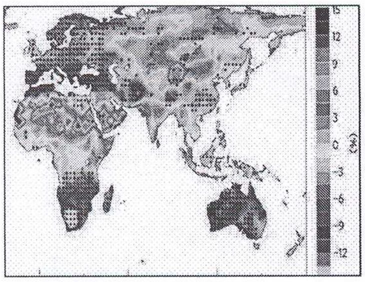
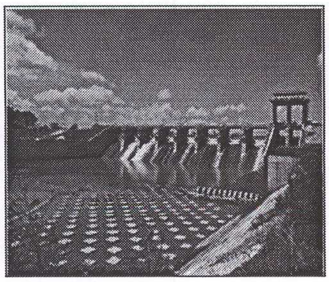

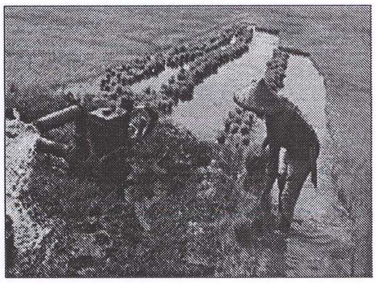

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THE STUDY ON PARAMETER SENSITIVITY ANALYSIS OF THE DENITRIFICATION-DECOMPOSITION (DNDC) MODEL

Duangnapa Vanichsan • Bancha Kwanyuen

The Denitrification-Decomposition (DNDC) model was developed several versions form DNDC version 8.7 to 9.3. The present, DNDC version 9.3 has been expanded in detail on the site information of the model to adjust input data to specific study area; (the site mode comprised of three major pages for inputting data (1) climate information (2) soil information and (3) farming management information, respectively). In addition, the model has also been recognized by several organizations such as Intergovernmental Panel on Climate Change (IPCC) and World Bank as a standard tool for prediction of GHG emission from paddy field. In this study, the model was applied to predict the methane emission in comparison to the field experiment using wet and dry technique i.e. irrigation water was applied only when the field was short of water (dry condition). However, the parameter calibration for the new version of DNDC model was rather difficult for the input data from the experiment paddy field (Nakhon Pathom province, Thailand). Consequently, this paper focused on the analysis on parameter sensitivity by considering all parameters and they will be classified into three groups: sensitive, moderate and less sensitive parameters on predicting methane emission in paddy field. The result found that soil induced the highest impact on methane emission while farming management had less impact. Moreover, this information could be valuable information for parameter calibration and application of the model for future user.

Keywords: Denitrification-Decomposition (DNDC) model, Sensitivity analysis

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Abstract The Denitrification-Decomposition (DNDC) model was developed several versions form DNDC version 8.7 to 9.3. The present, DNDC version 9.3 has been expanded in detail on the site information of the model to adjust input data to specific study area; (the site mode comprised of three major pages for inputting data (1) climate information (2) soil information and (3) farming management information, respectively). In addition, the model has also been recognized by several organizations such as Intergovernmental Panel on Climate Change (IPCC) and World Bank as a standard tool for prediction of GHG emission from paddy field. In this study, the model was applied to predict the methane emission in comparison to the field experiment using wet and dry technique i.e. irrigation water was applied only when the field was short of water (dry condition). However, the parameter calibration for the new version of DNDC model was rather difficult for the input data from the experiment paddy field (Nakhon Pathom Province, Thailand). Consequently, this paper focused on the analysis on parameter sensitivity by considering all parameters and they will be classified into three groups: sensitive, moderate and less sensitive parameters on predicting methane emission in paddy field. The result found that soil induced the highest impact on methane emission while farming management had less impact. Moreover, this information could be valuable information for parameter calibration and application of the model for future user..

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Introduction

Jagadeesh Babu et al. (2005) stated that the human population continued to increase by ~80 million people per year; the developing world would add another two billions people over the next three decades. Moreover, Li et al. (2002) reported that intensification of agriculture was imperative to meet the projected increasing demand for food. Rice cultivation is an important agricultural priority worldwide, because rice is the major cereal crop feeding two-thirds of the global population and is expected to continue to feed large numbers of the ever-growing population. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the major greenhouse gases (GHGs), and all have significant fluxes from agro-ecosystems. Agriculture, as a highly managed ecosystem, is likely being a target for GHG mitigation efforts. In 2001, IPCC stated that considering that only methane, it is second only to carbon dioxide and its global warming potential is 23 times greater than carbon dioxide on a mass basis. From the current situation, the country's bargaining power in global agricultural markets has been reduced because of the degradation of environment and global climate change.

CH_4 emission in paddy fields, CH_4 is produced due to the anaerobic degradation of organic matters. This process may be briefly summarized as follows: flooding promotes the change of chemical property of soil and population of microorganism such that there are oxygen shortage just about 1-2 cm below soil surface and microorganism will perform under anaerobic process using fat acid (i.e. formic acid and acetic acid) and alcohol (i.e. methanol and ethanol) as their energy source and carbondioxide gas as breathing gas with reduce process to generate methane gas. For the calculation of CH_4 emission, it may also be calculated using process-based model that simulates the underlying soil physical, chemical and biological processes, and one of such model was DNDC. In an earlier study, the author calibrated the model to get suitable parameters for input data of this paddy field (Nakhon Pathom Province, Thailand) but it was rather difficult to calibrate the model to receive a set of suitable parameters. Consequently, this paper focused on the study of parameter sensitivity analysis in order to identify a group of sensitive parameter which had high impact on the level of methane emission from paddy field. Moreover, this information can also be a supplemented data to other users for parameter calibration of the model

Methodology

Study area

The study area was located in Kamphaeng Saen District, Nakhon Pathom Province, Thailand. The experiment was conducted in 2010 with the average air temperature throughout the growing period about 30.8 °C and the rainfall for that wet season was 700 -1200 mm.

Field of experimental study

Field of experimental study refers to a farmer field with our instruction on water management based on wet and dry technique and regular measurement of methane gas. It is conducted as follows:

Experimental layout and treatment arrangement

The study field has an area of 1,600 m^2 and next to a control field with the same area. The experimental condition applied typical agricultural practice by farmers with an adapted wet and dry technique on water management. During dry season, farmers would irrigate the field only when the soil surface was dry and during wet season, farmers did not apply additional water to the fields since the rainfall was already sufficient.

Paddy field management

Rice was planted by broadcasting method. The growing period was started at the middle of dry season and ended at the start of rainy season i.e. rice seeds were soaked and planted on 10 March 2010 and grain yields were harvested on 10 July 2010. The variety of rice used in this experimental was cultivar-Suphan Buri 1. Chemical fertilizers were applied in three doses: 25 days, 50 days, and 100 days after broadcasting, respectively.

Herbicides and insecticides were applied in three doses: once before seeding, and the other at one and two months after planting.

Methane emission measurement

The CH_4 emission was measured once a week during rice growing period by a closed chamber method and the first measurement of methane emission was 30 days after broadcasting. All the measurements at both plots were performed in the morning (10:00-11:00 AM). The chambers were installed on paddy fields for approximately 1 hour and then turn on a fan in a chamber for mixing air for about 30 sec. as recommended by Bekku et al. (1995). Methane gas was measured by CH_4 meter. CH_4 meter was a digital' Testo AG Company, Germany. The CH_4 concentration was shown in part per million (ppm) unit. CH_4 meter was also calibrated with gas chromatography and correlation was 0.9998. Amnat (2007) recommended that CH_4 concentration should be converted to CH_4 flux using the "ideal gas law" (Equation 1).

$$C_i = (q_i \times M_i \times P) / (R \times T) \qquad (1)$$

Where

C_i = mass/vol. concentration (g m-3)
q_i = vol./vol. concentration (ppmV)
M = moles of gas
P = pressure
R = universal gas constant
T = temperature (Kelvin)

Moreover, Ishigaki et al. (2005) recommended that the methane flux should be calculated based on a linear regression analysis of an increase in concentration over time (Equation 2).

$$Flux = (V/A) \times (dC / dt) \qquad (2)$$

Where

Flux = volume of gas per area per time
V = volume of chamber (m^3)
A = area under the chamber (m^2)
(dC/dt) = slope of gas concentration per time

Description of the DNDC model

The DeNitrifiacation-DeComposition (DNDC) model was originally developed by Professor Changsheng Li of University of New Hampshire in the U.S.A.. DNDC version 8.7A and version 9.3 were used in this study which were a computer simulation model of carbon and nitrogen biogeochemistry in agro-ecosystems. The model could be used for prediction of crop growth, soil temperature and moisture regimes, soil carbon dynamics, nitrogen leaching, and emissions of trace gases including nitrous oxide (N_2O), nitric oxide (NO), dinitrogen (N_2), ammonia (NH_3), methane (CH_4) and carbon dioxide (CO_2). Regard to the structure of DNDC model, it was divided into 2 parts; 1) module of soil climate, crop growth and decomposition and 2) module of nitrification, denitrification and fermentation (Fig. 1).

For simulation runs, Nakagawa et al. (2008) concluded that the model required the information on climate, soil, vegetation, and farming practice for the simulated agricultural land. The simulation outputs were soil carbon and nitrogen changes, crop carbon and nitrogen uptake, nitrate leaching and trace gas emissions. The DNDC model can be downloaded for free via the internet (http:// www.dndc.sr.unh.edu/index.html).

The information required for model simulations

There was a relatively large amount of input data that needed to be provided before staring the simulation runs by DNDC model. Though the model provided the default values for some parameters, using accurate input parameters was recommended to ensure the success of the simulations (Nakagawa et al. 2008).

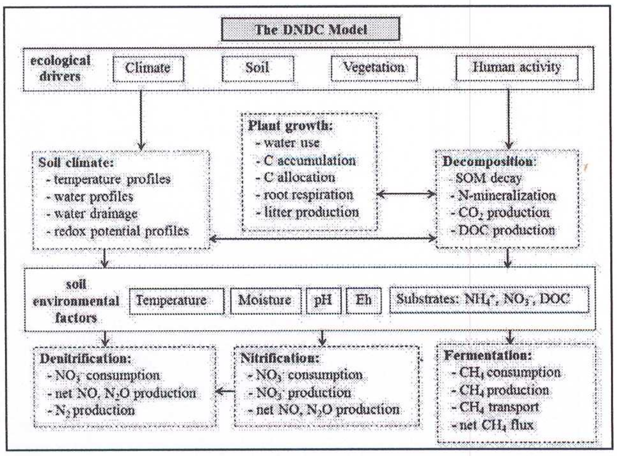

Fig. 1 The structure of DNDC model

Site and climate information

The latitude of the study area was 13°. Daily air temperatures and precipitations were required for the simulation. The meteorological data for these paddy fields located in Kamphaeng Saen District, Nakhon Pathom Province for 2010 was provided by Mae Klong Yai irrigation water management research station and it was modified to fit with the required format of the model.

Soil parameters

The type of the soil was needed to be selected at the interface of model for all model simulations. In the study area, the soil texture was silt loam. When the soil type was selected at the model's interface, the model automatically provided other soil parameters necessary for simulations such as WEPS at wilting point and at field capacity. The soil bulk density (Db), soil pH and soil organic content were needed to be entered manually at the model's interface. Table 1 showed the soil parameters provided by the model.

Crop parameters and farming management

Paddy rice was selected for DNDC model. The parameters were summarized in Table 2 for crop parameters and Table 3 for farming management.

Table 1 The soil parameters provided by the model

Parameters	Baseline value
Soil texture	Silt loam
Bulk density (g/cm^3)	1.43
Soil pH	6.5
Clay fraction	0.27
Field capacity	0.3
Wilting point	0.14
Initial soil organic C content (SOC) at surface soil (kg C / kg)	0.052
Depth of water–retention layer (cm)	50
Depth of top soil with uniform SOC content (m)	0.13
SOC decrease rate below top soil	1.2
Initial NO_3^- concentration at surface soil (mg N/kg)	0.1
Initial NH_4^+ concentration at surface soil (mg N/kg)	15.71
Microbial activity index	0.9
Slope (%)	0

Table 2 Crop parameters

Parameter	Baseline value
Date of planting	10 Mar
Date of harvest	10 Jul
Fraction of leaves and stems left in field after harvest	0.8
Initial biomass (kg dry matter/ha)	12.5
Initial photosynthesis efficiency	0.4
Maximum photosynthesis rate (kg CO_2/ha/hr.)	47
Development rate in vegetative stage	0.015
Development rate in reproductive stage	0.044

The sensitivity analysis of the DNDC model

The sensitivity analysis was performed by successive runs with the variation of a single parameter at a time while keeping all other parameters at the baseline value. This assumed that the parameters could be varied independently and that there was little interaction effect between parameters. Table 4 showed the range in this test for soil and climate properties and Table 5 showed the assumed bulk density to the considered soil.

Table 3 Farming management parameters

Parameter	Baseline value
Date of tillage	23 Feb
Depth of tillage (cm)	10
Date of first fertilization	2 Apr
Type of fertilization	Urea
Amount of first fertilization (kg N /ha)	35
Date of second fertilization	27 Apr
Type of fertilization	Urea
Amount of second fertilization (kg N /ha)	28.75
Date of third fertilization	17 May
Type of fertilization	Urea
Amount of third fertilization (kg N /ha)	28.75

Table 4 The range for the test of soil and climate properties

Parameters	Simulated range
Temperature (°C)	20-40
Soil texture	Sand, Loamy sand, Sandy loam, Silt loam, Loam, Sandy clay loam, Silty clay loam, Clay loam, Sandy clay, Silty clay, Clay, Organic soil
Soil pH	3-9
Clay fraction Field capacity Wilting point	Varied soil texture (used default)
Initial soil organic C content (SOC) at surface soil (kg C / kg)	Not varied
Depth of water–retention layer (cm)	Not varied
Depth of top soil with uniform SOC content (m)	Not varied
SOC decrease rate below top soil	Not varied
Initial NO_3^- concentration at surface soil (mg N/kg)	Not varied
Initial NH_4^+ concentration at surface soil (mg N/kg)	Not varied
Microbial activity index	Not varied
Slope (%)	Not varied

Table 5 The assumed bulk density to the considered soil

Soil texture	Db (g/cm^3)	Soil texture	Db (g/cm^3)
Sand	1.76	Silty clay loam	1.30
Loamy sand	1.67	Clay loam	1.27
Sandy loam	1.59	Sandy clay	1.25
Silt loam	1.43	Silty clay	1.23
Loam	1.37	Clay	1.10
Sandy clay loam	1.34	Organic soil	1.80

Table 6 The assumed flooding management by scenario

Scenario	Flood-ID	Flood-D	Flood-M	Drain-D	Drain-M
1	1st	1	Mar	8	Mar
	2nd	2	Mar	28	Mar
	3rd	28	Mar	25	Jun
2	1st	25	Feb	8	Mar
	2nd	8	Mar	28	Mar
	3rd	28	Mar	20	Jun
3	1st	25	Feb	8	Mar
	2nd	8	Mar	28	Mar
	3rd	28	Mar	27	Apr
	4th	27	Apr	20	Jun

In addition the scenarios of flood management were also tested considering all other parameters regarding farm management, soil and climate properties at the baseline value. Table 6 showed the assumed flooding management by scenario.

From Table 6, scenario 1 was traditional irrigation (20 to 30 cm flood depth), scenario 2 was shallow water depth (10 to 5 cm flood depth) and scenario 3 was alternate wetting and drying (5 to -5 cm flood depth).

Result and discussion

Methane emission with the growth stage of rice

The study in paddy field found that under water management of farmers' irrigation condition, the release methane flux ranged between 0.37 to 4.46 $mg/m^2/hr$ and the average was 1.65 $mg/m^2/hr$ (Table7). This condition had a high methane flux in initial tillering stage due to the initial growth stage of rice required the highest water requirement and its effected on the transport of methane from soil through aerenchyma in high quantity. Moreover, the application of chemical fertilizer was also promoted a high methane emission. Between tillering and initial booting stages, the water was kept at low level such that methane flux was slightly lower throughout this period. The methane flux was higher again during the initial of milky stage because the application of more water due to high water requirement in conjunction with the application of chemical fertilizers at this time. Finally, methane flux was decreased continuously until the harvest maturity stage because water requirement was steadily lower at this period and the filed should be dried for the harvesting period.

Calibration of DNDC model version 9.3

On calibration process of the model, it was found that for the best fitness, the average CH_4 flux from simulation was not closed to average CH_4 flux from observation (Fig. 2) and the correlation was only 0.438. At all setting, the parameter calibration for the new version of DNDC (version 9.3) model was rather difficult for the input data from the experiment paddy field.

Table 7 Variation of methane emission with the growth stage of rice

Growth stage	Day-Month	Day after Broadcast (Days)	Average CH_4 flux ($mg/m^2/hr$)
tiller ing	10-Apr	33	3.36
panicle initiation	26-Apr	49	1.35
Booting	17-May	70	1.08
Booting	25-May	78	0.37
Milky	8-Jun	92	4.46
Milky	19-Jun	103	1.22
ripening	25-Jun	117	0.79
harvest maturity	10-Jul	124	0.53
Total (g/m^2/crop)			4.24

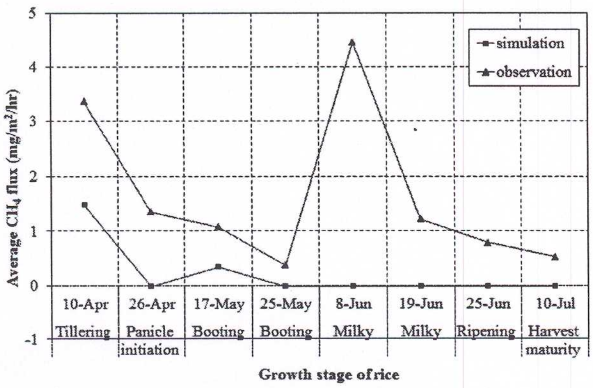

Fig. 2 The comparison of average CH_4 flux between observed data and DNDC model simulated

The sensitivity analysis of parameters of DNDC model

The DNDC version 8.7A was used for the sensitivity analysis instead of version 9.3 for the baseline parameters in Table 1 and Table 2 since the new version was not able to calibrate to fit with the study data and information.

Temperature

The result found that simulated CH_4 emission displayed an exponential response to air temperature over the test range of temperature 20-40 °C (Fig. 3). CH_4 flux increased from 44 to 2,089 kg C ha^{-1} y^{-1} accordingly for silt loam.

Soil pH

Since DNDC was a process-based model with internal bio-geochemical dynamics based on field and laboratory studies (Li, 2000), its sensitivity to external drivers was generally consistent with observations. The influence of soil texture had been well documented in effecting CH_4 emission from rice fields. Wang et al. (1993) demonstrated the influence of clay content on CH_4 flux. High clay content might entrap produced CH_4 leading to low CH_4 emission. It had been demonstrated that CH_4 production and emission were suppressed by acidic soil conditions.
The results found that the optimum pH for CH_4 emission was around 7.0 and CH_4 emission increased with increasing soil pH over the range of 4 to 8.5, but they were less sensitive for pH < 4 or pH > 8.5 (Fig. 4). Wang et al. (1993) stated that the pH of a flooded soil was usually close to 7.0 regardless of its starting point and it was at this pH that CH_4 production occurred. No significant change in CH_4 emission for soil pH below 5.7 or above 8.5 was consistent.

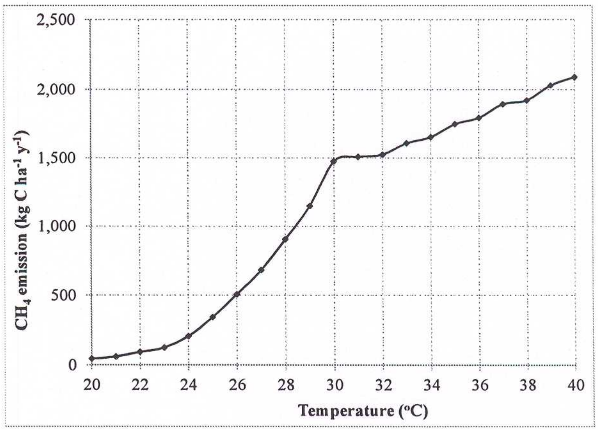

Fig. 3 Sensitivity of DNDC simulated annual CH_4 flux in paddy field in comparison with temperature

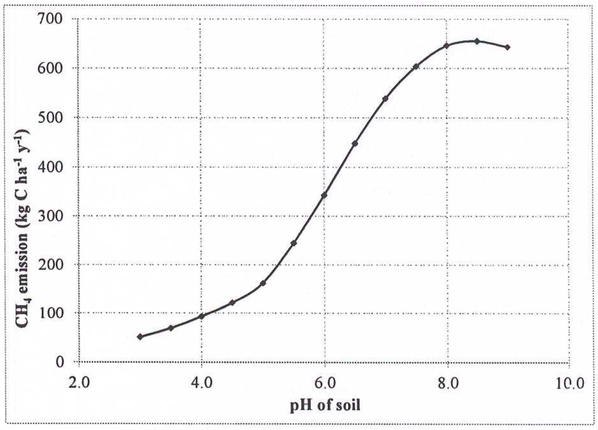

Fig. 4 Sensitivity of DNDC simulated annual CH_4 flux in paddy field in comparison with soil pH

Soil texture

At soil pH of 6.5 and farming management using parameters in Table 1 to Table 3, scenario 1 (Table 8) was selected for flooding management. The result showed that sand was the highest CH_4 emission which was 5,476 kg C ha^{-1} y^{-1} and sandy clay loam was the least CH_4 emission which was 175 kg C ha^{-1} y^{-1} (Table 8). Consequently, high clay content might entrap produced CH_4 leading to low CH_4 emission.

Table 8 Sensitivity of DNDC simulated annual CH_4 flux in paddy field in comparison with soil texture

Soil texture	Db (g/cm^3)	CH_4 emission ($kg\ C\ ha^{-1}\ y^{-1}$)
Sand	1.76	5,476
Loamy sand	1.67	1,574
Sandy loam	1.59	711
Silt loam	1.43	448
Loam	1.37	254
Sandy clay loam	1.34	175
Silty clay loam	1.30	429
Clay loam	1.27	557
Sandy clay	1.25	464
Silty clay	1.23	393
Clay	1.10	290
Organic soil	1.80	752

Farming management

Farming management focused on effect of flood conditions to methane emission in paddy fields (Table 6). The result showed that the traditional irrigation (control field) induced the highest impact on methane emission at 448 kg C $ha^{-1}\ y^{-1}$ while the shallow water depth and alternate wetting and drying showed less impact at 338 kg C $ha^{-1}\ y^{-1}$ and 5 kg C $ha^{-1}\ y^{-1}$, respectively. Consequently, the higher and longer flooding period of paddy field increased methane emission.

Conclusion

The result from calibration of DNDC model (version 9.3) found that correlation between simulation with observation was 0.438 so the model version 8.7 A was used instead with great improvement in fitness of result. The sensitivity analysis of the DNDC model showed that CH_4 emission was most sensitive to soil texture with seasonal flux increasing from 175 to 5,476 kg C $ha^{-1}\ y^{-1}$ The variation to climate were 44 to 2,089 kg C $ha^{-1}\ y^{-1}$ and the variation to farming management were 5 to 448 kg C $ha^{-1}\ y^{-1}$. Consequently, soil induced the highest impact on methane emission when soil texture was coarse texture, soil pH was alkaline soil.

However, the DNDC model may still need some more improvement in order to generate more accuracy of simulation results to fit with all conditions of input; nevertheless it is still a useful and powerful tool for simulating leaching and greenhouse gas emissions. The model can be used to help establishing appropriate farming management by running simulation with different farming managements, analyzing the results, and evaluating the adequacy of each farming management.

Acknowledgments

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