Effect of standing water levels on methane gas emission and yield performance of transplanted Aman rice (Oryza sativa L. cv. BRRI dhan51)

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INTRODUCTION

Global warming and climate change have become the main issue in Bangladesh. Climate change is strongly linked to increasing levels of specific greenhouse gases (GHGs) such as carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) that are responsible for global warming. Methane (CH₄) is an important greenhouse gas with both natural and anthropogenic sources (Wang et al., 2005). CH₄ is considered as the second important greenhouse gas next to CO₂ which has 25 times more global warming potential (GWP) than carbon dioxide contributing to 16% of the global warming. The global atmospheric concentration of CH₄ has increased steadily more concentrated in the air since the 18th century, more than doubling from around 750 parts per billion (ppb) to more than 1,850 ppb today. Like carbon dioxide, methane absorbs infrared radiation and warms the atmosphere. Atmospheric CH₄ originates from both natural and anthropogenic sources. Rice paddy is a large source of...
methane emission (Zhang et al., 2020). More than 50% of the global annual CH₄ emissions are of anthropogenic origin, and the cultivation of irrigated rice may account for up to 12% of this flux (IPCC, 2007 and Smartt et al., 2016). Recent estimates of CH₄ from rice fields range between 39 and 112 Tg CH₄ per year (Denman et al., 2007). Rice paddies are major source of atmospheric CH₄. The total annual global emission of CH₄ is estimated at 500 Tg yr⁻¹, but the accuracy of this estimate is highly uncertain. Improving estimates of CH₄ emission at the regional and global scales requires process-based models, integrating the environmental and biological factors that determine the rate of CH₄ emission. A clear understanding of the interaction between climate change and rice production will provide a sound basis for future decisions and technology developments by policymakers, agriculturists, environmentalist, rice producers and consumers alike. The CH₄ plays a major role in global warming and climate change, and its reduced emission is essential without adversely affecting crop production. CH₄ emitted from rice fields under various cultural practices has been an area of research, as little information is presently available on this aspect (Yan et al., 2003).

Rice (Oryzá satíva L.) is the most extensively cultivated food grain crop which contributes near about 95% of total food production in Bangladesh. Soil and climate conditions are very favorable for year round rice cultivation in Bangladesh. About 74.85% of cropped area of Bangladesh is used for rice production, where Aus. Aman and Boro rice covers 8.94%, 49.12% and 41.94%, respectively (BBS, 2018). The area and production of rice in Bangladesh is about 11.01 million hectares and 33.80 million tons, respectively (BBS, 2018). As a main food grain crop rice is produced at least twice in the same crop field in Bangladesh. In case of Rice Fallow-Rice cropping pattern, one rice crop is fully irrigated (Boro rice) and another is mostly rainfed (T. Aman rice). The flooded rice paddy has been identified as one of the most important sources of anthropogenic CH₄ emission (Jacobson, 2005). The farmers’ of Bangladesh are poor and marginal and still depend on traditional agriculture. They use cow dung, poultry litter, compost, biogas slurry, municipal compost, and vermicompost in their land those produce or enhance CH₄ emission from rice fields. These organic fertilizers are available to farmers as they rear poultry, cattle in their own houses. The largest present anthropogenic sources of CH₄ are rice fields, cattle and biomass burning. Therefore, producing more rice with less water is a formidable challenge for achieving food and water security for these regions (Khalil and Shearer, 2000). Climate change is become a big challenge for agriculture sector. If the farmer wants to increase agriculture production, he needs to follow adaption method to mitigate the effect of climate change. As extensive research works are necessary to find out the methane gas emission and grain yield in Aman rice at medium low lying area under standing water level. The present investigation was undertaken to assess CH₄ gas emission and grain yield in Aman rice under different levels of standing water.

**MATERIALS AND METHODS**

**Experimental period, location and site**

The experimental was carried out during July to December 2015 (T. Aman season). The experimental site was medium low lying area of Mohanganj Upazila (24.87 °N latitude and 90.97 °E longitude) under Netrokona District, Bangladesh. The soil of the experimental field belongs to the non-calcareous dark grey floodplain soil under the Old Brahmaputra Flood Plain (AEZ-9). The experimental area was under subtropical climate characterized by moderate high temperature, heavy rainfall, flash flood and high humidity during the T. Aman season (July-October, 2015) (Table 1).

**Experimental treatments and design**

The experimental treatments were: T₁: Standing water level from soil surface (5 cm), T₂: Standing water level from soil surface (10 cm), T₃: Standing water level from soil surface (15 cm), T₄: Standing water level from soil surface (20 cm), T₅: Standing water level from soil surface (25 cm). The experiment was laid out in a randomized complete block design (RCBD) with three replications. The experimental field was divided into three blocks. The area of each plot was 20 square meter (5.0 m × 4.0 m). The treatment combinations were randomly distributed to unit plots. BRRI dhan51 was used as the test crop.

**Crop husbandry**

Seeds were soaked in water in bucket for 24 hours and then taken out of water and kept thickly in gunny bags. During July the experimental field was ploughed and cross plough three times followed by laddering to obtain the desirable tilth. The land was cleaned by removing weeds, stubbles and crop residues. Nursery beds were made wet by application of water both in the morning and evening on the day before uprooting the seedlings. Seedlings were uprooted carefully early in the morning on 6 August 2015 and transplanting in row in the main field at the 2 seedlings per hill with 15 cm × 25 cm spacing. Thirty days old seedlings were uprooted from the seed bed and transplanted in the main field. Five hills were selected at random from each unit plot excluding border rows to record the data on crop characters and yield components. The rice was harvested plot wise on 05 December 2015. The harvested crop of each plot was separately bundled, tagged and brought to the threshing floor. The grains were threshed, cleaned, sun dried and weighed to record the grain yield. The grain yield was adjusted to 14% moisture content. Straw was sun dried and weighed to record the straw yield. Finally grain and straw yields plot⁻¹ were recorded and converted to t ha⁻¹. Harvest index (%) was calculated with the following formula (Paul et al., 2020).

\[
\text{Harvest index (\%) = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100}
\]

Where,

Economic yield = Grain yield, Biological yield = Grain yield + Straw yield
Gas samples collection

One chamber was installed in each experimental plot (Plate 1). Gas samples were collected at different growth stages of rice plant to get the trend of \( \text{CH}_4 \) emissions during the cropping season (Plate 2). Gas samples were collected by 50 ml gas-tight syringes at 0, 10 and 20 minutes intervals after chamber placement over the rice planted plot. The samples were analyzed for \( \text{CH}_4 \) by using gas chromatograph (GC-2014) equipped with an FID (flame ionization detector). The analysis column used a stainless steel column packed with Porapak NQ (Q 80-100 mess). The collected samples were stored in an evacuated glass vials until its laboratory analysis. Sample collected before chamber closing was used to determine the background concentration of methane. The concentration difference between 0 min and 20 min gave the total emission occurred during 20 min when gas chamber was closed.

Gas sample analysis

Gas sample was analyzed in the Central Laboratory of Bangladesh Agricultural University (BAU), Mymensingh. Seasonal total emissions of \( \text{CH}_4 \) were calculated from the sum of daily emission rates. The data were processed with MS, Excel, and average value and standard deviation is calculated.

Analytical techniques

Gas samples were collected by using the closed-chamber method (Ali et al., 2008) during the rice cultivation. The dimensions of close chamber were 62 × 62 × 112 cm. One chamber was installed in each experimental plot. Gas samples were collected at two times (11.00 am- 2.00 pm) in three stages (vegetative, flowering and ripening stage) to get the average \( \text{CH}_4 \) emissions during the cropping season.

Calculation of \( \text{CH}_4 \) flux

\( \text{CH}_4 \) flux was calculated by using the following formula (Rolston, 1986)

\[
F = \rho \left( \frac{V}{A} \right) \left( \frac{\Delta c}{\Delta t} \right) \frac{273}{T}
\]

Where

\( F = \text{methane flux (mg m}^{-2} \text{hr}^{-1} \)  \\
\( \rho = \text{gas density (0.714 mg CH}_4 \text{ m}^{-3} \)  \\
\( V = \text{volume of the chamber (m}^3 \)  \\
\( A = \text{surface area of chamber (m}^2 \)  \\
\( \Delta c/\Delta t = \text{rate of increase of methane gas concentration in the chamber (mg m}^{-3} \text{ hr}^{-1} \)  \\
\( T = 273 + \text{mean temperature in chamber (°C) } \)

Statistical analysis

Data on the plant characteristics and \( \text{CH}_4 \) emission were analyzed using the analysis of variance (ANOVA) technique with the help of computer package programme MSTAT-C (Russell, 1986) and mean differences were adjusted by Duncan's Multiple Range Test (Gomez and Gomez, 1984).

Table 1. Meteorological parameters during study period.

| Date          | Air temperature | Relative* humidity (%) | Rainfall* (mm) (Total) |
|---------------|-----------------|------------------------|------------------------|
|               | Maximum         | Minimum                |                        |
| July, 2015    | 31.56           | 26.83                  | 86.00                  | 16.14                  |
| August, 2015  | 31.96           | 26.31                  | 97.00                  | 12.63                  |
| September, 2015 | 32.02         | 24.03                  | 87.68                  | 12.30                  |
| October, 2015 | 32.05           | 23.2                   | 82.9                   | 78                     |
| November, 2015 | 30.03          | 18.1                   | 82.2                   | 4.3                    |
| December, 2015 | 25.2            | 13.3                   | 83.4                   | 0.0                    |

Source: Department of Irrigation and Water Management, BAU, Mymensingh - 2202.

Plate 1. Site view of experimental plot.

Plate 2. Collection of gas sample from paddy field.
RESULTS AND DISCUSSION

Effect of standing water level on CH₄ emission

The CH₄ emission was significantly affected by standing water levels (Figure 1). It was found that the CH₄ emission was significantly varied from 6.3 to 13.11 mg m⁻² h⁻¹ at 24 DAT, where the treatment T₅ (Standing water 20 cm) level showed the highest CH₄ emission while the lowest was recorded in the treatment T₁ (Standing water 5 cm) level. Similar trend of CH₄ emission was also recorded at 48 DAT. At 85 DAT, treatment T₄ (Standing water 20 cm) level showed the highest CH₄ emission (about 35 mg m⁻² h⁻¹) while the lowest CH₄ emission 17.9 mg m⁻² h⁻¹ was found from treatment T₁ (Standing water 5 cm) (Figure 1). This was supported by Ding et al. (2002) who reported that CH₄ emission increased as standing water depth incremented from 15 to 20 cm. The author noticed that standing water depth determined the type of marsh plants, which governed CH₄ transport, and the amount of plant litters, which resulted in the difference of labile organic C for methanogenesis among marshes. Zou et al. (2005) reported that water table depth could be used as a management option and control CH₄ emission from rice fields and CH₄ emission could be considerably reduced by lowering the water table. However, reduction of water table may trigger CH₄ emissions from soil pores (Bubier and Moore, 1994).

Effect of standing water level on CH₄ emission rate at different growth stages of BRRI dhan51.

Soil redox potential (Eh): Soil redox potential (Eh) values were recorded at different rice growth stages. It was found that the reduction of soil redox status influenced significantly by the advancement of the growth stages. At 24 DAT, soil Eh ranged from -92.33 to -114.6 mV, -121 to -215 mV at 48 DAT (PS), -125 to -224 mV at 64 DAT (BS), -214.6 to -241.6 mV at 85 DAT (HS) and -155.6 to -193.6 mV at 108 DAT (RS). Among the treatment only T₄ (Standing water level 5 cm) showed the less soil reduction potential of Eh (-92.33 mV) of 24 DAT, while treatment T₃ (Standing water level 20 cm) showed the highest soil reduction potential of Eh (-238.67 mV) at this stage. At 48 DAT, soil Eh value was observed (-121.3 mV) in treatment T₁ while treatment T₄ showed highly reduced end Eh value (-224 mV). Similarly at 64 DAT, treatment T₃ (Standing water level 20 cm) showed the capability to reduce the most intense of soil redox reduction (-238.67 mV). Later on (85 DAT), the soil Eh value decreased towards -214.6 (T₃) to -241.6 mV (T₄). Finally at 108 DAT, soil redox status improved towards -155.6 mV (T₄) to -193.5 mV (T₅) (Figure 2).

Soil pH: The data of soil pH was recorded at 24, 48, 64, 85 and 108 DAT where all the data recording stages were statistically due to the effect of different standing water level. At 24 DAT, the highest pH content of soil (7.6) was recorded from the T₂ treatments (standing water level 10 cm). At this stage (24 DAT), standing water level T₁ (standing water level 5 cm) treated soil recorded the lowest pH content (6.79). At 64 DAT, the ranges of pH was 6.84 to 7.72 where the lowest was found from the treated soil of standing water level T₁ (standing water level 5 cm) and the highest was observed from the treated soil of standing water level T₂ (standing water level 10 cm). From the above result it was found that the highest and the lowest pH value of 85 DAT was found 7.73 in the treatment of T₂, T₃ and T₄ and the lowest value is 6.87 in the treatment T₁ (standing water level 5 cm). Finally the pH value in 108 DAT highest and lowest value was found 7.27 and 6.74 respectively in the treatment of standing water level T₂ (standing water level 10 cm) and T₁ (standing water level 5 cm) (Figure 3). Wang et al. (1993) observed that the CH₄ production rate in paddy soil peaked at a pH between 6.9 and 7.1. A pH of below 5.75 or above 8.75 completely suppressed CH₄ production.

Soil pH at different growth stages of BRRI dhan51.

Changes in soil redox potential (Eh) with rice plant growth stages (BRRI dhan51).
Table 2. Effect of different levels of water on the yield contributing characters and yield of transplant Aman rice.

| Treatments (Standing water level) | Plant height (cm) | Panicles hill$^{-1}$ (no.) | Length of panicle (cm) | Number of filled grains hill$^{-1}$ | Weight of 1000-grain (g) | Grain yield (kg ha$^{-1}$) | Straw yield (kg ha$^{-1}$) | Harvest index (%) |
|----------------------------------|-------------------|-----------------------------|------------------------|-----------------------------------|--------------------------|---------------------------|-----------------------|------------------|
| T$_1$ (5 cm)                     | 98.00ab           | 17.33ab                     | 29.00                  | 2011.0b                           | 23.47                    | 4191.6c                   | 5487.0b               | 42.62b           |
| T$_2$ (10 cm)                    | 98.33a            | 23.33a                      | 28.67                  | 2660.0a                           | 23.78                    | 5260.0a                   | 6725.0a               | 43.89a           |
| T$_3$ (15 cm)                    | 96.00c            | 18.33ab                     | 27.67                  | 2116.0a                           | 23.67                    | 4506.0b                   | 5050.0d               | 47.20a           |
| T$_4$ (20 cm)                    | 97.33abc          | 17.33ab                     | 28.00                  | 1985.0b                           | 22.27                    | 4388.0bc                  | 5992.0c               | 44.40a           |
| T$_5$ (25 cm)                    | 96.33bc           | 16.67b                      | 27.00                  | 1896.0b                           | 23.36                    | 4333.4bc                  | 5433.0c               | 43.3a            |
| LSD$_{0.05}$                     | 1.60              | 5.959                       | 3.44                  | 1.60                              | 3.66                     | 3.66                      | 1.48                 | 1.30             |
| CV (%)                           | 0.88              | 17.02                       | 7.04                   | 11.17                             | 3.66                     | 3.66                      | 1.48                 | 1.30             |

Table 3. Chemical properties of post-harvest soil under different treatments.

| Treatments (Standing water level) | OC (%) | OM (%) | TN (%) | P (ppm) | K (meq/100g soil) | S (ppm) | Level of significance |
|----------------------------------|--------|--------|--------|---------|------------------|---------|----------------------|
| T$_1$ (5 cm)                     | 1.27   | 2.450  | 0.13   | 40.53b   | 0.20             | 8.75    | *                   |
| T$_2$ (10 cm)                    | 1.24   | 2.333  | 0.13   | 48.05a   | 0.19             | 9.68    | *                   |
| T$_3$ (15 cm)                    | 1.28   | 2.083  | 0.11   | 32.79c   | 0.20             | 10.93   | *                   |
| T$_4$ (20 cm)                    | 1.21   | 2.460  | 0.13   | 39.98b   | 0.21             | 10.14   | *                   |
| T$_5$ (25 cm)                    | 1.28   | 2.060  | 0.14   | 37.60bc  | 0.19             | 9.39    | *                   |
| LSD$_{0.05}$                     | 0.15   | 0.43   | 0.05   | 4.70     | 0.084            | 3.93    | NS                  |
| CV%                              | 3.90   | 3.84   | 17.32  | 1.77     | 24.05            | 20.84   | NS                  |

Effect of standing water level on crop characters, yield components and yield

Plant height, number of panicles hill$^{-1}$, number of filled grains hill$^{-1}$, grain yield, straw yield and harvest index were significantly influenced by standing water level (Table 2). The tallest plant (98.33 cm) was recorded in T$_2$ (standing water 10 cm) which was statistically identical with T$_1$ (standing water 5 cm) followed by T$_4$ (20 cm) and T$_5$ (standing water 25 cm) and the lowest one (96.00 cm) was recorded in T$_3$ (standing water 15 cm). This result was in conformity with Sarkar et al. (2017) who noticed that water management in rice influenced on plant height. The highest number of panicles hill$^{-1}$ (23.33) was recorded in T$_2$ (standing water 10 cm) which was at par with T$_1$ (standing water 5 cm), T$_3$ (standing water 15 cm) and T$_4$ (standing water 20 cm) while the lowest number of panicles hill$^{-1}$ was obtained in T$_5$ (standing water 25 cm). It means different water regime regulate the production of effective tillers and higher water level decreased in T$_5$ (standing water 25 cm). Length of panicle was not significantly influenced by standing water level (Table 2). Numerically the longest panicle length (29 cm) was recorded in T$_1$ (standing water 5 cm) where the shortest panicle (27.00 cm) was obtained at T$_3$ (standing water 25 cm). The highest number of filled grains hill$^{-1}$ (2660.0) was recorded in T$_2$ (standing water 10 cm) which was as good as (2116.0) T$_3$ (standing water 15 cm) while the lowest number of filled grains hill$^{-1}$ (1896.0) was recorded in T$_5$ (standing water 25 cm). Thousand-grain weight was not significantly influenced by standing water level (Table 2). Numerically the highest 1000-grain weight (23.78 g) was recorded in T$_2$ (standing water 10 cm) while the lowest value (22.27 g) was recorded in T$_4$ (standing water 20 cm). The highest grain yield (5260.0 kg ha$^{-1}$) was recorded in T$_2$ (standing water 10 cm) followed by T$_3$ (standing water 15 cm) while the lowest grain yield (4191.6 kg ha$^{-1}$) was obtained in T$_1$ (standing water 5 cm). The highest number of panicles and number of filled grains hill$^{-1}$ are contributed the highest grain yield in T$_2$ (standing water 10 cm). The highest straw yield (6725.0 kg ha$^{-1}$) was obtained from T$_2$ (standing water 10 cm) and lowest straw yield (5050.0 kg ha$^{-1}$) was recorded in T$_3$ (standing water 15 cm). The highest plant height in T$_2$ (standing water 10 cm) might be responsible for the highest straw yield. These results corroborate with the findings of Paul et al. (2019) who reported that crop characters, yield components, grain and straw yields varied due to variation of water management in rice. The highest harvest index (47.2%) was obtained in T$_3$ (standing water 15 cm) which was as good as T$_2$ (standing water 10 cm), T$_4$ (standing water 20 cm) and T$_5$ (standing water 25 cm) but the lowest harvest index (42.62%) was obtained at T$_1$ (standing water 5 cm).

Chemical properties of post-harvest soil under different levels of standing water

Percentage of organic carbon (OC): The organic carbon in post-harvest soil was not significant due to the effect of different levels of standing water (Table 3). Numerically, the highest organic carbon (1.28 %) was recorded in T$_3$ (standing water 15 cm) and T$_5$ (standing water 25 cm) the lowest content of organic carbon (1.21%) studied postharvest soil in the water level T$_4$ (standing water 20 cm).
**Percentage of organic matter (OM):** The organic matter in postharvest soil was not significant due to the effect of different levels of standing water (Table 3). Numerically, the highest total organic matter (2.46 %) was recorded in T4 (standing water 20 cm) and lowest organic matter content (2.06 %) in postharvest soil was recorded in the water level T1 (standing water 25 cm).

**Total nitrogen (N):** Total nitrogen was not significantly influenced by level of standing water in the rice field (Table 3). However, numerically, the highest N (0.14 ppm) was recorded in T1 (standing water 25 cm) and the lowest content of N (0.11 ppm) in the water level T3 (standing water 15 cm).

**Available phosphorus:** The phosphorus in post-harvest varied significantly due to the effect of standing water level (Table 3). The highest phosphorus value was found (48.05 ppm) in the treatment T2 (standing water 10 cm) followed by T1 (standing water 5 cm) which was at par with and the lowest content of phosphorus (32.79 ppm) studied postharvest soil in the water level and T3 (standing water 15 cm).

**Exchangeable potassium:** The exchangeable potassium was not significant due to the effect of different levels of standing water (Table 3). The highest value of potassium was recorded (0.21meq/100g soil) in T2 (standing water 20 cm) while the lowest content of phosphorus (0.19 meq/100g soil) studied postharvest soil in the water level T3 (standing water 20 cm).

**Available sulphur:** Sulphur content of post-harvest soil was not varied significantly due to effect of standing water level (Table 3). Numerically the highest value of sulphur found (10.93 ppm) in the T3 (water level 15 cm) while the lowest value of sulfur (8.75 ppm) in the water level T1 (standing water 5 cm).

**Conclusion**

CH$_4$ emission gradually increased with rising standing water levels and remained static condition at 20-25 cm water level. The highest CH$_4$ emission was observed at 20 cm standing water levels and the lowest CH$_4$ emission was recorded at 5 cm standing water level. The maximum CH$_4$ peak recorded at 85 DAT. In this study, the CH$_4$ flux during rice cultivation followed the sequence 20 cm > 25 cm > 15 cm > 10 cm > 5 cm. Soil Eh gradually decreased with progress of time and plant growth. The highest plant height, number of grains hill$^{-1}$, grain yield and straw yield were observed at 10cm standing water level while the lowest grain yield and straw yield were recorded at 5 cm and 15 cm water level, respectively. The highest amount of available phosphorus was found at 10 cm standing water level followed by 5 cm standing water level while the lowest one was recorded at 15 cm water level. From this study it can be concluded that 10 cm standing water level is suitable for transplant Aman rice cultivation considering the higher grain yield and nutrients availability and lower methane emission compared to other standing water level.

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