Agr. For. Meteorol.* 272–273 118–127

[15] Sandhu N and Kumar A 2016 *Traits for dry direct-seeded rice.* Technical Assistance Consultant’s Report Regional: Development and Dissemination of Climate-Resilient Rice Varieties for Water-Short Areas of South Asia and Southeast Asia, P.433

[16] Farmer G T and Cook J 2013 *Climate change science: a modern synthesis.* In The Physical Climate, 1st ed.; Springer: New York, NY, USA

[17] Yoshida S 1981 *Fundamental of rice crop science.* International Rice Research Institute (IRRI). Los Banos, Laguna, Philippines. 269p

[18] Sato S and Uphoff N 2007 *A review of on-farm evaluation of system of rice intensification (SRI) methods in eastern Indonesia.* CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources. Wallingford: Commonwealth Agricultural Bureau International

[19] Sahrawat K L 2000 Elemental composition of the rice plant as affected by iron toxicity under field conditions *Commun. Soil Sci. Plant Anal.* 132 2819–2827.