

1
2
3
4
5
6
7
8
9
10
11
12

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

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 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.

13
14
15
16
17
18

Keywords: *DNDC, methane emission, mid-season drainage and Rice,*

1. INTRODUCTION

19 "Rice (*Oryza sativa L.*) cultivation is one of the most important sources of emissions of
20 greenhouse gases (GHGS), mainly nitrous oxide (n₂o), methane (CH₄), and carbon dioxide
21 (co₂) and is the major driving force for climate change" [1,2,3]. "Rice cultivation, accounting
22 for 22% of global anthropogenic agricultural emissions of CH₄" [4]. "Understanding the
23 dynamics of CH₄ and CO₂ fluxes in paddy fields is crucial for improving the accuracy of
24 estimating CH₄ and CO₂ emissions from global paddy fields" [5]. "In fact, anaerobic condition
25 in the soil is the prerequisite for biological methane production" [6]. "Flooding continuously in
26 conventional rice cultivation system stimulates the biological process of methane production
27 by inducing the anaerobic condition in the soil" [7]. "According to an estimate by IPCC , these
28 fields contribute 11% (60 Tg yr⁻¹) of global CH₄ emissions. However, the range in this
29 estimate is wide (20-100 Tg yr⁻¹), largely due to uncertainties in estimates of CH₄ emission
30 under a diversity of environmental and agronomic conditions" [8].

31 "Changes in farming management practices, such as tillage, fertilization, irrigation,
32 manure amendment etc., are currently being evaluated for their potential in mitigating
33 greenhouse gases emitted from the agricultural sector. It has been widely reported that
34 replacing conventional tillage with no-till results in soil organic carbon (SOC) storage" [9]. "In

35 general no till or reduced tillage in comparison to conventional tillage results in lower CO₂
36 emission and greater CO₂ sequestration in soil" [10].

37 "Water management is a most important factor for CH₄ emission from rice fields"
38 [11]. "Anoxic condition and flooding favored methane release. Therefore appropriate
39 drainage and drying significantly reduced CH₄ emission" [12]. "Many studies proved that the
40 mid-season drainage, entailing purposeful drainage and subsequent field drying for around
41 ten days at the later tillering stage could increase the productive tillering volume and rice
42 yields and the soil drying after the milk ripening stage will prevent the delayed ripening"
43 [13,14,15 & 16]

44 "Nitrogen fertilizer applied in the form of ammonium sulphate reduces the CH₄
45 emission. Due to the application sulphur, sulphur oxidizing bacteria are grown in turn reduce
46 the population of methanotrophs Ammonium sulphate and urea were applied at rates of 0
47 (control), 100 and 300 kg N ha⁻¹ and the results showed that CH₄ emission, on the average,
48 decreased by 42 and 60% in the ammonium sulphate treatments and 7% and 14% in the
49 urea treatments at rates of 100 and 300 kg N ha⁻¹, respectively, compared to the control"
50 [17].

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

59

60 2. MATERIAL AND METHODS

61
62 The field experiment was conducted during 2017 and 2018 with modified
63 management practices was conducted using the rice variety CO 50 at Agricultural Research
64 station, Bhavanisagr, Erode district of Tamil Nadu. Comprehensive biogeochemistry model,
65 DNDC, developed by [20] was used to seek the best management practices for mitigating
66 methane and CO₂ emission from paddy cultivation. In this study the DNDC model (version
67 9.3; <http://www.dndc.sr.unh.edu/>) was applied. The observed weather parameters for the
68 year 2017 and 2018 were used for this study. Cropping sequence was taken for both two
69 consecutive years. Input parameters such as climate (maximum temperature, minimum
70 temperature, precipitation and wind speed), atmospheric N deposition, soil bulk density,
71 texture (clay fraction), total organic C content, pH and crop management practices (tillage,
72 irrigation, fertilization, manure amendment and grazing) were given. Two water management
73 practices, continuous flooding and continuous flooding with mid-term drainage on 45th to 55th
74 Days after Transplanting (DAT) and 65th to 75th DAT were examined for its efficacy to
75 mitigating greenhouse gases as well as water use efficiency.

76 2.1 MODEL CALIBRATION

77 A field experiment conducted in Agricultural Research Station (ARS), Bhavanisagar during
78 2018 was used for the calibration of the model. The experiments were carried out at the M3
79 block, ARS, Bhavanisagar, Tamil Nadu. The Geo-coordinates of the site is 11°29' N, 77°08' E
80 and 256 m MSL with annual rainfall of 703.7 mm [cold weather period (Jan-Feb) -18.7,
81 summer (March-May) -148.4, South West monsoon season (June-Sept) -213.1 and North
82 East monsoon season (Oct-Dec) -323.5. The maximum temperature ranged from 33-35° C.
83 Minimum temperature was ranging from 19-22° C. Soil type represents Sathyamangalam
84 and Kodiveri series. Soil is reddish brown to yellowish brown loam and clay loam having
85 near neutral reaction (available N, P, K-238, 23, 194 Kg ha⁻¹ respectively, organic carbon -
86 0.48 %, pH - 7.57 and EC - 0.37 dSm⁻¹).

87 Biometric observations were recorded at regular interval. The treatments are as follows T₁ -
88 control + RD of NPK, T₂ - zero tillage and midseason drainage + RD of NPK, T₃ - midseason
89 drainage + RD of NPK, T₄ - sulphate application + RD of PK, T₅ - BGA + *Methylo*troph + RD
90 of NPK, T₆ - T₃ + T₄ + RD of PK and T₇ - T₃ + T₅ + RD of NPK. 25 kg of ZnSo₄ was given for
91 all the treatments and 60 kg of N source in the form of ammonium sulphate remaining in the
92 form of urea was given for T₄ and T₆, Mid-season drainage was provided at 40th to 50th DAT
93 and 60th to 70th DAT for T₃, T₂, T₆ and T₇. Zero till/no till was given to T₂. Emissions of CH₄
94 and N₂O were measured frequently from the plots following the standard methodologies [21
95 & 22]. Total dry matter, grain yield and N uptake were measured at maturity.

96 2.2 SENSITIVITY ANALYSES

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

101 3. RESULTS AND DISCUSSION

102 Predicted grain and biomass yield agreed well with observed values (Table 1 and Figure 1).

103 The observed emission of CH₄ during the growing season was ranges from 48.00 to 91.69
104 mg m⁻² day⁻¹ compared to continuous flooding (T₁ –Control), while the simulated emission
105 was ranges from 65.09 to 6.71 kg C ha⁻¹ yr⁻¹ compared to continuous flooding (T₁ –Control).

106 The deviation of the simulated value from the observed value was less than 5% (Table 2 and
107 Figure 2).

108 The DNDC model simulated that the continuous flooding irrigation with
109 Recommended Dose of NPK (T₁) produced lower rice yield (observed-5878 kg ha⁻¹ and
110 simulate -5629 kg ha⁻¹) than the intermittent irrigations. Longer the drainage period for 4
111 days and 3 days flooding treatment seemed to produce more rice yield by the DNDC model.
112 A similar trend in yields and CH₄ emission is found in the pot experiments [23].
113
114

115 **Sensitivity analysis for impacts of tillage practices, N fertilizer (ammonium sulphate)**
116 **and water management on yield and GHG emission**

117 Different modified agronomic practices such as till/zero till, flooding and intermittent
118 irrigation, nitrogen fertilizer (urea and ammonium sulphate) were significantly influenced the
119 simulated yield (Table 1 and Figure 1) and emissions of GHG from soil (Table 2 and Figure
120 2). Field drying at mid-tillering stage has been shown to reduce CH₄ emission by 15-80% as
121 compared to continuous flooding, without a significant effect on grain yield. The present
122 investigation revealed that methane emission was reduced in T₃ (Mid-season drainage + RD
123 of NPK) compared to control (41%). The combination of both mid-season drainage as well
124 as BGA application reduced methane emission up to 47.7% compared to control. This result
125 was close conformity with [24], reported that mid-season drainage mitigated CH₄ emissions
126 by 60%. CH₄ can be mitigated by intermittent drainage, *i.e.* by stopping irrigation and
127 allowing the standing water to drain from the field. Water management also influenced the
128 simulated yield and emissions of GHG from soil (Table 2 and Figure 2). Methane emission
129 was reduced in T₃ compared to control (24.1%). The combination of both mid-season
130 drainage as well as BGA application reduced methane emission up to 23.2% compared to
131 control.

132 Substituting 60 kg ha⁻¹ N with ammonium sulphate reduced the methane emission
133 (37.1%) as compared to control. Simulated results also revealed the same trend (24.1 %)
134 compared to control. Similar result was obtained by [25] studied the effect of urea and
135 ammonium sulfate application on CH₄ emission. The model accurately predicted the
136 negative effect of ammonium sulfate on CH₄ emission. This was done by accounting for the
137 electron donors and competitive reduction of electron acceptors.

138 The carbon exchange between paddy fields and the atmosphere is also greatly
139 influenced by cultivation practices and field management. Simulated CO₂ emission was
140 reduced in zero tillage with mid-season drainage (29.2%) than compared to the control
141 (Table 3 and Figure 3). Studies of [26] proved that cumulative CO₂ fluxes after ploughing

142 were considerably greater than from a no-till field. Agricultural fields under no-till
143 conservation tillage cropping methods were found to sequester 300 kg C ha⁻¹ yr⁻¹, whereas
144 conventionally tilled crops exhibited no annual carbon sequestration [27].

145 **4. CONCLUSION**

146
147 The application of existing knowledge at the field, farm, and regional levels for improving
148 agronomic management, measuring changes in SOC and GHG emissions with changing land
149 use, and creating alternatives for GHG emission mitigation will be greatly accelerated by
150 models like DNDC. The main effects of N and water on GHG emissions from paddy farming
151 are captured by the DNDC model. According to the analysis, the model can be used to
152 investigate GHG-related problems in rice cropping systems.

153 **Disclaimer (Artificial intelligence)**

154 **Option 1:**

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

158 **REFERENCES**

- 159
160
161 [1] IPCC (2014a). *Contribution of Working Groups I, II and III to the 5th Assessment Report*
162 *of the Intergovernmental Panel on Climate Change. Climate Change 2014: Synthesis*
163 *Report*. Geneva, Switzerland: IPCC. (2014).
- 164 [2] Arunrat, N., Sereenonchai, S., and Pumijumnonng, N. (2018). On-Farm evaluation of the
165 potential use of greenhouse gas mitigation techniques for rice cultivation: A case study in
166 Thailand. *Climate* 6, 36. doi: 10.3390/cli6020036
- 167 [3] Smith, P., Clark, H., Dong, H., Elsiddig, E. A., Haberl, H., Harper, R., et al. (2014).
168 "Agriculture, forestry and other land use (AFOLU)," in Edenhofer, O., Pichs-Madruga, R.,
169 Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., et al. (eds.), *Climate change, 2014:*
170 *Mitigation of Climate Change*. IPCC Working Group III Contribution to AR5, (Cambridge, UK:
171 Cambridge University Press) 811–922. doi: 10.1017/CBO9781107415416.017
- 172 [4] Smartt, A. D., Brye, K. R., Rogers, C. W., Norman, R. J., Gbur, E. E., Hardke, J. T., et al.
173 (2016). Previous crop and cultivar effects on methane emissions from drill-seeded, delayed-
174 flood rice grown on a clay soil. *Appl. Environ. Soil Sci.* doi: 10.1155/2016/9542361

- 175 [5] Komiya, S., Noborio, K., Katano, K., Pakoktom, T., Siangliw, M., & Toojinda, T. (2015).
176 Contribution of ebullition to methane and carbon di-oxide emission from water between plant
177 rows in a tropical rice paddy field. *Int. sch. res. Notices.*, pp. 1-8.
- 178 [6] Feng, Y., Xu, Y., Yu, Y., Xie, Z., & Lin, X. (2012). Mechanisms of biochar decreasing
179 methane emission from Chinese paddy soils. *Soil Biol. Biochem.*, 46, 80-88.
- 180 [7] Mitra, S., Majumdar, D., & Wassmann, R. (2012). Methane Production and Emission in
181 Surface and Subsurface Rice Soils and Their Blends. *Agric. Ecosyst. Environ.*, 158, 94-102.
- 182 [8] IPCC., Climate change 1995: Impacts, adaptations and mitigation of climate change:
183 scientific-technical analyses, contribution of working group II to the second assessment
184 report of the IPCC. WMO/UNEP, Geneva, 1995, pp. 745-771.
- 185 [9] Lal, R. (1999). Soil management and restoration for C sequestration to mitigate the
186 accelerated greenhouse effect. *Prog. Environ. Sci.*, 1, 307-326.
- 187 [10] Ball, B. C., Scott, A., & Parker, J. P. (1999). Field N₂O and CH₄ fluxes in relation to
188 tillage, compaction and soil quantity in Scotland. *Soil Tillage Res.*, 53, 29-39.
- 189 [11] Hargreaves, K. J., & Fowler, D. (1998). Quantifying the effect of water table and soil
190 temperature on the emission of methane from peat wetland at the field scale. *Atmosph.*
191 *Environ.*, 32(19), 3275-3282.
- 192 [12] Neue, H. U., Wassmann, R., Lantin, R. S., Alberto, M. C. R., Aduna, J. B., &
193 Jarellana, A. M. (1996). Factors affecting methane emission from rice fields. *Atmosph*
194 *environ.*, 30, 1751-1754.
- 195 [13] Li, C., Frolking, S., Crocker, G. J., Grace, P. R., Klir, J., Korcdhens, M., &
196 Poulton, P. R. (1997). Simulating trends in soil organic carbon in long-term experiments
197 using the DNDC model, *Geoderma.*, 81, 45-60.
- 198 [14] Liu, X., Zhou, T., Liu, Y., Zhang, X., Li, L., & Pan, G. (2019). Effect of mid-season
199 drainage on CH₄ and N₂O emission and grain yield in rice ecosystem: A meta-
200 analysis. *Agricultural Water Management*, 213, 1028-1035.

201 [15] Tabbal, D. F., Bouman, B. A. M., Bhuiyan, S. I., Sibayan, E. B., & Sattar, M. A. (2002).
202 On-farm strategies for reducing water input in irrigated rice; case studies in the
203 Philippines. *Agricultural Water Management*, 56(2), 93-112.

204 [16] Wu, Q., He, Y., Qi, Z., & Jiang, Q. (2022). Drainage in paddy systems maintains rice
205 yield and reduces total greenhouse gas emissions on the global scale. *Journal of Cleaner*
206 *Production*, 370, 133515.

207 [17] Zucong, C., Guangxi, X., Xiaoyuan, Y., Hua, X., Haruo, T., [Kazuyuki](#), & Katsuyuki, Y.
208 M. (1997). Methane and nitrous oxide emissions from rice paddy fields as affected by
209 nitrogen fertilizers and water management. *Plant and Soil*, 196(1), 7-14.

210 [18] Li, C., Frolking, S., & Harriss, R. (1994). Modeling carbon biogeochemistry in
211 agricultural soils. *Glob. Biogeochem. Cycles*, 8, 237-254.

212 [19] Li, C., Frolking, S., & Frolking, T.A. (1992). A model of nitrous oxide evolution from
213 soil driven by rainfall events: Model structure and sensitivity. *J. Geophys. Res.*, 97, 9759-
214 9776.

215 [20] Pathak, H., Bhatia, A., Prasad, S., Singh, S., Kumar, S., Jain, M. C., & Kumar, U.
216 (2002). Emission of nitrous oxide from soil in rice-wheat systems of Indo-Gangetic plains of
217 India. *Environ. Monit. Assess.*, 77(2), 163-178.

218 [21] Pathak, H., Prasad, S., Bhatia, A., Singh, S., Kumar, S., Singh, J., & Jain, M.C.
219 (2003). Methane emission from rice-wheat cropping system of India in relation to irrigation,
220 farmyard manure and dicyandiamide application. *Agric. Ecosys. Environ.*, 97, 309-316.

221 [22] Minamikawa, K., & Sakai, N. (2005). The effect of water management based on soil
222 redox potential on methane emission from two kinds of paddy soils in Japan. *Agric. Ecosyst.*
223 *Environ.*, 107, 397-407.

224 [23] Itoh, M., Sudo, S., Mori, S., Saito, H., Yoshida, T., Shiratori, Y., Suga, S., Yoshikawa,
225 N., Suzue, Y., Mizukami, H., Mochida, T., & Yagi, K. (2011). Mitigation of methane emissions
226 from paddy fields by prolonging mid-season drainage. *Agric. Ecosyst. Environ.*, 3861, 1-14.

227 [24] Cai, Z., Sawamoto, T., Li, C., Kang, G., Boonjawat, J., Mosier, A., Wassmann, R., &
228 Tsuruta, H. (2003). Field validation of the DNDC model for greenhouse gas emissions in
229 East Asian cropping systems. *Glob. Biogeochem. Cycles.*, 17(4), 1107-1111.

230 [25] Reicosky, D. C., Dugas, W. A., & Torbert, H. A. (1997). Tillage induced soil CO₂ loss
231 from different cropping systems. *Soil Tillage Res.*, 41,105-118.

232 [26] Robertson, G. P., Paul, E. A., & Harwood, R. R. (2000). Greenhouse gases in
233 intensive agriculture: Contributions of individual gases to the radiative forcing of the
234 atmosphere. *Science*, 289, 1922-1925.

235

236

237

238

239

240

241

242

243

244

245

246

247

248

249

250

251

252

253

254

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

255 T₁ - Control + RD of NPK, T₂ - Zero Tillage and Mid-season drainage + RD of NPK, T₃ - Mid-
256 season drainage + RD of NPK, T₄ - Sulphate application + RD of PK, T₅ - BGA +
257 *Methylotroph* + RD of NPK, T₆ - T₃ + T₄ + RD of PK and T₇ - T₃ + T₅ + RD of NPK
258

259

260

261

262

263

264

265

266

267

268

269

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

270 T₁ - Control + RD of NPK, T₂ - Zero Tillage and Mid-season drainage + RD of NPK, T₃ - Mid-
 271 season drainage + RD of NPK, T₄ - Sulphate application + RD of PK, T₅ - BGA +
 272 *Methylotriph* + RD of NPK, T₆ - T₃ + T₄ + RD of PK and T₇ - T₃ + T₅ + RD of NPK
 273

274

275

276

277

278

279

280

281

282

283

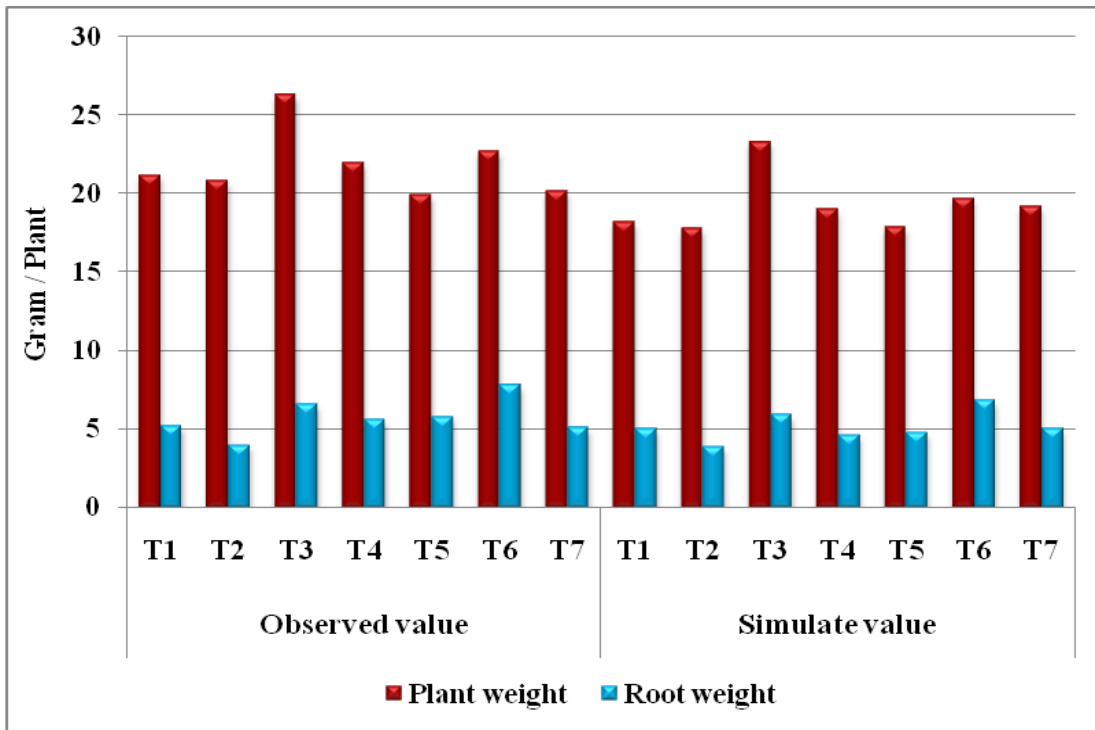
Table 3. CO₂ emission (kg C ha⁻¹ yr⁻¹) from DNDC model output

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

284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311

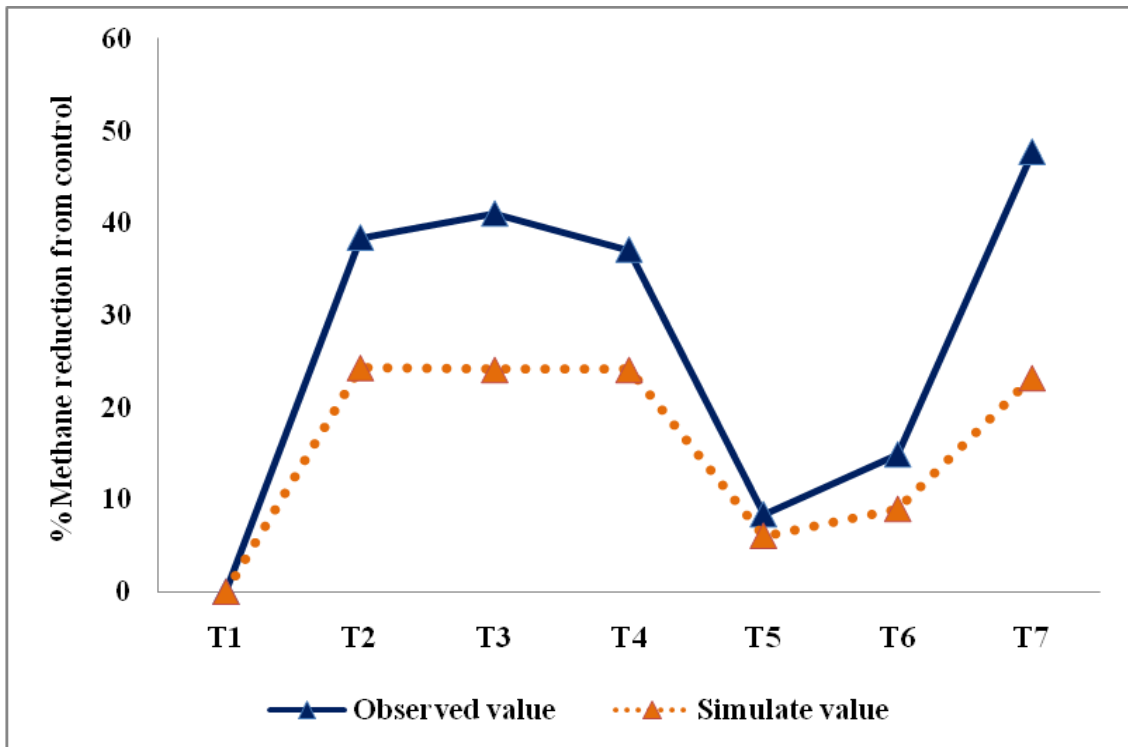
T₁ - Control + RD of NPK, T₂ - Zero Tillage and Mid-season drainage + RD of NPK, T₃ - Mid-season drainage + RD of NPK, T₄ - Sulphate application + RD of PK, T₅ - BGA + *Methylotroph* + RD of NPK, T₆ - T₃ + T₄ + RD of PK and T₇ - T₃ + T₅ + RD of NPK

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



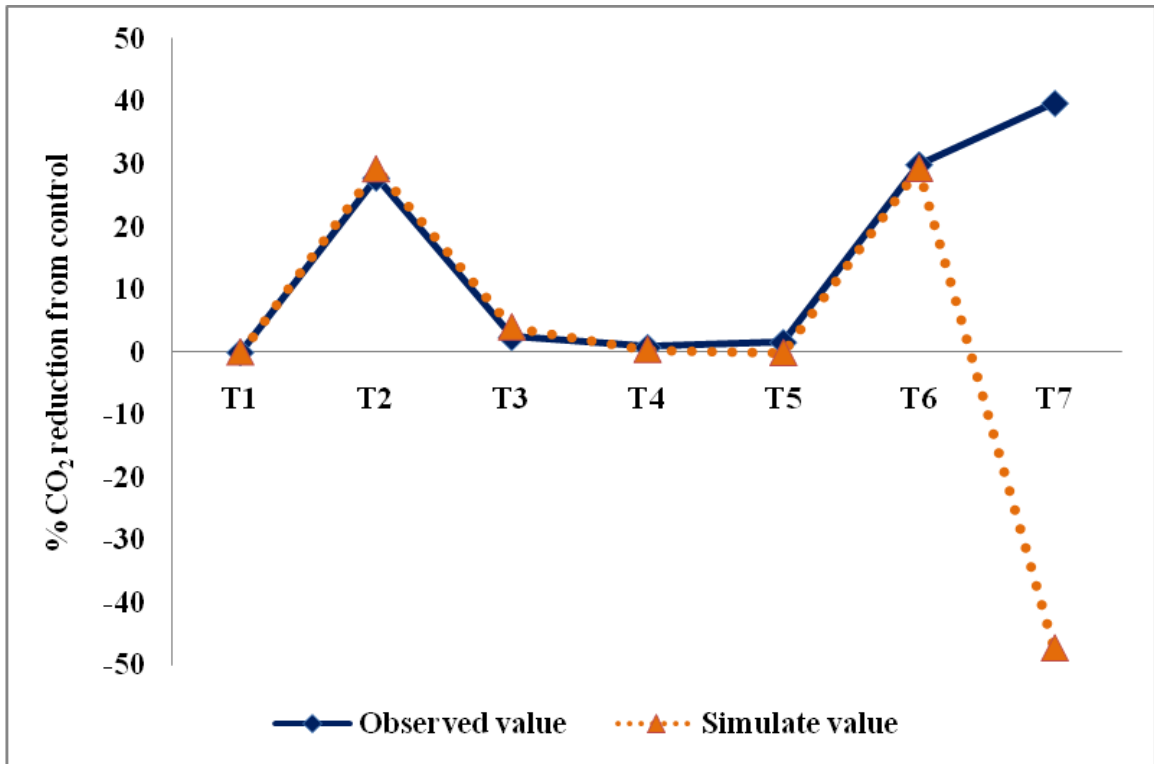
312
 313
 314
 315
 316
 317
 318
 319
 320
 321
 322
 323
 324
 325
 326
 327
 328
 329
 330
 331
 332
 333
 334
 335
 336
 337
 338
 339
 340

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



341
 342
 343
 344
 345
 346
 347
 348
 349
 350
 351
 352
 353
 354
 355
 356
 357
 358
 359
 360
 361
 362
 363
 364
 365
 366
 367
 368
 369

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



370
371
372

UNDER PEER