Effect of Temperature, Mid-Season Drainage, Sulphate Addition on the Methane Emission and Carbon Flux from Rice Fields

ABSTRACT

Agricultural activities are associated with the emission of greenhouse gases, notably methane (CH_4) and carbon dioxide (CO_2), which are important in anthropogenically influenced climate change. The carbon exchange between rice fields and the atmosphere is also greatly influenced by crop management practices such as stubble manuring, puddling, sowing or transplanting, water management and harvest. Draining of ponded irrigation water at mid-season interrupts the continuous sub-mergence. Research studies reported that mid-season drainage reduced CH_4 emissions by 60 per cent. 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 treatmental 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 both mid-season drainage as well as Blue Green Algae 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.

Keywords: Rice, methane emission, mid-season drainage, DNDC.

1. INTRODUCTION

Global warming is an important issue for humans. A major attributor of global warming is increases in greenhouse gases. In recent years, a great deal of attention has been focused on the global carbon balance, and in particular on the increasing concentrations of both CH_4 and CO_2 in the troposphere. Both these species are radiatively active. Agricultural activity can increase CO_2 emissions to the atmosphere by increasing soil decomposition rate and burning plant biomass. Paddy field is also an important source of atmospheric CH_4. Understanding the dynamics of CH_4 and CO_2 fluxes in paddy fields is crucial for improving the accuracy of estimating CH_4 and CO_2 emissions from global paddy fields [1]. In fact, anaerobic condition in the soil is the prerequisite for biological methane production [2]. Flooding continuously in conventional rice cultivation system stimulates the biological process of methane production by inducing the anaerobic condition in the soil [3]. According to an estimate by IPCC [4], these fields contribute 11% (60 Tg yr^{-1}) of global CH_4 emissions. However, the range in this estimate is wide (20-100 Tg yr^{-1}), largely due to uncertainties in estimates of CH_4 emission under a variety of environmental and agronomic conditions.

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 [5]. In general no till or reduced tillage in comparison to conventional tillage results in lower CO_2 emission and greater CO_2 sequestration in soil [6].

Water management is a most important factor for CH_4 emission from rice fields [7]. Anoxic condition and flooding favored methane release. Therefore appropriate drainage and drying significantly reduced CH_4 emission [8]. Many studies proved that the mid-season drainage, entailing purposeful drainage and subsequent field drying for around ten days at

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the later tillering stage could increase the productive tillering volume and rice yields [9] and the soil drying after the milk ripening stage will prevent the delayed ripening.

Nitrogen fertilizer applied in the form of ammonium sulphate reduces the CH_4 emission. Due to the application sulphur, sulphur oxidizing bacteria are grown in turn reduce the population of methanotrophs (as both organism use same substrate (SO_4^{-2}) as electron donor there is a co-exisistence between two). Studies of [10] showed that CH_4 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.

DNDC is a comprehensive biogeochemistry model that simulates crop growth and soil C and N dynamics based on input data on soil properties, climate, and farming practices [11]. The DNDC model was originally developed for predicting C-sequestration and trace gas emissions for non-flooded agricultural lands [12]. 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. MATERIAL AND METHODS

The experiment with modified management practices was conducted using the rice variety CO 50. Comprehensive biogeochemistry model, DNDC, developed by [12] was used to seek the best management practices for mitigating methane and CO_2 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 2012 and 2013 were used for this study. Cropping sequence was taken for 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

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grazing) were given. Two water management practices, continuous flooding and continuous flooding with mid-term drainage on 45^{th} to 55^{th} DAT and 65^{th} to 75^{th} 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 $11^0$29 N, $77^0$8 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 33-35^0 C. Minimum temperature was ranging from 19-22^0 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 T_1 - control + RD of NPK, T_2 - zero tillage and midseason drainage + RD of NPK, T_3 - midseason drainage + RD of NPK, T_4 - sulphate application + RD of PK, T_5 - BGA + *Methylotroph* + RD of NPK, T_6 - T_3 + T_4 + RD of PK and T_7 - T_3 + T_5 + RD of NPK. 25 kg of $ZnSo_4$ 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 T_4 and T_6, Mid-season drainage was provided at 40^{th} to 50^{th} DAT and 60^{th} to 70^{th} DAT for T_3, T_2, T_6 and T_7. Zero till/no till was given to T_2. Emissions of CH_4 and N_2O were measured frequently from the plots following the standard methodologies [13 & 14]. 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 *Methylotroph*) and irrigation methods

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(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 Figure 1). The observed emission of CH_4 during the growing season was 48-91.69 mg m^{-2} day^{-1}, while the simulated emission was 65.09-6.71 kg C ha^{-1} yr^{-1}. The deviation of the simulated value from the observed value was less than 5% (Table 2 and Figure 2).

The DNDC model simulated that the continuous flooding irrigation produced lower rice yield than the intermittent irrigations (Table 3 and Figure 3). 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 CH_4 emission is found in the pot experiments [15].

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 Figure 1) and emissions of GHG from soil (Table 2 and Figure 2). Field drying at mid-tillering stage has been shown to reduce CH_4 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 T_3 (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 [16], reported that mid-season drainage mitigated CH_4 emissions by 60%. CH_4 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 Figure 2). Methane emission was reduced in T_3 compared to control (24.1%). The combination of both mid-season

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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 [17] studied the effect of urea and ammonium sulfate application on CH_4 emission. The model accurately predicted the negative effect of ammonium sulfate on CH_4 emission. This was done by accounting for the electron donors and competitive reduction of electron acceptors.

The carbon exchange between paddy fields and the atmosphere is also greatly influenced by cultivation practices and field management. Simulated CO_2 emission was reduced in zero tillage with mid-season drainage (29.2%) than compared to the control (Table 3 and Figure 3). Studies of [18] proved that cumulative CO_2 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 [19].

4. CONCLUSION

Models such as DNDC would be very useful to accelerate the application of available knowledge at field, farm and regional levels for optimizing agronomic management, quantifying changes in SOC and GHG emissions with changing land use, and developing mitigation options for GHG emissions. 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.

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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

T_1 - Control + RD of NPK, T_2 - Zero Tillage and Mid-season drainage + RD of NPK, T_3 – Mid-season drainage + RD of NPK, T_4 - Sulphate application + RD of PK, T_5 - BGA + *Methylotroph* + RD of NPK, T_6 - T_3 + T_4 + RD of PK and T_7 - T_3 + T_5 + RD of NPK

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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

T_1 - Control + RD of NPK, T_2 - Zero Tillage and Mid-season drainage + RD of NPK, T_3 - Mid-season drainage + RD of NPK, T_4 - Sulphate application + RD of PK, T_5 - BGA + *Methylotroph* + RD of NPK, T_6 - T_3 + T_4 + RD of PK and T_7 - T_3 + T_5 + RD of NPK

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Table 3. CO_2 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

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T_1 - Control + RD of NPK, T_2 - Zero Tillage and Mid-season drainage + RD of NPK, T_3 - Mid-season drainage + RD of NPK, T_4 - Sulphate application + RD of PK, T_5 - BGA + *Methylotroph* + RD of NPK, T_6 - T_3 + T_4 + RD of PK and T_7 - T_3 + T_5 + RD of NPK

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

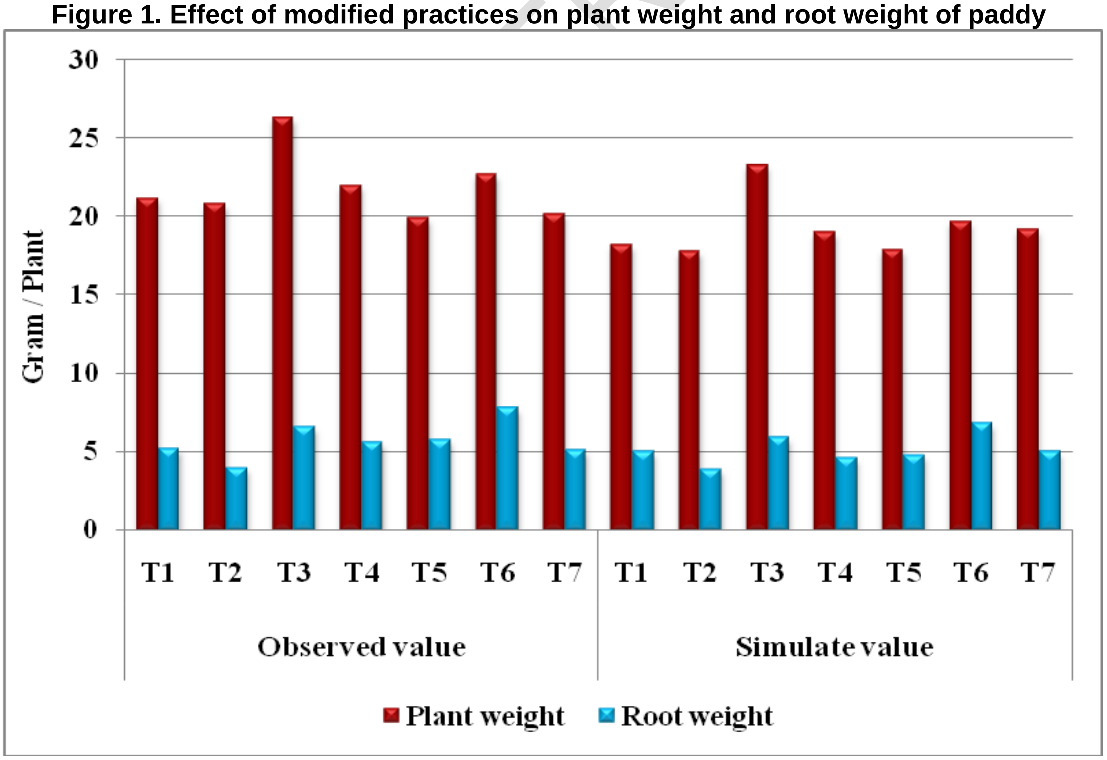

Figure 2. Per cent Methane reduction over control from experimental plots planted to rice

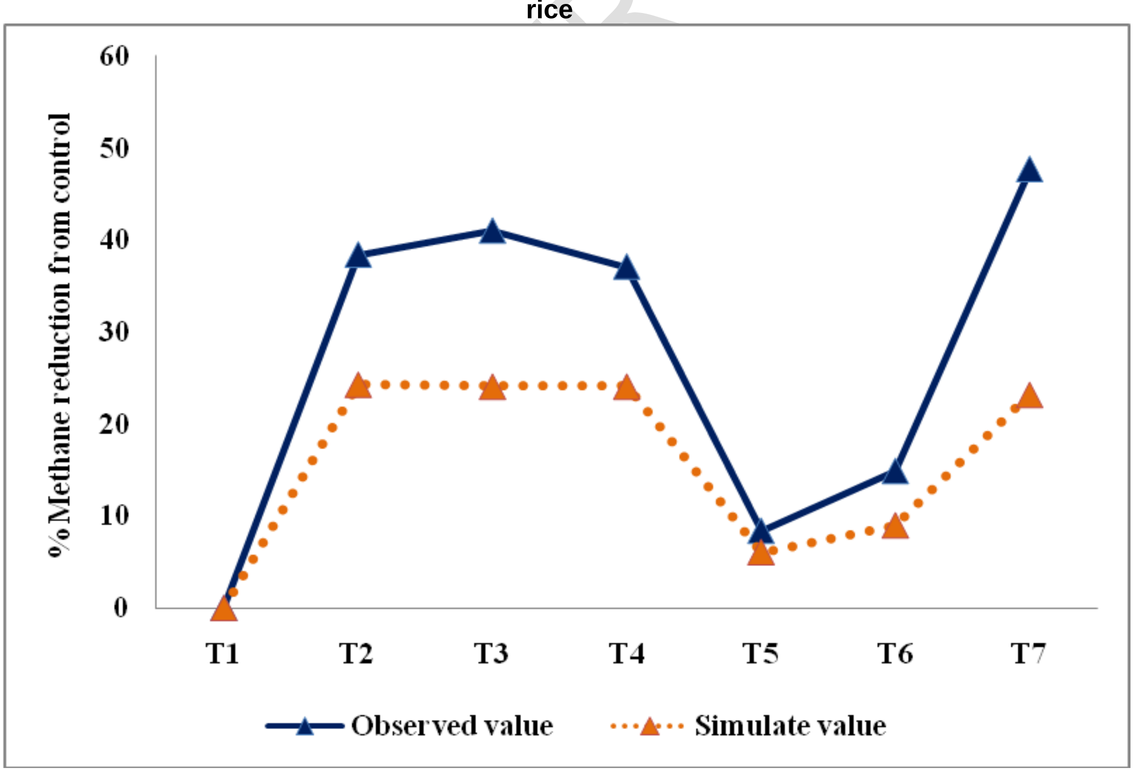

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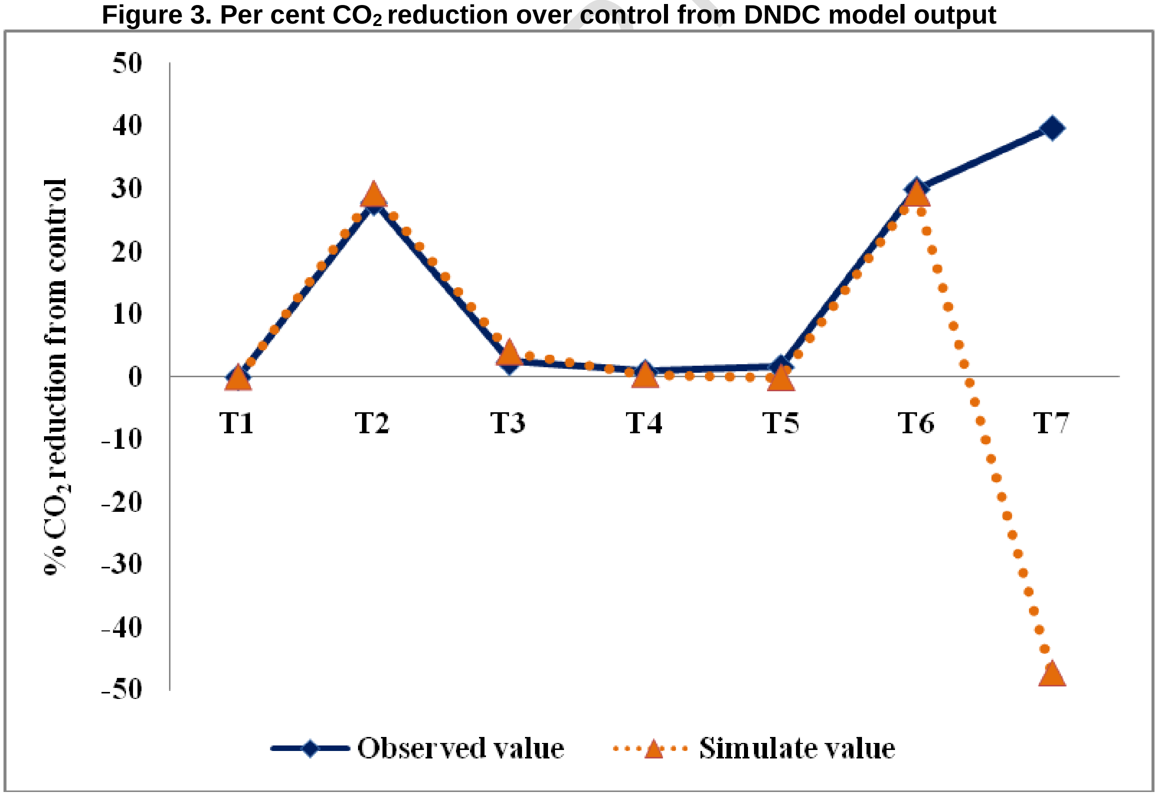
Figure 3. Per cent CO_2 reduction over control from DNDC model output



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