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ESTIMATION OF GREENHOUSE GASES EMISSION FROM A RICE FIELD OF KELANTAN, MALAYSIA BY USING DNDC MODEL

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Global warming is the main cause of greenhouse gases (GHG) including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The Denitrification and Decomposition (DNDC) model is considered a good tool to validate and estimate these gases from various agricultural practices. The farmers of Kota Bharu, Kelantan, Peninsular Malaysia grow rice in soils which has clay loam soil texture with 5.59 soil pH and 0.0193 kg ha^{-1} initial soil organic carbon. The farmers grow two rice crops by applying 248 kg N ha^{-1} $year^{-1}$. The model validation was found satisfactory and gave correct simulations while comparing with other international modeled studies. The yearly DNDC simulation for CO_2 flux rate was 4392 kg C ha^{-1}, 33.7 N_2O kg ha^{-1} $year^{-1}$ with -2 CH_4 flux. The Global Warming Potential (GWP) for CO_2 flux was 16105 kg CO_2-eq ha^{-1} and N_2O of 16403 kg CO_2-eq ha^{-1}; however, CH_4 was found as sink (-66 kg CO_2-eq ha^{-1}). Bulk of all these gases had 32442 kg CO_2-eq ha^{-1} net GWP. The DNDC simulations of field uncertainties by N rates (20% less than recommended, recommended and 20, 40 and 60% more than recommended) and SOC rates at 0.04, 0.03, 0.02 and 0.0193 kg C kg^{-1}) were run through linear correlation. The unit increase in N as well as SOC rates correspondingly increased NH_3 volatilization by 4.09, 3.76, 2.31 and 1.28 kg N ha^{-1} $year^{-1}$, respectively, N_2O flux by 10.06, 6.80, 6.51 and 1.16kg N ha^{-1}, respectively, NO flux by 0.76, 3.25, 3.14 and 2.03 kg N ha^{-1} $year^{-1}$ and N_2 flux by 17.87, 18.21, 21.75 and 25.22 kg ha^{-1} $year^{-1}$, respectively. In conclusion, the validation of agricultural data through DNDC model was perfect. The ongoing agricultural practices in the area have been found contributing small quantities of CO_2 and N_2O except CH_4 which is serving as sink. In future, the increase in soil organic carbon as well as nitrogen rates probably may involve this area towards more GHG (CO_2, N_2O, CH_4) emissions.
Keywords: GHG, rice, CO_2, N_2O, CH_4, climate change

INTRODUCTION

The human activities have led many changes in the earth's climate due to constant increases in green house gases. The different agricultural practices have raised not only average temperatures, but have influenced soil physico-chemical properties as well as high concentrations of tropospheric ozone which caused shift of optimal production zones towards specific crops. The weather forecast (1980 to 2008) of Malaysia shows that rice yield would decrease between 4.3 to 6.1% with 1°C increase in temperature (Ali and Ali, 2009). The atmospheric methane is also considered for the disturbances of cultivated wetlands specially rice fields and natural wetlands (Le Mer and Roger, 2001).

In rice soils, the CH_4 is produced through anaerobic decomposition of organic matter which can readily emit CH_4 in to the atmosphere accounting for about 90% in the growing season (Butterbach-Bahl *et al*., 1997), indicating significant quantities of methane in the environment (Yan *et al*., 2003). However, in the wetland peat soils, the methane emission could be doubled (Hosono and Nouchi, 1997).

Generally, N applied through organic and inorganic sources is not efficiently used by crops (Cassman *et al*., 2003). Improving nitrogen fertilizer efficiency could reduce emissions of N_2O and now a day's slow-release fertilizers are getting importance to avoid N_2O emission. The other practices include: application of nitrogen according to crop needs, avoiding time delays and excess rates (Monteny *et al*., 2006). The other factors of N_2O emissions were found high in intensively managed, heavily fertilized filed (Goossens *et al*., 2001), higher NPK fertilizer applications (Kaiser and Ruser, 2000), higher farmyard manure applications (Schmid *et al*., 2001), and organic matter (Włodarczyk *et al*., 2002) content. In addition, the conversion of uplands in to flooded fields (Xing *et al*., 2002), soil organic carbon, acidity (Tokuda and Hayatsu, 2001), and soil texture (Gliński *et al*., 2000) are also contributing significant N_2O emissions. The emission of CH_4 in the tropics is hundred times more than the European countries (Inubushi *et al*., 2003).

The regulation of CO_2 is through photosynthesis (Widen, 2002). The release of soil carbon could also be through bare soil containing sufficient amount of organic matter, tillage practices and slowing the rates of organic matter decomposition (Halvorson *et al*., 2002).

There are many variations and uncertainties while estimating CO_2, N_2O and CH_4 from soils (Le Mer and Roger, 2001). The DNDC model was first adapted to simulate GHG emissions from rice ecosystems by Li *et al*. (2004). Pathak *et al*. (2005) and Babu *et al.* (2006) further refined the DNDC model developed by Li *et al.* (2004) to simulate emissions of CO_2, CH_4, and N_2O under the conditions found in the rice paddies. Yet, no or little research has been conducted to measure the nature, scale, magnitude and frequency of GHG emissions from rice soils influenced by climate, soil characteristics and management practices. Therefore, investigations on current agricultural activities/practices and entire suite of greenhouse gases from rice growing region of Kelantan, Malaysia were conducted through modeling approach i.e. Denitrification and Decomposition (DNDC).

MATERIALS AND METHODS

***Study area and description of the agricultural system modelled*:** The soil and agriculture system studied for simulation was located in the Kota Bharu (Kelantan) situated between 6°8′N 102°15′E (Fig. 1). Kelantan is one of the rice growing states of Malaysia located at north-east of Peninsular Malaysia which receive an annual rainfall sufficient for irrigation. However, Kelantan river is also supporting rice fields for timely irrigation. Temperatures range between 21 to 32°C throughout the year which supports rice cultivation in two seasons in a year.

Figure 1. Map showing locations of sampling from rice field of Kelantan, Malaysia.

***DNDC model description*:** The DeNitrification and DeComposition (DNDC) model is based on four sub-models viz. (i) thermal/hydraulic, (ii) crop growth, (iii) decomposition, and (iv) denitrification which assess GHG emissions in rice growing area (Fig. 2, 3).

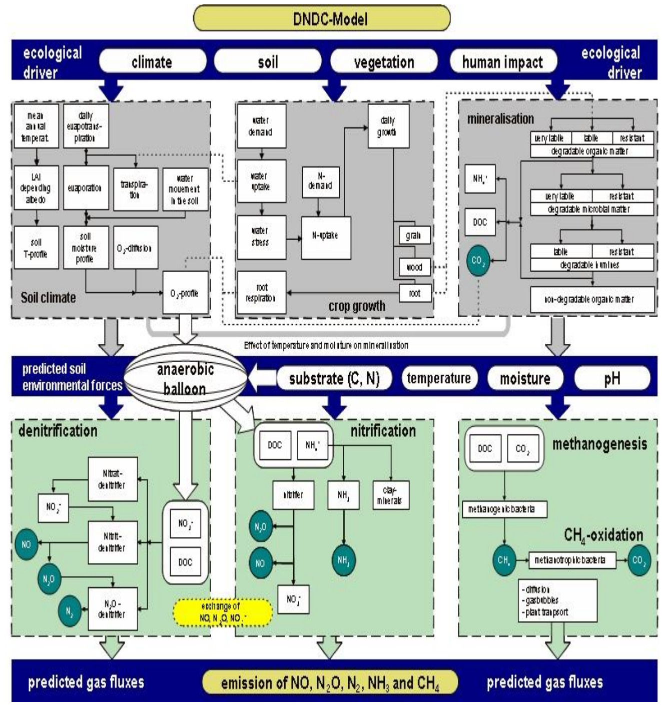

Figure 2. Schematic diagram of DNDC model structure (Li, 2000).

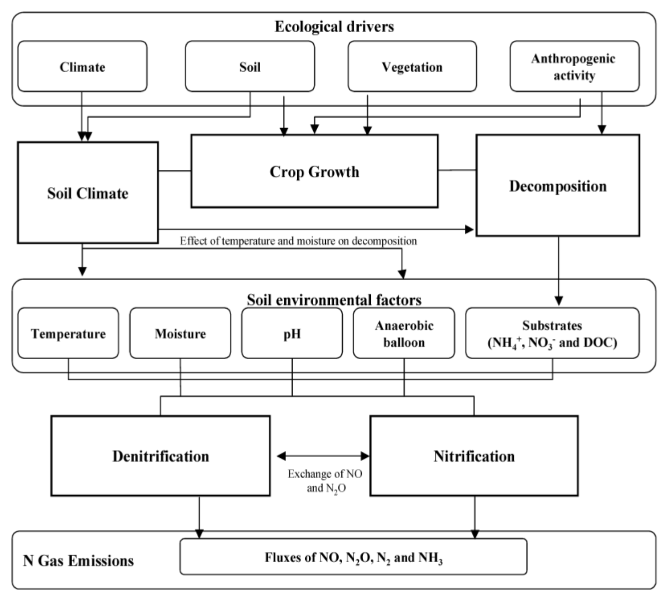

Figure 3. Data set required and process in DNDC simulation

***Model calibration and sensitivity*:** In DNDC model, total SOC was analysed in the laboratory as 0.02 kg C kg^{-1}, and model automatically generated 1.0 as microbial activity index (Li *et al.*, 1997). During calibration, all the soil related data and plant growth were put, based on the laboratory analysis. Crop grain and straw yield, temperature, rainfall, irrigation of the area were fed in the model.

A set of sensitivity simulations was performed through DNDC model by a series of model runs in through simulated years i.e. by altering 20% increase or decrease over N and SOC rates for future forecast. However, soil, crop and farming practices remained the same.

***Climate*:** Daily rainfall, maximum and minimum temperature data were collected from the nearby weather station. The weather files of three years data were prepared as described in the DNDC guide (version 9.2) including Julian days, daily minimum and maximum air temperature (°C) , and daily precipitation.

***Crop and land management information*:** Information regarding fertilizer inputs and farm management practices (tillage, manure amendments, irrigation and flooding, crop rotation, land preparation, water management, and harvesting dates) were collected from farmers of the area.

***Soil analysis and analytical procedures*:** Triplicate soil samples from the rice areas were collected at the depth of 0-15 cm followed by laboratory analyses at the Department of Land Management, Faculty of Agriculture, UPM, Malaysia.. The soil texture was determined by Bouyoucos hydrometer method (Bouyoucos, 1962). The soil bulk density was calculated through the methods of Blake and Hartage (1986). The soil porosity was calculated as: % Porosity = 1- (Bulk density) x 100 (Anderson and Ingram, 1993). Saturated hydraulic conductivity was measured using the constant head method (Klute and Dirksen, 1986). The soil moisture content was measured by gravimetric method (Black, 1965). The percent moisture was calculated on oven dry basis as: Moisture % = weight of fresh soil - weight of oven dried soil/ weight of oven dried soil x 100. The soil organic matter (SOM) was determined using methods of Walkley and Black (1934). The organic carbon was determined by the $K_2Cr_2O_7$ wet combustion method followed by titration (Walkley and Black, 1934). Total N in soil was measured using the micro kjeldahl digestion method (Bremner, 1960). The NH_4-N and NO_3-N were determined following the procedures of Bremner and Keeney (1960). The soil pH was measured at a ratio of 1:2.5 (soil: water) following the method as described by Benton (2001) using digital pH meter. Electrical conductivity of soil saturated extract was determined with the help of a conductivity meter.

***Plant sampling and analyses*:** From study location, a sample of one square meter randomly (replicated three times) was harvested (All above ground material) from rice field for plant analysis. Plants fresh weight of roots, shoots was recorded immediately after the sampling. Seeds were threshed manually. All the plant parts were dried at constant temperature of 70°C for 90 hours. The Wiley mill was used to pass ground material through a 20-mesh screen, and then processed for laboratory analysis.

Total nitrogen in plant was analyzed through micro KJELDAHL digestion method (Bremner, 1960). Organic carbon (%) in plant and grain was determined through the methods of (Merry and Spounce, 1988) using CR-412 carbon analyzer. The biomass fraction for grain and leaf + stem for each crop were calculated using methods of Lecoeur and Sinclair (2001) and Kemanian *et al.* (2007).

For C conversion, the CO_2 in the soil C was multiplied by 3.67. For CH_4, the soil C was multiplied by 1.33. For N_2O, N was multiplied by 1.57 (all on the basis of molecular weight). For conversion of GHG to CO_2 equivalent, it was multiplied by 1, CH_4 by 25 and N_2O by 298. The totals were then summed-up and expressed GWP kg CO_2 equivalent100 associated with the production per one hectare of each rice crop (IPCC, 2001).

RESULTS AND DISCUSSION

***DNDC data input for Kelantan, Malaysia*:** Daily weather data in Julian day, maximum and minimum daily air temperature (°C), and daily precipitation (mm) were put according to model format and simulation are shown in Figure 4.

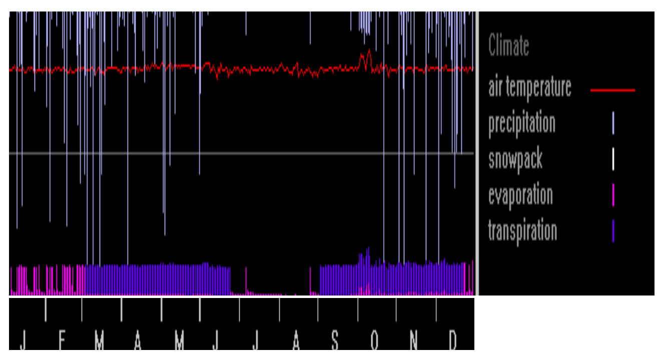

Figure 4. DNDC simulation for climate of Kelantan, Malaysia.

The rice soil of Kelantan, Malaysia had clay loam soil texture, 35.37% clay content, 1.65 g cm^{-3} bulk density, 0.57 WFPS field capacity, 0.27 WFPS wilting point, 0.44 m hr^{-1} saturated hydraulic conductivity, 5.59 soil pH, 0.706% porosity and 0.0231kg C ha^{-1} initial SOC. In the farm management, the design of cropping system had one cropping system (rice-rice) during simulated years. The numbers of crops planted in a year were two i.e. rice followed by rice with crop ID-20. Totally two tillage practices with mouldboard plough (20 cm) were worked out one week prior to planting in every season crop. The first season crop was planted on 1st March and harvested on June 25th, 2013. The second season crop was planted on 1st September and harvested on 25th, 2013. The first season crop received 1547.78 kg C ha^{-1} from the left over biomass of previous crop.

The first season crop had 0.4 biomass fraction for grain and 0.41 for stem + leaf. However, model automatically simulated 0.06 for roots. The biomass fraction for second season crop was 0.41 for grain and 0.34 stem + leaf. The root biomass fraction was dependent on the biomass of grain which was automatically calculated by DNDC. The C:N for each rice crop was calculated individually for each season. The analysed biomass C/N ration was 50 in grain, 78 in leaf + stem, and 66 in root for first season crop. In second season crop, the biomass C/N ratio was 45 in grain, 84 in leaf + stem and 39 in roots.

Upon feeding input parameters, the DNDC calculated the crop N demand. The N fixation index (1.05) was automatically generated. Li (2007) also reported that N fixation index equals to 1 for all crops which do not fix N. The model itself generated leaf area index (Darnmer *et al.*, 2008) and default value for vascularity as 0.2 for rice. The first and second season rice crops received equal (2200) thermal degree days. The amount of irrigation was reduced due to sufficient rainfall whole the year in this region and thus, totally 600 mm irrigation water was applied in both the rice growing seasons against simulated 300 mm seasonal water demand. The four fertilizations were surface applied in both the rice growing seasons. In each crop, first application was given during puddling and second 45 days after sowing. Recommended nitrogen @124 kg ha^{-1} was applied per crop and thus, totally 248 kg N ha^{-1} year^{-1} was applied. Farmers of this area do not use any type of manure in their fields. The option ID 3 straw was used. The straw yield after harvest of each crop was put at 4500 and 4700 C kg ha^{-1} in first and second season crops, respectively. The amount of straw yield was converted into C (kg ha^{-1}) which was 1547.78 and 1344.53 kg C ha^{-1} with C:N ratio of 78 and 84 in the 1st and 2nd seasons, respectively. In this area, farmers performed two weeding; one weeding in each season after 45 days of planting. The grazing is not being practiced in the rice in this region; hence, cutting option was selected. In each crop one cutting was practiced and thus total two cuttings were performed. The cut amount for first and second season was 1547.78 and 1344.53 kg C ha^{-1}, respectively. The model simulations are shown in Figures 5 and 6.

***Model validation*:** Validations while comparing the data obtained from the farmer's fields and model simulations were found correct underlying processes. Supporting this research, the Table 1 lists some published validation studies of DNDC.

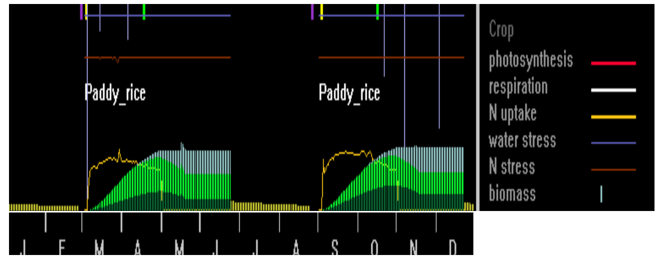

Figure 5. DNDC simulation for crop traits in Kelantan, Malaysia

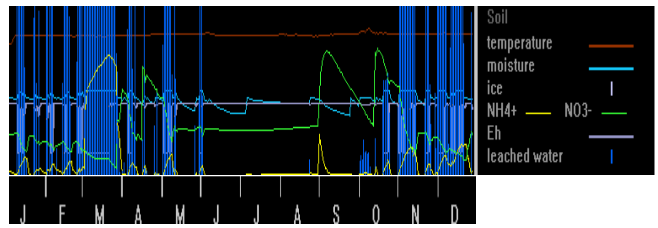

Figure 6. DNDC simulation for soil traits in Kelantan, Malaysia.

The DNDC simulations for grain and biomass yields were within the variance in yields. Simulated grain yield (kg C ha^{1}) for season-1 and 2 was about 1% higher than the observed data. Similar pattern was also found for left over plant biomass (leaf + stem and roots) in both the seasons. Adhya *et al.* (2000) also found very little differences in the observed and simulated data. In Kelantan, the farmers apply N @ 120 ha^{-1}. The observed crop N uptake was 72 and 75.97 kg N ha^{-1} against simulated uptake of 60 and 76 kg N ha^{-1} in 1st and 2nd season rice, respectively. According to biological yield obtained from this area against application of 120 N ha^{-1}; the DNDC simulated only demand of 61 and 76 kg N ha^{-1} for 1st and 2nd seasons, respectively (Table 2). Thus, model validation was perfect for Malaysian paddies.

***Yearly soil N balance*:** The yearly application @ 240 kg N ha^{-1} in both seasons caused loss of N from the soil. The simulated results for yearly soil N balance shown in Table 3 indicates that left over straw contributed 35.8 N, crop sub N 7.3 and roots 21.6 kg N ha^{-1} year^{-1}. Both crops had 130.3 N uptakes. The NH_3 volatilization loss was about 14 kg ha^{-1} year^{-1} with 33.7 N_2O flux, 19.0 NO flux and 188.1 N_2 flux ha^{-1} year^{-1}.

***Yearly soil C balance*:** After harvest, rice straw and roots remained in the soil. Thus the availability of root residues contributes microbial decomposition at the beginning of the subsequent growing season. Simulated yearly C balance in Kelantan area was 2892.3, 573.6 and 1696.2 kg C ha^{-1} year^{-1} input through straw, crop residues and roots, respectively which recorded SOC 4392.4 kg C ha^{-1} year^{-1} and CH_4 emission (-2.3 kg C ha^{-1} year^{-1}) (Table 4). The methane is the end product of the anaerobic degradation of soil organic matter. Li (2007) reported that the allocation of available C

Table 1. Validation studies comparing DNDC predictions against experimental measurement

Reference	Systems modeled	Predicted properties	Country
Babu *et al*. (2005)	Rice	Grain yield; CH_4 emission	India
Babu *et al*. (2006)	Rice, rice-wheat	N_2O, CH_4	India
Beheydt *et al*. (2008)	Crops	Soil NH_4, NO_3, WFPS, N_2O	Belgium
Brown *et al*. (2002)	Grassland, winter wheat	N_2O	UK
Li *et al*. (1997)	Grass, crop rotations	SOC	England, Australia, Germany, Czech Republic
Li (2000)	Winter wheat, maize, rice	NO, N_2O, CH_4, NH_3	China; Costa Rica; USA
Pathak *et al*. (2005)	Rice grain yield, total biomass,	crop N uptake, CH_4, N_2O	India
Smith *et al*. (2002)	Crops	N_2O	Canada
Smith *et al*. (2008)	Crops	Soil temperature, NO_3, NH_4, moisture content, N_2O	Canada
Zhang *et al*. (2002)	Winter wheat, rice, corn	Soil water, biomass of each organ, plant N	China; USA

Table 2. DNDC model field validation of Kelantan, Malaysia paddies

Variable	Observed	Simulated	Increase/decrease (%)
		Season-1	
Grain yield (kg C ha^{-1})	1511	1516	+1
Leaf + stem (kg C ha^{-1})	1547.78	1554.00	+1
Root (kg C ha^{-1})	-	568	-
N demand (kg ha^{-1})	120	61	-51
N uptake (kg N ha^{-1})	72	60	
		Season-2	
Grain yield (kg C ha^{-1})	1594	1601	+1
Leaf + stem (kg C ha^{-1})	1344.53	1327.00	-1
Root (kg C ha^{-1})	-	976	-
N demand (kg ha^{-1})	120	76	-63
N uptake (kg N ha^{-1})	75.97	76	

from crop residues and its rate of reduction inside the anaerobic balloon would influence CH_4 emissions. The uncertainty in terms of CH_4 emissions in this study reveals that there might be insufficient crop residues which generated negative CH_4 emissions from Kelantan rice area.

Table 3. Soil nitrogen balance (kg N ha^{-1} $year^{-1}$) with the application of 240 kg N ha^{-1} $year^{-1}$

N input source	(kg N ha^{-1} $year^{-1}$)
Left over straw N input	35.8
Crop sub N input	7.3
Crop root N input	21.6
N uptake (kg ha^{-1})	130.3
NH_3 volatilization	14.0
N_2O flux	33.7
NO flux	19.0
N_2 flux	188.1

Table 4. Soil organic carbon balance (kg C ha^{-1} $year^{-1}$)

N outputs	(kg C ha^{-1} $year^{-1}$)
Straw C input	2892.3
Crop residues C input	573.6
Crop root C input	1696.2
Change in SOC	- 4392.4
CH_4 emission	- 2.3

Greenhouse Gas Emission:

***CO_2 flux rate*:** The DNDC simulations for Kelantan, Malaysia showed 4392 kg C ha^{-1} CO_2 flux rate (Table 5, Fig. 7). In India also CO_2 flux rate 4054 kg c ha^{-1} (Pathak and Wassmann, 2007) There are several reasons to explain CO_2 flux rate i.e. oxidation of soil organic matter, microbial biomass pool releasing organic matter that is used by the remaining microbes (Kieft *et al*., 1987) and liberation of CO_2 bound in soil carbonates (Emmerich, 2003).

The soil C storage generally increases through elevated atmospheric CO_2 which increases soil CO_2 flux by about 15 to 50%. The other possible reason might be increases in soil microbes (Zak *et al*., 2000). The elevated atmospheric CO_2 also enhances CH_4 flux rate which may increase up to 58% (Cheng *et al*., 2006) in paddies.

The N_2O flux was not much affected by elevated CO_2 in the rice studies conducted by Cheng *et al*. (2006). However, Kettunen *et al*. (2006) reported that elevated CO_2 supported for higher N_2O flux rates.

The reports are also available indicating that elevated CO_2 increases soil CO_2 flux through deposition of plant organs (Rogers *et al*., 1994), increased root exudation leading to larger pools of labile C in the rhizosphere (Zak *et al*., 1993). In contrast, in this study, rice management practices had little effect on soil CO_2 flux except the use of plowing practices. The farmers in Kelantan use mouldboral plow which is reported to have greater CO_2 flux. A major exception was the incorporation of left residues of previous crop in Kelantan, Malaysia. It has been reported that tillage or soil disturbances in relation to surface residue, the C substrates are rapidly acted by microbes resulting in further flux of CO_2 to the atmosphere (Runion *et al*., 2004) as well as immediate release of CO_2 (Morris *et al*., 2004). Thus, agricultural lands generate very large CO_2 fluxes both to and from the atmosphere (IPCC, 2001).

***N_2O* emissions:** The results of the simulation showed 33.7 kg ha^{-1} year^{-1} N_2O flux (Table 5, Fig. 7) flux. Zhijian *et al*. (2008) also reported 0.7 to 39.4 g N_2O-N ha^{-1} day^{-1}, and 0.5 to 16.8 kg N_2O-N ha^{-1} year^{-1} emission in different crops including rice (Kaiser and Ruser, 2000).

In Kelantan, the moisture availability was more than needed and N applications were also made as required. The moisture, N and C altogether regulate denitrification activity (Kettunen *et al*., 2006) by enhancing N_2O. In this region, rainfall is frequent. However, during dry days, farmers use canal water to make paddies flooded. The flooded conditions due to rainfall or irrigation usually favor N_2O production. In this study, mouldboard plow was also used in the tillage practices, followed by tractor operated soil puddler. These tillage practices could also be possible reasons to increase N mineralization and gaseous losses of N through soil aeration. In general, management practices had little impact on soil N_2O flux in our study.

Despite the fact that soil N_2O-N flux was only 33.7 kg ha^{-1} year^{-1} in Kelantan, these values were low compared to IPCC (2001) reported for other areas of the world. The change in management practices also boost up N_2O emission (Liu *et al*., 2006). However, in Kelantan same cropping system (rice-rice) has been practiced since long time; thus this cropping system has no impact on N_2O emission.

The soils of Kelantan site were found to be medium textured and have a clay content inferior to 35.37%. De Datta (1987) found evidence for nitrous oxide production during denitrification in the anaerobic layer of flooded rice fields. As the influence of ammonium (NH_4^+) ion availability on the rate of the nitrification-denitrification reaction has been well established by Li (2007), the phenomenon of NH_4^+ adsorption to clay is likely to negatively influence the rate of denitrification even during the short-term wetting and drying cycles associated with rice production (Li, 2007). It is well known fact that quantity of N_2O emissions to the atmosphere can offset the rate at which CH_4 can be consumed by aerobic soil systems via oxidation (Mosier, 1998). Thus, the ratio between the amount of C and N present in SOM influences the emission of CO_2, CH_4 and N_2O from agricultural soils.

It is much clear that N_2O emissions in an agriculture system are mostly influenced by: temperature, rainfall, as well as by management practices, i.e. fertilizer N rates, cropping patterns, left over crop residues, and tillage (Skiba and Smith, 2000). However, there could be variations in N_2O emissions in response to climate and soil conditions.

***CH_4* flux rate:** Methane flux in this study was -2 C ha^{-1} year; and negative value indicates as sink (Table 5, Fig. 7). It has been observed that CH_4 flux results from animal production. However, row crop agriculture contributes very little and can sometimes act as a sink (Johnson *et al*., 2007).

***Global warming potential (GWP)*:** The GWP was driven by the fluxes of CO_2, this is supported by the fact that there was higher CO_2 (16105 kg CO_2-eq ha^{-1}), N_2O (16403 kg CO_2-eq ha^{-1}). However, CH_4 had negative values which served as sink (-66 kg CO_2-eq ha^{-1}). Bulk of all these gases had 32442 kg CO_2-eq ha^{-1} net GWP (Table 5, Fig. 7), indicating Kelantan paddies had GHG emission to some extent lesser than those having intensive and conventional farming system (Johnson *et al*., 2007;). This shows that GWP was increased by both elevated CO_2 and management practices especially N fertilizers and left over crop residues as well as soil CO_2 flux.

Table 5. Greenhouse gases in Kelantan, Malaysia paddies

CO_2 flux rate (kg C ha^{-1})	4392
N_2O flux rate (kg N ha^{-1})	33.7
CH_4 flux rate (kg C ha^{-1})	- 2
Global warming potential (GWP)	
CO_2 (kg CO_2 equivalent ha^{-1})	16105
N_2O (kg CO_2 equivalent ha^{-1})	16402
CH_4 (kg CO_2 equivalent ha^{-1})	- 66
Net GWP (kg CO_2 equivalent ha^{-1})	32442

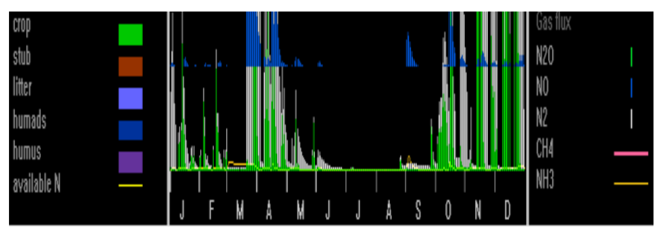

Figure 7. Greenhouse gas fluxes in Kelantan, Malaysia.

***Uncertainties*:** In the field uncertainties may happen due to application of inadequate or higher N fertilizer rates as well as variation in SOC content of the soil. Thus, different rates of N and SOC content were simulated through DNDC model to predict and forecast the outcomes of GHG emission. However, the data for other field practices in this site remained same.

***Uncertainties in NH_3* volatilization:** The linear regression was performed by N rates (20% less than recommended, recommended and 20, 40 and 60% more than recommended N) and SOC rates @ 0.04, 0.03, 0.02 and 0.0193 kg C kg^{-1} for NH_3 volatilization. The unit increase in N rate as well as SOC correspondingly increased NH_3 volatilization by 4.09, 3.76, 2.31 and 1.28 kg N ha^{-1} year^{-1}. The coefficient of

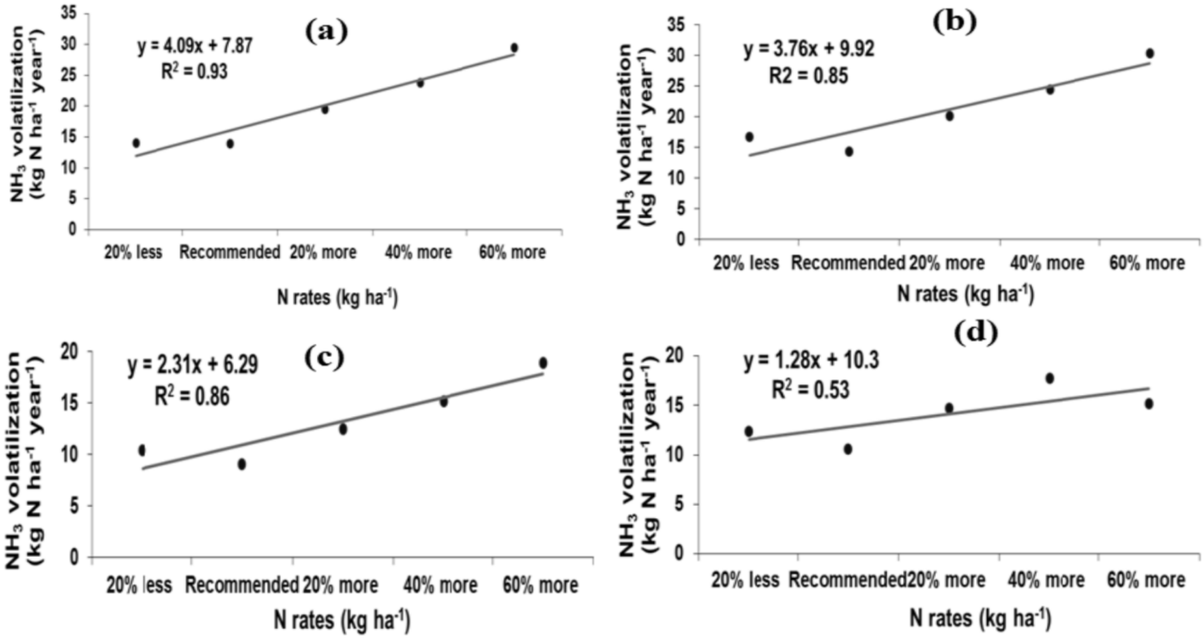

Figure 8. Linear regression between N rates and SOC (a) 0.04 (b), 0.03 (c), 0.02 (d) 0.0193 for NH_3 volatilization

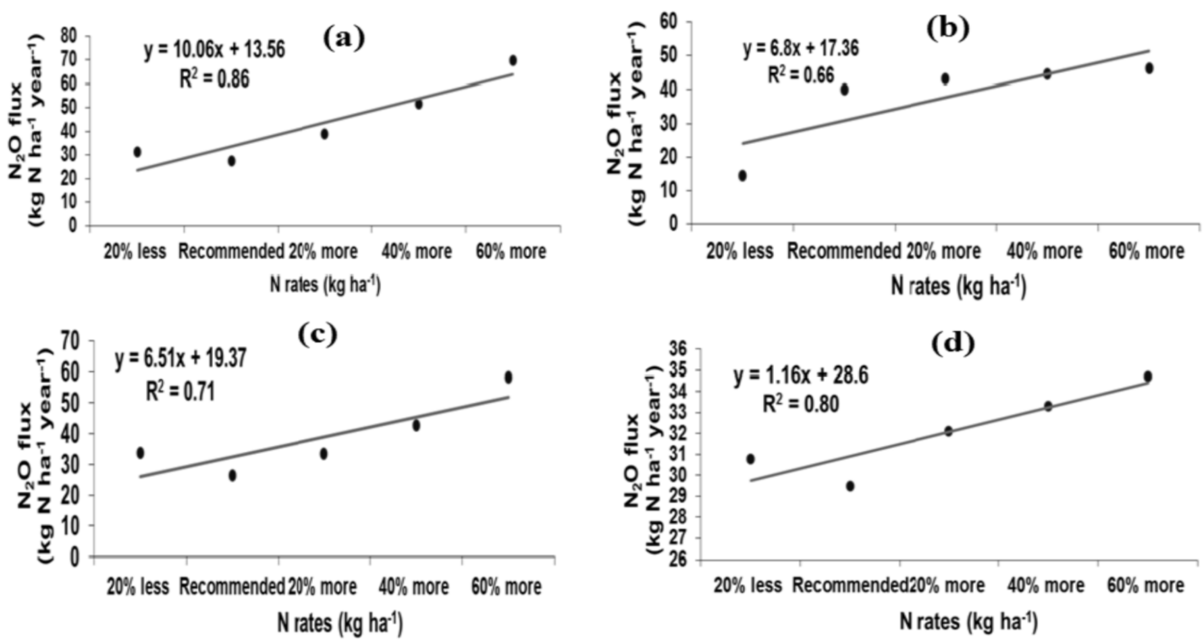

Figure 9. Linear regression between N rates and SOC (a) 0.04 (b), 0.03 (c), 0.02 (d) 0.0193 for N_2O flux rate

determination in all SOC contents ranged between 0.85 and 0.86 except 0.04 SOC which had 0.53 coefficient of determination which indicates strong positive relationship between N and SOC for NH_3 volatilization (Fig. 8).

***Uncertainties in N_2O* flux:** The linear regression between N rates and SOC contents showed increasing trend in N_2O flux. The unit change in SOC i.e. 0.04, 0.03 and 0.02 kg C kg^{-1} correspondingly recorded N_2O flux as 10.06, 6.80 and 6.51 kg N ha^{-1}, respectively. However, SOC at 0.0193 kg C kg^{-1} had sharp decline (1.16 kg N ha^{-1}) in N_2O flux. The coefficient of determination in all SOC contents across N rates ranged between 0.66 and 0.86 with strong positive relationship between N fertilizer and SOC (Fig. 9).

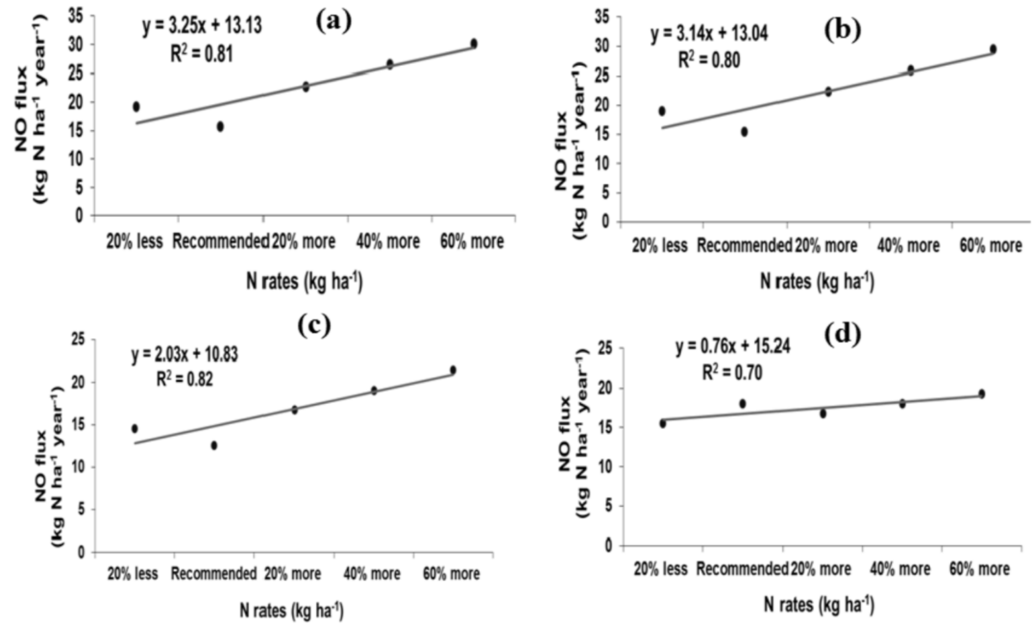

Figure 10. Linear regression between N rates and SOC (a) 0.04 (b), 0.03 (c), 0.02 (d) 0.0193 for NO flux rate

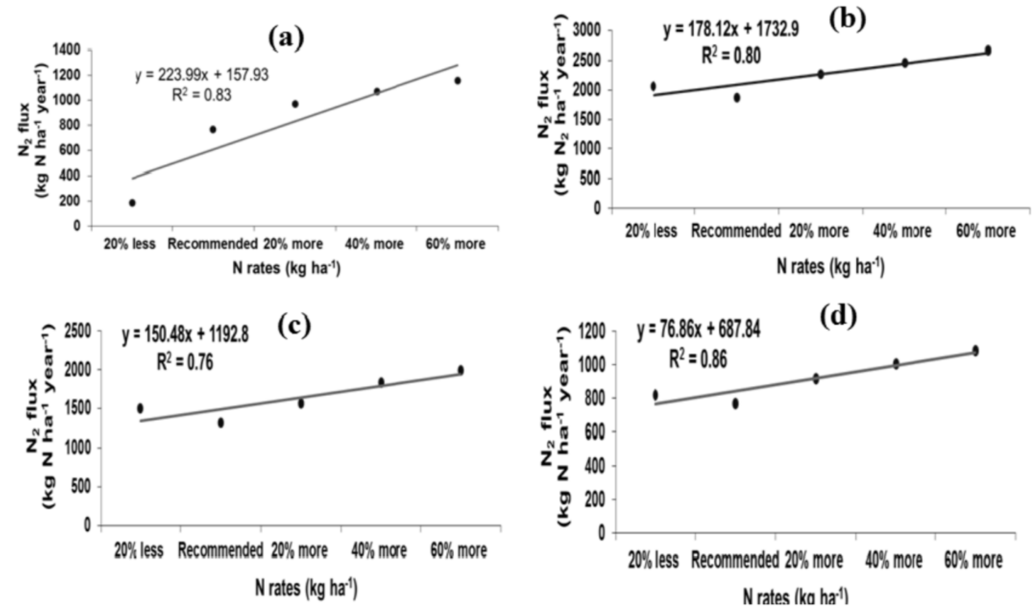

Figure 11. Linear regression between N rates and SOC (a) 0.04 (b), 0.03 (c), 0.02 (d) 0.0193 for N_2 flux rate

Uncertainties in NO flux**:** The linear regression showed decreasing trend in NO flux. A unit increase in SOC content i.e. 0.04, 0.03, 0.02 and 0.0193 correspondingly decreased NO flux by 3.25, 3.14 and 2.03 kg N ha^{-1} year^{-1}, respectively; except SOC at 0.04 which had lower NO flux (0.76 kg N ha^{-1} year^{-1}). The observed coefficient of determination in all SOC contents across N rates ranged between 0.70 to 0.82 indicating strong positive association between N and SOC content for NO flux (Fig. 10).

Uncertainties in N_2 flux**:** The linear regression showed positive relationship between N rates and SOC and had increasing trend in N_2 flux. Across N rates, a unit increase in SOC content (0.04, 0.03, 0.02 and 0.0193 kg C kg^{-1}) correspondingly recorded N_2 flux by 17.87, 18.21, 21.75 and

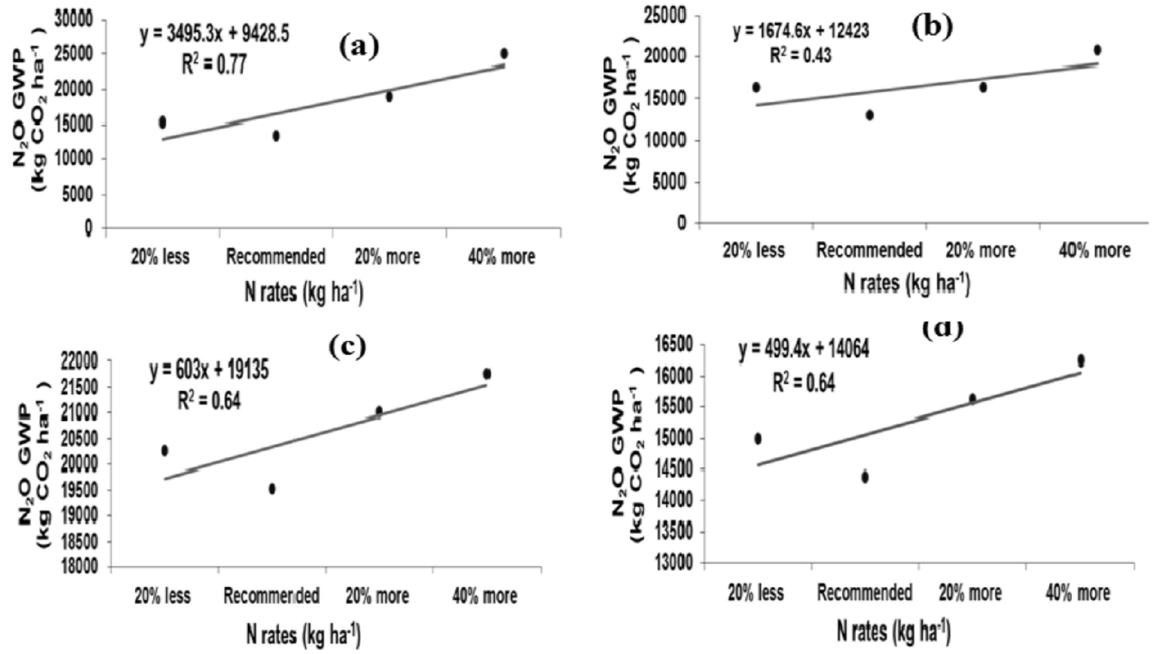

Figure 12. Linear regression between N rates and SOC (a) 0.04 (b), 0.03 (c), 0.02 (d) 0.0193 for N_2O GWP flux rate

25.22 kg ha^{-1} year^{-1}, respectively. The strong positive correlation (78 to 80%) existed between N and SOC (Fig. 11).

***Uncertainties in N_2O GWP flux*:** The linear regression between N and SOC rates showed positive relationship with increasing trend in N_2O GWP flux rate. A unit increase in SOC rate correspondingly increased N_2O GWP flux rate across N rates. The coefficient of determination ranged from 0.64 to 0.77; being low (0.43) in 0.02 kg C kg^{-1} SOC (Fig. 12).

***Conclusions*:** In an agriculture system it is difficult to estimate the accurate GHG emission. However, DNDC made easy to estimate and validate the data. In rice soils of Kelantan Malaysia, the CO_2 flux rate was increasing due to SOC, deposition of left- over crop residues, elevated C and tillage practices. The N_2O emissions were greater due to current N rates, cropping system (rice-rice), flooded conditions due to excessive annual rainfall and canal water. The clay content in soil and use of mouldboard plow followed by tractor operated soil puddler was also enough contributing soil N_2O flux. Methane flux was negative indicating the soil as sink. The net GWP was favoured by both elevated CO_2 and management practices especially N fertilizer and left over crop residues as well as soil CO_2 flux. The simulations for Uncertainties showed that a unit increase in N rate as well as SOC correspondingly increased NH_3 volatilization and rest of fluxes (N_2O, NO, N_2, GWP).

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