



Effect of Mid-Season Drainage, Sulphate Addition and Blue Green Algae on the Yield, Methane Emission and Carbon Flux from Rice Fields

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The current study was undertaken with the objective of estimating methane emission and carbon flux with modified management practices (mid season drainage, zero tillage and sulphate application) using DNDC model and calibration and validation of the model at field scale. Methane (CH₄) and carbon dioxide (CO₂), two greenhouse gases (GHG) linked to agricultural activities are key contributors to climate change caused by human activity. Crop management techniques such as stubble manuring, puddling, sowing or transplanting, water management, and harvesting have a significant impact on the carbon exchange between rice fields and the atmosphere. Mid-season irrigation water pond draining stops the ongoing submergence. The research studies reported that mid-season drainage reduced CH₄ emissions. Hence an experiment was conducted at Agricultural Research Station, Tamil Nadu Agricultural University, Bhavanisagar with an objective of identification of management practices which emits low level of methane gas from rice ecosystem using rice variety CO 50 as test crop and modified management practices and sulphate application as treatments. Biometric observations were recorded and methane emission was quantified at 15 days interval from transplanting to harvest. Ten clumps of rice plants were sampled and Photosynthetically Active Radiation (PAR) was recorded at 15 days interval. The DeNitrification-DeComposition (DNDC) model was run for the treatment conditions. The field observations revealed that methane emission was low (41%) in the treatment of mid-season drainage when compared to control. The combination of mid-season drainage as well as Blue Green Algae (BGA) + Methylo-troph along with Recommended Dose of NPK (T7) application reduced the methane emission up to 48 per cent compared to control. The results generated from the DNDC model also revealed the similar results. The DNDC model captures the major impacts of water and N on GHG emissions from paddy cultivation. The analysis suggested that the model can be applied for studying the GHG related issues in rice cropping systems.

Keywords: DNDC; methane emission; mid-season drainage; rice.

1. INTRODUCTION

“Rice (*Oryza sativa L.*) cultivation is one of the most important sources of emissions of greenhouse gases (GHGS), mainly nitrous oxide (N₂O), methane (CH₄), and carbon dioxide (CO₂) and is the major driving force for climate change” [1-3]. “Rice cultivation, accounting for 22% of global anthropogenic agricultural emissions of CH₄” [4]. “Understanding the dynamics of CH₄ and CO₂ fluxes in paddy fields is crucial for improving the accuracy of estimating CH₄ and CO₂ emissions from global paddy fields” [5]. “In fact, anaerobic condition in the soil is the prerequisite for biological methane production” [6]. “Flooding continuously in conventional rice cultivation system stimulates the biological process of methane production by inducing the anaerobic condition in the soil” [7]. “According to an estimate by IPCC, these fields contribute 11% (60 Tg yr⁻¹) of global CH₄ emissions. However, the range in this estimate is wide (20-100 Tg yr⁻¹), largely due to uncertainties in estimates of

CH₄ emission under a diversity of environmental and agronomic conditions” [8].

“Changes in farming management practices, such as tillage, fertilization, irrigation, manure amendment etc., are currently being evaluated for their potential in mitigating greenhouse gases emitted from the agricultural sector. It has been widely reported that replacing conventional tillage with no-till results in soil organic carbon (SOC) storage” [9]. “In general no till or reduced tillage in comparison to conventional tillage results in lower CO₂ emission and greater CO₂ sequestration in soil” [10].

“Water management is a most important factor for CH₄ emission from rice fields” [11]. “Anoxic condition and flooding favored methane release. Therefore appropriate drainage and drying significantly reduced CH₄ emission” [12]. “Many studies proved that the mid-season drainage, entailing purposeful drainage and subsequent field drying for around ten days at the later

tillering stage could increase the productive tillering volume and rice yields and the soil drying after the milk ripening stage will prevent the delayed ripening” [13-16].

“Nitrogen fertilizer applied in the form of ammonium sulphate reduces the CH₄ emission. Due to the application sulphur, sulphur oxidizing bacteria are grown in turn reduce the population of methanotrophs Ammonium sulphate and urea were applied at rates of 0 (control), 100 and 300 kg N ha⁻¹ and the results showed that CH₄ emission, on the average, decreased by 42 and 60% in the ammonium sulphate treatments and 7% and 14% in the urea treatments at rates of 100 and 300 kg N ha⁻¹, respectively, compared to the control” [17].

“De Nitrification-De Composition (DNDC) is a comprehensive biogeochemistry model that simulates crop growth and soil Carbon (C) and Nitrogen (N) dynamics based on input data on soil properties, climate, and farming practices” [18]. “The DNDC model was originally developed for predicting C-sequestration and trace gas emissions for non-flooded agricultural lands” [19]. Hence, the current study was undertaken with the objective of estimating methane emission and carbon flux with modified management practices (mid season drainage, zero tillage and sulphate application) using DNDC model and calibration and validation of the model at field scale.

2. MATERIALS AND METHODS

The field experiment was conducted during 2017 and 2018 with modified management practices was conducted using the rice variety CO 50 at Agricultural Research station, Bhavanisagr, Erode district of Tamil Nadu. Comprehensive biogeochemistry model, DNDC, developed by [20] was used to seek the best management practices for mitigating methane and CO₂ emission from paddy cultivation. In this study the DNDC model (version 9.3; <http://www.dndc.sr.unh.edu/>) was applied. The observed weather parameters for the year 2017 and 2018 were used for this study. Cropping sequence was taken for both two consecutive years. Input parameters such as climate (maximum temperature, minimum temperature, precipitation and wind speed), atmospheric N deposition, soil bulk density, texture (clay fraction), total organic C content, pH and crop management practices (tillage, irrigation, fertilization, manure amendment and grazing)

were given. Two water management practices, continuous flooding and continuous flooding with mid-term drainage on 45th to 55th Days after Transplanting (DAT) and 65th to 75th DAT were examined for its efficacy to mitigating greenhouse gases as well as water use efficiency.

2.1 Model Calibration

A field experiment conducted in Agricultural Research Station (ARS), Bhavanisagar during 2018 was used for the calibration of the model. The experiments were carried out at the M3 block, ARS, Bhavanisagar, Tamil Nadu. The Geo-coordinates of the site is 11°29' N, 77°08' E and 256 m MSL with annual rainfall of 703.7 mm [cold weather period (Jan-Feb) -18.7, summer (March-May) -148.4, South West monsoon season (June-Sept) -213.1 and North East monsoon season (Oct-Dec) -323.5]. The maximum temperature ranged from 33-35° C. Minimum temperature was ranging from 19-22° C. Soil type represents Sathyamangalam and Kodiveri series. Soil is reddish brown to yellowish brown loam and clay loam having near neutral reaction (available N, P, K-238, 23, 194 Kg ha⁻¹ respectively, organic carbon - 0.48 %, pH - 7.57 and EC - 0.37 dSm⁻¹).

Biometric observations were recorded at regular interval. The treatments are as follows T₁ - control + RD of NPK, T₂ - zero tillage and midseason drainage + RD of NPK, T₃ - midseason drainage + RD of NPK, T₄ - sulphate application + RD of PK, T₅ - BGA + *Methylotrroph* + RD of NPK, T₆ - T₃ + T₄ + RD of PK and T₇ - T₃ + T₅ + RD of NPK. 25 kg of ZnSo₄ was given for all the treatments and 60 kg of N source in the form of ammonium sulphate remaining in the form of urea was given for T₄ and T₆, Mid-season drainage was provided at 40th to 50th DAT and 60th to 70th DAT for T₃, T₂, T₆ and T₇. Zero till/no till was given to T₂. Emissions of CH₄ and N₂O were measured frequently from the plots following the standard methodologies [21,22]. Total dry matter, grain yield and N uptake were measured at maturity.

2.2 Sensitivity Analyses

Sensitivity of the model to the changes in type of nitrogen fertilizer, tillage practices (till/no till), bio-inoculants application (BGA and *Methylotrroph*) and irrigation methods (conventional and intermittent irrigation) on rice yield and GHG emissions was analyzed using the baseline data (weather, soil, cultivar, location and other inputs).

3. RESULTS AND DISCUSSION

Predicted grain and biomass yield agreed well with observed values (Table 1 and Fig. 1). The observed emission of CH₄ during the growing season was ranges from 48.00 to 91.69 mg m⁻² day⁻¹ compared to continuous flooding (T₁ – Control), while the simulated emission was ranges from 65.09 to 6.71 kg C ha⁻¹ yr⁻¹ compared to continuous flooding (T₁ –Control). The deviation of the simulated value from the observed value was less than 5% (Table 2 and Fig. 2).

The DNDC model simulated that the continuous flooding irrigation with Recommended Dose of NPK (T₁) produced lower rice yield (observed-5878 kg ha⁻¹ and simulate -5629 kg ha⁻¹) than the intermittent irrigations. Longer the drainage period for 4 days and 3 days flooding treatment seemed to produce more rice yield by the DNDC model. A similar trend in yields and CH₄ emission is found in the pot experiments [23].

3.1 Sensitivity Analysis for Impacts of Tillage Practices, N Fertilizer (ammonium sulphate) and Water Management on Yield and GHG Emission

Different modified agronomic practices such as till/zero till, flooding and intermittent irrigation, nitrogen fertilizer (urea and ammonium sulphate) were significantly influenced the simulated yield (Table 1 and Fig. 1) and emissions of GHG from

soil (Table 2 and Fig. 2). Field drying at mid-tillering stage has been shown to reduce CH₄ emission by 15-80% as compared to continuous flooding, without a significant effect on grain yield. The present investigation revealed that methane emission was reduced in T₃ (Mid-season drainage + RD of NPK) compared to control (41%). The combination of both mid-season drainage as well as BGA application reduced methane emission up to 47.7% compared to control. This result was close conformity with [24], reported that mid-season drainage mitigated CH₄ emissions by 60%. CH₄ can be mitigated by intermittent drainage, *i.e.* by stopping irrigation and allowing the standing water to drain from the field. Water management also influenced the simulated yield and emissions of GHG from soil (Table 2 and Fig. 2). Methane emission was reduced in T₃ compared to control (24.1%). The combination of both mid-season drainage as well as BGA application reduced methane emission up to 23.2% compared to control.

Substituting 60 kg ha⁻¹ N with ammonium sulphate reduced the methane emission (37.1%) as compared to control. Simulated results also revealed the same trend (24.1 %) compared to control. Similar result was obtained by [25] studied the effect of urea and ammonium sulfate application on CH₄ emission. The model accurately predicted the negative effect of ammonium sulfate on CH₄ emission. This was done by accounting for the electron donors and competitive reduction of electron acceptors.

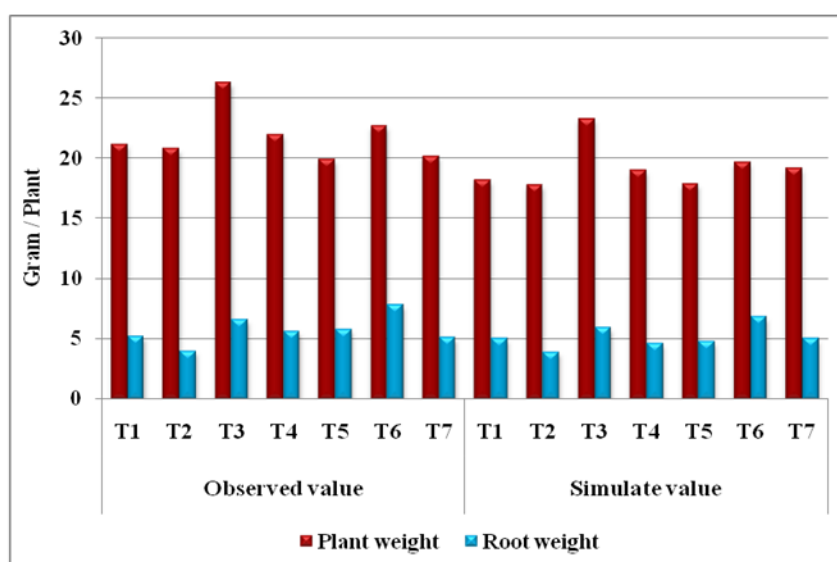


Fig. 1. Effect of modified practices on plant weight and root weight of paddy

Table 1. Effect of modified practices on the yield of rice

Treatments	Observed value			Simulate value		
	Plant weight (g plant ⁻¹)	Root weight (g plant ⁻¹)	Grain yield (kg ha ⁻¹)	Plant weight (g plant ⁻¹)	Root weight (g plant ⁻¹)	Grain yield (kg ha ⁻¹)
T ₁	21.2	5.2	5878	18.2	5.02	5629
T ₂	20.8	4.0	6925	17.8	3.90	6531
T ₃	26.3	6.6	6988	23.3	5.9	6580
T ₄	22.0	5.6	6869	19.0	4.6	6529
T ₅	19.9	5.8	6710	17.9	4.8	6229
T ₆	22.7	7.8	6773	19.7	6.8	6231
T ₇	20.2	5.1	6634	19.2	5.0	6230

T₁ - Control + RD of NPK, T₂ - Zero Tillage and Mid-season drainage + RD of NPK, T₃ - Mid-season drainage + RD of NPK, T₄ - Sulphate application + RD of PK, T₅ - BGA + Methylothrop + RD of NPK, T₆ - T₃ + T₄ + RD of PK and T₇ - T₃ + T₅ + RD of NPK

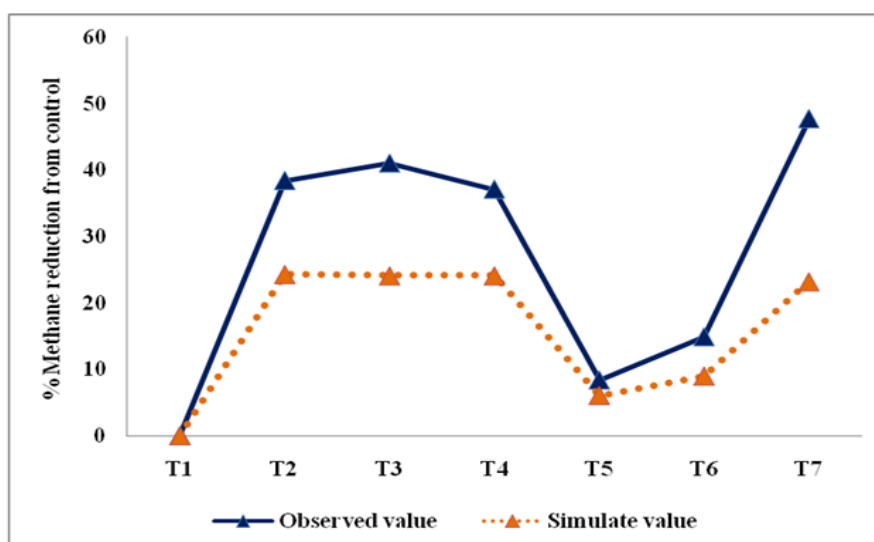


Fig. 2. Per cent Methane reduction over control from experimental plots planted to rice

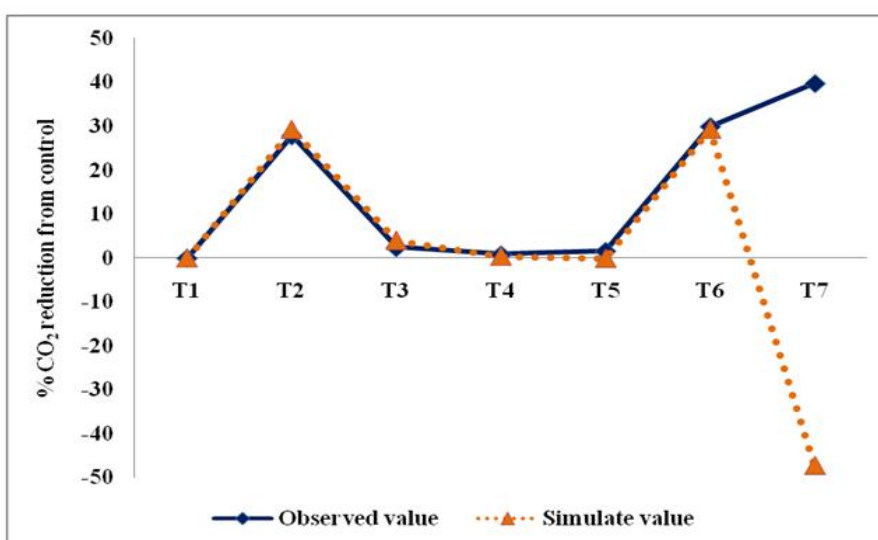


Fig. 3. Per cent CO₂ reduction over control from DNDC model output

Table 2. Methane flux (mg m⁻² day⁻¹) of experimental plots planted to rice

Treatments	Observed value		Simulate value	
	Methane flux (mg m ⁻² day ⁻¹)	% Methane reduction from control	Methane emission 'C' (kg C ha ⁻¹ yr ⁻¹)	% Methane reduction from control
T ₁	91.69	-	6.71	-
T ₂	58.65	38.4	5.11	24.3
T ₃	56.10	41.0	5.09	24.1
T ₄	57.66	37.1	5.77	24.1
T ₅	88.17	8.4	6.31	6.1
T ₆	83.79	14.9	6.12	9.0
T ₇	48.00	47.7	5.15	23.2

T₁ - Control + RD of NPK, T₂ - Zero Tillage and Mid-season drainage + RD of NPK, T₃ - Mid-season drainage + RD of NPK, T₄ - Sulphate application + RD of PK, T₅ - BGA + Methyloctroph + RD of NPK, T₆ - T₃ + T₄ + RD of PK and T₇ - T₃ + T₅ + RD of NPK

Table 3. CO₂ emission (kg C ha⁻¹ yr⁻¹) from DNDC model output

Treatments	Observed value		Simulate value	
	CO ₂ emission (mg m ⁻² hr ⁻¹)	% CO ₂ reduction from control	CO ₂ emission 'C' (kg C ha ⁻¹ yr ⁻¹)	% CO ₂ reduction from control
T ₁	13.45	-	2244	-
T ₂	9.71	27.8	1588	29.2
T ₃	13.21	2.4	2152	4.0
T ₄	13.10	0.8	2243	0.4
T ₅	13.31	1.6	2245	-0.1
T ₆	9.32	29.9	1588	29.3
T ₇	13.02	39.7	2338	-47.2

T₁ - Control + RD of NPK, T₂ - Zero Tillage and Mid-season drainage + RD of NPK, T₃ - Mid-season drainage + RD of NPK, T₄ - Sulphate application + RD of PK, T₅ - BGA + Methyloctroph + RD of NPK, T₆ - T₃ + T₄ + RD of PK and T₇ - T₃ + T₅ + RD of NPK

The carbon exchange between paddy fields and the atmosphere is also greatly influenced by cultivation practices and field management. Simulated CO₂ emission was reduced in zero tillage with mid-season drainage (29.2%) than compared to the control (Table 3 and Fig. 3). Studies of [26] proved that cumulative CO₂ fluxes after ploughing were considerably greater than from a no-till field. Agricultural fields under no-till conservation tillage cropping methods were found to sequester 300 kg C ha⁻¹ yr⁻¹, whereas conventionally tilled crops exhibited no annual carbon sequestration.

4. CONCLUSION

The application of existing knowledge at the field, farm, and regional levels for improving agronomic management, measuring changes in SOC and GHG emissions with changing land use, and creating alternatives for GHG emission mitigation will be greatly accelerated by models like DNDC. The main effects of N and water on

GHG emissions from paddy farming are captured by the DNDC model. According to the analysis, the model can be used to investigate GHG-related problems in rice cropping systems.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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