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EMISSION OF NITROUS OXIDE AND METHANE FROM ALLUVIAL SOIL THROUGH INCUBATION

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Abstract. Methane and nitrous oxide emission from alluvial soil under incubation using varying doses of urea and water content were studied for Tangibanta and Sorada. The N_2O emission was observed to increase with time and tapers off after attaining the peak. The theoretical emission was evaluated using empirical equations and matches well with the experimental values. The CH_4 and N_2O emission both increased with the increase in Water Filled Pore Space (WFPS) and urea concentration. The nitrification and denitrification reaction rates were determined with and without acetylene. Michaelis-Menten equation was used to evaluate the K_m and V_{max} values. The rate of emission of N_2O increased with increase of WFPS and urea concentration whereas the emission factor showed a reverse trend. The CH_4 emission rate was observed to be comparatively low with respect to N_2O emission rate around a factor of 10.

Keywords: incubation, soil contamination, emission rate, Michaelis-Menten, Principal component analysis (PCA), WFPS, Air pollution.

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Introduction

The concentration of greenhouse gases (GHG) like carbon dioxide (CO_2), N_2O and CH_4 are increasing progressively. Amongst all greenhouse gases CH_4 and N_2O are the second and fourth greatest contributors towards enhancing global warming effect (IPCC 2007). The global warming potential (GWP) for CH_4 (based on 100 year time horizon) is reported to be 21 years, while that of N_2O is 310 with reference to CO_2 (Kampschreur *et al.* 2009). The gases like CH_4 and N_2O contribute around 15 and 5% to the total annual global rise respectively. Agricultural and associated sectors produce about 50 and 70% to the total anthropogenic emission of CH_4 and N_2O respectively. Besides global warming, nitrous oxide is also responsible for the destruction of stratospheric ozone (Yang *et al.* 2011). Globally, agricultural N_2O emissions have increased by nearly 17% from 1990 to 2005, and are projected to increase ~35–60% by 2030 due to increased nitrogen (N) fertilizer use (Gogoi, Baruah 2012). The biogenic emission of N_2O is due to microbial decomposition of nitrogenous compounds available in soil, municipal effluents, sediments and water bodies. The formation is either through nitrification or denitrification or nitrifier denitrification or combination of all these three processes (Horak, Siska 2006). These effects are suggestive of the fact that study of N_2O emission from soil is vital for the research on GHG management. The nitrification proceeds when NH_4^+ (Ammonium ion) or NH_3 (Ammonia) is oxidized to NO_3^- (Nitrate ion) via NO_2^- (Nitrite ion). The oxidation process passes through various intermediates like NH_2OH (Hydroxyl amine) and NO_2^-. The process of NH_3 oxidation can be arrested by using an inhibitor like C_2H_2 (Kineey *et al.* 2005). Acetylene in the concentration range of 0.1 to 10 Pa forms a very reactive unsaturated epoxide, which eventually inhibits the formation of ammonia monooxygenase through covalent bonding. Denitrification is a process where NO_3^- is reduced to N_2 (Atmospheric nitrogen) through different intermediates like NO_2^-, NO (Nitric oxide) and N_2O. The reaction is mediated by different denitrifiers (Rivett *et al.* 2008). Nitrifier denitrification is another way of nitrification where NH_3 or NH_4^+ is oxidized directly to NO_2^- followed by reduction. Methane is produced under reducing atmosphere when the redox potential reaches -180 mV. The condition obligates anaerobes to act through either CO_2 reduction or trans-methylation process (Dutta 2007; Baruah *et al.* 2010; Wang *et al.* 2001). Anaerobiosis in the soil upon submergence results in

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the reduction of inorganic compounds and favors mineralization of organic matter through methanogenic fermentation.

Emission of CH_4 and N_2O from soil is also affected by various physico-chemical factors (Dutta 2007), i.e. soil oxidants, which act as electron accepters for organic matters, determine the emission rate (Mosier *et al.* 2004). Fields flooded over long periods or with intermittent flooding, especially with standing crops, are considered as an important source of these two important greenhouse gases due to simultaneous existence of aerobic and anaerobic environments (Synder *et al.* 2009). CH_4 emission is found to be higher in flooded organic soil, but they also emit substantial amounts of N_2O under intermittent flooding as NO_3 undergoes denitrification during temporary exposure to air (Das *et al.* 2011; Singh *et al.* 2003). Thus the quantity and quality emission of CH_4 and N_2O from different water-soil regimes are complicated but interrelated and needs in-depth analyses for planning of sustainable mitigation strategies.

GHG emission from soil through denitrification and nitrification are highly complicated. Apart from emission of N_2O, the soil also emits CH_4 by methanotrophs. Yet, ample understanding of the above processes is desired as because substantial literatures are available, but the same is somewhat scarce regarding GHG emission from agricultural field; therefore an in-depth analysis is needed to be carried out to correlate the same with various parameters. Keeping in view the importance of this subject our Institute is actively engaged in regular monitoring of GHG from various soil regimes and a part has been published (Ramulu *et al.* 2008, 2009; Sahoo *et al.* 2010). Considering the work carried out before, the objective of the present study is to measure the N_2O emission and to evaluate the rate of N_2O emission through nitrification and denitrification process with the variation of two parameters, i.e. urea and WFPS, which plays as an important aspect for N_2O emission along with microbes and organic carbon content. Some attempts have also been made to correlate the emission of CH_4 with N_2O. Michaelis – Menten type equation is also carried out to establish the relation between total N_2O emissions through nitrification and denitrification with respect to urea addition as a substrate. The interdependence of urea and WFPS for GHG emission was also studied under incubation.

1. Methods

1.1. Site description

The sampling sites were two different agricultural fields one at Tangibanta (latitude N 20° 20′ and longitude E 85° 49′) and other at Sorada (latitude N 19° 50′ and longitude E 84° 19′) situated at a distance of 20 and 250 Km from Bhubaneswar, India respectively. Both of the places have alluvial soil having area of about 700–800 m^2. The field at Tangibanta is used for pulse as well as paddy cultivation on rotation basis. The Sorada field is used exclusively for pulse cultivation. In IPCC terminology, both of the places can be classified as rain-fed, intermittently flooded soil-water regime. The farmer at Tangibanta used farmyard manure before land preparation for Kharif rice (August–December) and very little nitrogen (N) – fertilizer, usually urea (50 kg per acre) used a few weeks after transplantation or before inflorescence to boost growth. No insecticide or pesticides were used. While kharif rice is cultivated during summer monsoons, pulses are sown after a short fallow period during Rabi (January–March) season. In case of Sorada, neither chemical fertilizer nor any pesticides were used. Farmyard manure was added only before sowing.

1.2. Sampling and experimental setup

Soil was sampled during the fallow period (just before plantation) from both Tangibanta (after December) and Sorada (before August) sites. Two different sampling sites were chosen basically as the agricultural practices were completely different. All soil samples were collected in random positions at each site from 5–10 cm depth with an auger (Andert *et al.* 2011) because large portion of active root zone is present where both aerobic and anaerobic microorganisms are present. After collection, the soil samples were homogenized by the classic cone and quartering technique (Gerlach *et al.* 2002) to give one composite sample for each soil and were put inside labeled airtight polythene bags. It was air-dried, crushed and sieved with a 2 mm sieve (Fangueiro *et al.* 2008). Soil physicochemical parameters were studied fallowing the SSSA/ASA guidelines for soil study (Sparks 1996). The soil texture of both the spot was sandy clay loam (23.5–27% clay, 20.6–22.5% silt, 50.4–54.6% sand). It also contains 0.4–0.6% carbon, 0.08–0.11% total N as micronutrients. The moisture content of Sorada soil was less compared to Tangibanta. pH of the soil was slightly acidic, i.e. 5.5–6.9 for both the sites. For incubation experiments, two parameters were varied, such as external addition of N – fertilizer and variation of WFPS. 100 grams of the dried and powdered soil were taken in incubation bottles (250 ml, Borosil) with or without urea. For the set of experiment, 10, 50, 100 and 150 mg of urea per kg of soil were taken in incubation containers along with control (without urea). Urea was used as the nitrogen source due to its easy availability and wide use. The incubation bottles were closed with airtight rubber stoppers made up of polypropylene. These were kept in an incubator (REMI- CI 6S) at 37 °C during the study period. For the other variable like WFPS 10 g of weighted soil was dried at 105 °C for 48 hours to get the dry weight. Initial 100% WFPS was obtained by gravimetric method (Kinney *et al.* 2005). WFPS was varied from 30–75% gravimetrically. During the incubation experiments different WFPS were maintained by adding distilled water. The loss of evaporation was determined by taking the weight of the incubation bottles at periodic intervals (Hayakawa *et al.* 2009). Incubation experiment was also carried out using C_2H_2 (Kinney *et al.* 2005) in order to determine the nitrification and denitrification rate simultaneously. The nitrification and denitrification rates were determined as follows:

$$\text{Soil} = \text{net } N_2O \text{ produced by nitrification as well as denitrification;} \tag{1}$$

$$C_2H_2 \text{ amended soil} = \text{net } N_2O \text{ produced by denitrification only;} \tag{2}$$

$$\text{Eq. (1)} - \text{Eq. (2)} = N_2O \text{ produced by nitrification.} \tag{3}$$

1.3. Gas sampling and analysis

Air samples were drawn through disposable syringe every day at about 10 a.m. and estimated with gas chromatograph. A PerkinElmer Auto system GC with FID was used for CH_4 estimation while a Shimadzu AA30 GC with ECD detector was used to analyse N_2O. Both the GCs were dedicated and equipped with auto gas samplers, semi-micro columns and appropriate software to process the acquired data. Both NIST traceable primary and laboratory prepared secondary standards were used for quality assurance.

1.4. Soil sample analysis

Soil parameters like moisture content, total organic carbon (TOC), NH_3–N (Ammonia nitrogen), $NO_3^- - N$ (Nitrate nitrogen) and $NO_2^- - N$ (Nitrite nitrogen) were analyzed following standard methods (Andert *et al.* 2011; Reddy *et al.* 1989). All urea variation incubation experiments were carried out at 50% WFPS.

1.5. Statistical analysis

Two way analysis of variance (ANOVA) and Fisher t-test was used to determine whether the incubation parameters have any significant variance over the emission of the GHG. Using the null hypothesis technique the significance of the incubation parameters was determined. ANOVA analyses were carried out using MS-Office Excel 2007.

PCA was used to identify the correlation between GHG emission vis-à-vis the incubation parameters like days, ammonia, nitrate, TOC, moisture and urea. PCA is widely used to reduce variables and to extract a small number of latent factors in order to analyse the relationships among observed variables. To make the results more easily interpretable, the PCA with VARIMAX normalized rotation was also applied, that can maximize the factor loadings through variables for each factor. In this study, all principal factors extracted from the variables with Eigen values up to 1 were considered since the results for values ≤ 1 were not significant (Kim *et al.* 2009). When PCA with VARIMAX normalized rotation was performed, each PCA score contained information about all the variables combined into a single number, while the loadings indicated the relative contribution each variable makes to that score. PCA was evaluated using SPSS-13.

All experiments were carried out in quartet and average was used for interpreting the results. The variation was within ±5%.

2. Results and discussion

2.1. Emission of N_2O

Figure 1 shows a typical emission curve during incubation studies under various WFPS. The graph can be divided into two parts, i.e. initial increase followed by decrease. The rate equation for N_2O emission during initial and final stages can be written as:

$$Y = Be^{-k_1 t} + Ce^{k_2 t}, \tag{4}$$

where: $Y = N_2O$ emission; $T =$ Time in days. k_1, $k_2 =$ Rate constant for initial and final stages respectively and B, $C =$ Fitting parameters.

The values for B, C, k_1 and k_2 were calculated (Cardenas *et al.* 2003) using Excel-solver technique. The values are shown in Table 1.

2.2. Effect of water filled pore space

It was observed that N_2O emission efficiency increased with the increase of WFPS as shown (Fig. 1). The soil moisture content influences the oxygen diffusion, thus determining the N_2O emission efficiency. Increase

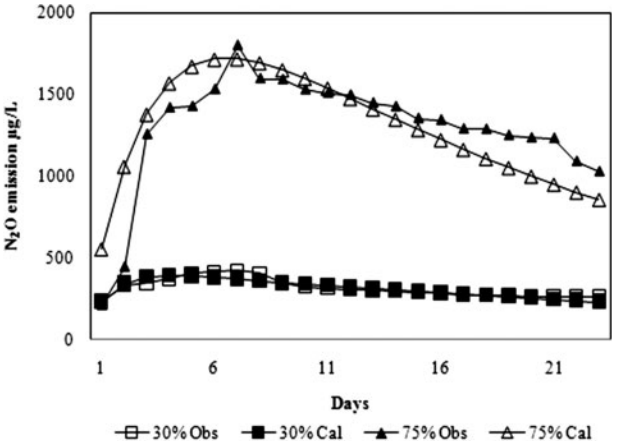

Fig. 1. Emission of N_2O with the variation of WFPS (Sorada)

Table 1. Calculation of k_1, k_2, B and C values during incubation studies using Sorada soil samples by varying WFPS

WFPS	k_1	k_2	B	C
30%	0.03	0.92	439.36	−210.28
75%	0.05	0.36	2686.61	−2134.53

of WFPS plays a vital role in interposing a barrier for O_2 diffusion thereby controlling the rate of nitrification. It was reported (Cleemput 1998) that denitrification was favored at WFPS > 60%, but it may be favored at lower concentration too if the soil has poor porosity and so retaining the moisture for a long time. Table 2 shows the emission of N_2O through nitrification and denitrification routes. This was calculated based on the difference of N_2O emission between incubation experiments carried out in presence and absence of C_2H_2. It was observed that majority of N_2O emission was due to nitrification. The N_2O emission through nitrification and denitrification routes was fitted onto a 1st order plot as shown (Fig. 2) for incubation experiments using Sorada soil. Similar results were obtained for Tangibanta soil and therefore not shown separately. The rates of emission of GHG for Sorada soil were lower than Tangibanta as in the former no chemical fertilizers were used. This suggests that chemical fertilizers play a vital role in determining the emission rates of GHG. It can be concluded from correlation of determinant values that the N_2O emission followed 1st order plot. The reaction rates for both of the soils for different WFPS are shown in Table 3 using the 1st order plot. ANOVA was applied to find out whether the WFPS played a vital role in determining the N_2O emission efficiency and for this purpose null hypothesis technique was used. Null hypothesis assumes that there is no variation of GHG emission with the change of WFPS. So if the F value (calculated) is less than or equal to F critical then it is assumed that there is no variance (Gupta 2005). On the contrary if the F calculated value is more than F critical then the null hypothesis does not hold good, i.e. there is significant variation of GHG emission with the change of WFPS. The F critical as well as F calculated along with p values is shown in Table 4. Table 4 unequivocally proves that WFPS played a significant role for GHG emission for both of the soils.

Table 2. Nitrous oxide (N_2O) emission through nitrification and denitrification routes. (Conditions: Temperature −37 °C)

Parameter	N_2O-emission in both nitrification and denitrification (µgN /Kg soil)		N_2O emission in nitrification (µgN /Kg soil)		N_2O emission through nitrification (%)	
WFPS (%)	Tangi	Sorada	Tangi	Sorada	Tangi	Sorada
30	6.6	4.7	2.5	4.7	38.4	41.9
40	14.9	10.8	7.8	10.8	52.6	56.5
60	38.6	29.4	27.1	29.4	70.2	68.1
75	58.2	52	39.7	52	68.2	69.4
Urea (mg/Kg soil)						
0	10.7	8.6	5.64	4.3	52.2	50.5
10	11.3	12	7.19	7.2	63.4	59.7
50	14.5	16	11.3	11.8	78.2	73.7
100	13.5	20.7	9.7	13.8	72.1	66.9
150	15.40	22.5	12.5	17.5	81.1	77.6

2.3. Effect of urea concentration

Urea concentration was varied from 0–15 mg/100 mg of soil in order to evaluate the N_2O emission through nitrification and denitrification routes. It was reported (Carter 2007) that urea hydrolyzed rapidly to NH_4^+ by enzymatic action vides reaction. The NH_4^+ thus produced would participate further in nitrification as well as denitrification reactions. NH_4^+ would be oxidized during nitrification to NO_3^-, which would be utilized by the denitrifiers. The extent of nitrification and denitrification processes taking place with various initial doses of urea is shown (Table 2). It was observed that the total emission of N_2O increased with the increase in urea addition. Two way ANOVA analyses were carried out and it was observed that urea played a significant role in determining the N_2O emission as shown (Table 4) using null hypothesis technique. ANOVA studies show the significant role played by urea concentration during GHG emission. Apart from two external variables one internal variable as form of soil was also considered. As mentioned earlier incubation studies were carried out using two different soils. In order to evaluate whether the soil plays an important role in emission of GHG Fisher t-test was also carried out using null hypothesis technique. The results are also shown (Table 4). The N_2O emission depends on external addition of urea up to 10 mg/Kg of soil and beyond that both the soil showed similar emission rate as at higher nitrogen concentration the initial nitrogen content in the soil was very small compared to external addition of urea. On the contrary CH_4 emission showed a significant variation between the soils suggesting thereby the emission follows a different route.

Both the variables like WFPS and urea addition followed 1st order rate kinetics. Since the emission of CH_4 and N_2O depends on WFPS as well as urea concentration therefore, the reaction can be considered as pseudo first order. So the rate equation for CH_4 or N_2O emission can be written as:

$$Rate\ of\ GHG\ emi = -dc/dt = k(WFPS)^{n1}(Urea)^{n2}, \quad (5)$$

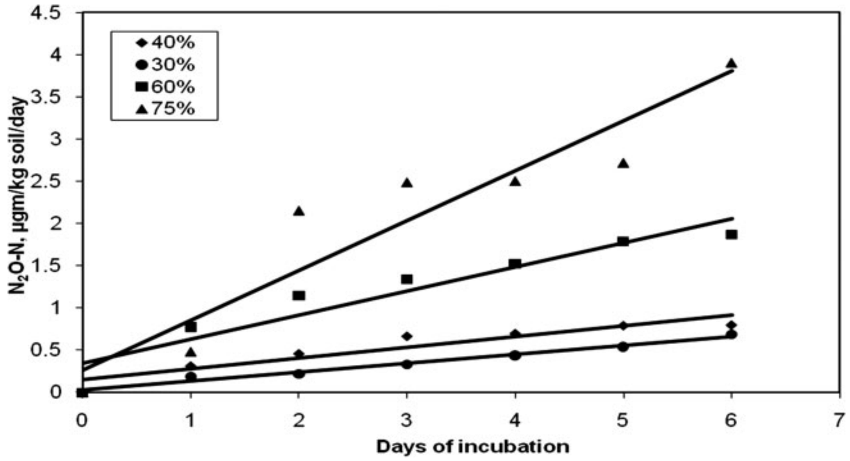

Fig. 2. Nitrification and denitrification rate of Sorada soil (Conditions: Temperature −37 °C, WFPS −30%, 40%, 60% and 75%)

where: c = concentration of GHG; n is order of reaction or dependence factor; k is specific reaction rate (Mishra *et al.* 2009). By converting the equation in logarithm form:

$$Log\,(R) = \log k + n_1 \log\,(WFPS) + n_2 \log\,(Urea). \quad (6)$$

To determine the dependence factor, experiments are arranged to fit Eq. (6). For this purpose only one parameter was varied at a time keeping the other parameter constant. The n values for N_2O and CH_4 emissions were obtained by plotting a graph between log (reaction rate) versus the log (parameter). The slope would give the n values. From the coefficient of determination values it can be concluded that the linearity in all the cases is good (shown in Table 3). Table 3 also shows the n values for two different gases using two different parameters. Using the n values the rate equations can be written using Eq. (5) which would help in determining theoretically the emission rates using set of values.

2.4. Evaluation of K_m and V_{max} values

The total N_2O emission via nitrification and denitrification routes with respect to urea addition can be fitted to a Michaelis-Menten type equation (Silvennoinen *et al.* 2008) as shown in Eq. (7).

$$1/r = (K_m/V_{\max})X(1/S) + (1/V_{\max}), \quad (7)$$

where: r = Reaction rate of N_2O through nitrification and denitrification route (μg/Kg soil/day); $V_{\max}$ = Maximum N_2O emission rate, μg/Kg soil / day; S = Concentration of substrate (Urea), mg/Kg of soil; K_m = Substrate concentration (mg/Kg soil) at which the reaction rate is half normal.

A straight line would be obtained if the reciprocal of N_2O emission rate is plotted against the substrate concentration. Extrapolating the linear regression to

Table 3. Emission rates of nitrous oxide (N_2O) and CH_4 with dependence factor during incubation (Conditions: Temperature −37 °C)

Parameter	Reaction Rate, μgN /Kg soil/ day (N_2O)		Dependence factor		Coefficient of determination (R^2)		Reaction Rate, μg/Kg soil/day (CH_4)		Dependence factor		Coefficient of determination (R^2)	
WFPS (%)	Tangi	Sorada	Tangi	Sorada	Tangi	Sorada	Tangi	Sorada	Tangi	Sorada	Tangi	Sorada
30	0.15	0.11	1.59	1.85	0.99	0.91	0.05	0.04	0.37	0.20	0.92	0.52
40	0.22	0.12					0.06	0.04				
60	0.42	0.28					0.07	0.04				
75	0.65	0.59					0.07	0.05				
Urea (mg/Kg soil)												
10	0.6	0.11	0.15	0.43	0.90	0.91	0.61	0.04	0.07	0.05	0.98	0.31
50	0.76	0.21					0.54	0.04				
100	0.86	0.23					0.53	0.04				
150	0.89	0.4					0.51	0.05				

Table 4. Statistical analysis using two way ANOVA and Fisher t-test to show the significance of incubation parameters

	Tangibanta				Sorada			
	WFPS (30–75%)		Urea (0–150 mg/Kg of soil)		WFPS (30–75%)		Urea (0–150 mg/Kg of soil)	
	N_2O	CH_4	N_2O	CH_4	N_2O	CH_4	N_2O	CH_4
F value	19.67	24.62	44.55	17.03	4.46	69.45	17.52	4.29
P value	2.98E − 09	4.8314	7.60E12	2.92E10	1.23E06	5.94E20	1.32E10	7.51E − 03
F critical	2.36	2.08	2.51	2.48	1.71	2.75	2.48	2.73

Fisher t-test of Tangibanta soil with urea variation

	Fisher t-test (N_2O)			Fisher t-test (CH_4)		
Urea variation(mg/Kg of soil)	t-value	P-value	t-critical	t-value	P-value	t-critical
Control	2.8	4.00E − 03	1.68	1.46	7.79E − 02	1.71
10	1.71	4.70E − 02	1.68	3.24	1.97E + 03	1.72
50	0.85	0.2	1.68	3.71	6.47E − 05	1.72
100	0.58	0.28	1.68	3.57	8.93E − 04	1.72
150	1.05	0.15	1.68	4.6	8.46E − 05	1.72

its intercept on the abscissa would give the negative reciprocal of K_m. The results are shown (Fig. 3). The K_m values for Tangibanta and Sorada soil were found to be 4.58 and 19.8 mg/Kg soil respectively while the V_{max} values were 0.83 and 0.32 µg/kg soil/day respectively. Higher V_{max} observed in case of Tangibanta soil may be due to addition of nitrogenous fertilizers during paddy cultivation whereas no fertilizer was applied to Sorada soil.

2.5. Calculation of Emission factor (EF)

The extent of N_2O formation in soil and emission is a direct function of the amount of ‘N’ fertilizer applied. It can be expressed as the emission factor (EF), which is the amount of N_2O emitted expressed as a fraction or percentage of the ‘N’ fertilizer applied to the soil. It was observed that the rate of emission increased with the increase in urea dose whereas the emission factors showed a reverse trend. The emission factor in this case varied in the range 1 to 4% of the ‘N’ fertilizer applied compared to 0.1–7.3% reported by other workers for similar kind of soils (Dobbie, Smith 2003). Bouwman (1996) experimentally derived a mean EF equaling 1.25 ± 1% of the ‘N’ fertilizer applied. This value was accepted as the (IPCC 1997) default value. The higher EF at lower ‘N’ fertilizer application observed in the present studies may be due to the activity of the soil microbes acting as efficient denitrifiers. Alternative explanation could be the controlled temperature and closed atmosphere prevailing in incubation experiments (Cleemput 1998). The N_2O emission increased initially but tapered off with time after two weeks of incubation. The decrease in N_2O concentration may be due to further reduction to N_2. The emission of N_2O under this condition may be either due to direct denitrification or nitrification followed by partial denitrification (Cleemput 1998). Further reduction of N_2O to N_2 suggests the dominance of denitrification towards the end, if not during the entire period.

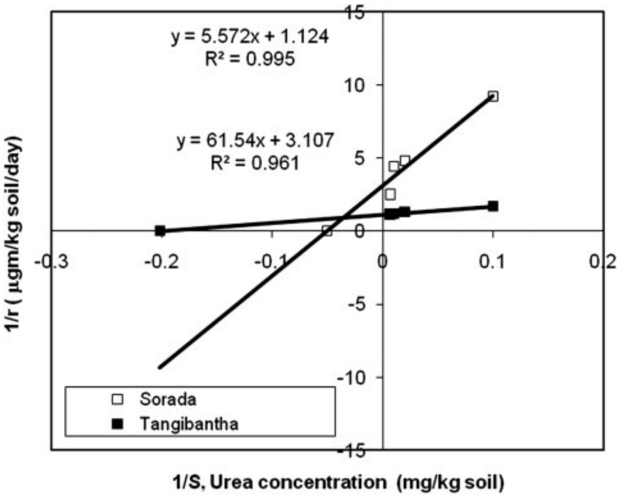

Fig. 3. Michaelis-Menten fitting curve of nitrification and denitrification routes with respect to urea addition (Conditions: Temperature − 37 °C, WFPS − 50%)

2.6. Emission of CH_4

CH_4 emission, like N_2O, depends on the soil properties as well as microbiological activities in soil. CH_4 is generally emitted from the soil by the decomposition of mainly organic matters (Mitra *et al.* 2002). The emission of CH_4 during incubation experiments in all parameters increased progressively unlike N_2O (data not shown). The CH_4 emission rates under different incubation studies are shown (Table 3) along with dependence factor. It was further observed that CH_4

Table 5. Principal component analysis

	Factor		
	1	2	3
Days		0.94	
N_2O			0.90
CH_4		0.77	
Ammonia	0.86		
Nitrate	0.85		
Total Organic Carbon			
Moisture		−0.81	
Urea	0.88		
Eigen values	2.61	2.41	1.06
Cumulative variance	32.62	62.71	75.92

emission rate was lower compared to N_2O. The lower CH_4 emission rate may be due to lower organic carbon in both of the soils. Another possible explanation for low CH_4 may be anaerobic oxidation resulting in loss of CH_4 as shown in Eq. (8).

$$5CH_4 + 8NO_3^- + 8H^+ = 5CO_2 + 4N_2 + 14H_2O. \quad (8)$$

Table 4 shows the two way ANOVA and Fisher t-test. The results were similar to N_2O emission.

2.7. Chemical composition of the soil

Chemical composition of the soil like NH_3–N, $NO_3^- - N$ and TOC contents were analyzed at regular intervals. Out of these three parameters, NH_3–N decreased considerably with time whereas the decrease in the other two parameters was marginal. The extent of loss of NH_3–N increased with higher addition of urea from external sources. The rate of decrease varied between 0.75–5.56 μgm/day, the lowest and the highest correspond to the no addition and maximum addition of urea respectively. The $NO_2^- - N$ concentration variation was negligible during the entire period of incubation.

2.8. Principal Component Analysis (PCA)

PCA is an important tool in solving the problem of analyzing the structure of the interrelationship among a large number of variables. It defines a set of common underline dimension known as factors. In the present case we have considered the factor loading >0.5 to achieve a confidence level >95%, as in the present case the total data set is >120 (Hair *et al.* 1998). Factor-I accounted for 32.6% of cumulative variance having eigen value of 2.6. Factors-I contained three variables like ammonia, nitrate and urea. All these factors played a vital role in generation of GHG during incubation. Therefore Factor-I may be termed as 'GHG generation'. Factor-II accounts for 62.7% of cumulative variance having eigen value of 2.4. It contained variables like days, CH_4 and moisture content. Therefore, Factor-II is termed as 'CH_4 emission'. Factor-III accounts for cumulative variance of 75.9% having eigen value of 1.05. So Factor-II can be termed as 'N_2O emission'. Results are shown in Table 5.

Conclusions

1. It can be concluded that the emission of N_2O and CH_4 depends on the availability of nitrogen source, soil character and prevailing environmental conditions.
2. It was observed that N_2O emission attained a maximum and then tapered off, while CH_4 emission increased progressively with time as well as lower carbon content in both soils.
3. The emission of CH_4 was observed to be low, may be due to further oxidation by NO_3^- as well as lower carbon content in both the soil.
4. Theoretical N_2O emission was calculated using empirical equation and it explained well with the experimental values.
5. The emission of N_2O and CH_4 gases greatly depends on both nitrogen and WFPS variation used in this study.
6. Statistically it was proved that the two experimental parameters i.e. urea and WFPS played significant roles ($P \leq 0.001$) in determining the emission level.
7. The PCA classified the variables as three different influencing factors.

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