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Seasonal and temporal changes in nitrous oxide emission with fertilizer application in rice ecosystem of North Bank Plain Agroclimatic Zone of North East India

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Abstract: Fertilizer dosage can influence nitrous oxide (N_2O) emissions in rice (*Oryza sativa* L.) fields. An experiment was conducted to find out the temporal and seasonal variations in N_2O emissions under different doses of fertilizers and to identify the best fertilizer combination for lower N_2O emission and adequate yield potential. Two rice varieties Phorma (local cultivar) and Luit (high yielding variety) were grown, with nine different fertilizer treatments. N_2O fluxes were measured by a closed chamber technique. Temporal fluxes coincide with fertilizer application. Higher seasonal N_2O emission (E_{sif}) of 224.05 mg N_2O-N/m^2 (in Phorma) and 182.16 mg N_2O-N/m^2 (in Luit) was observed in treatment T_9 (45:22:22 N-P_2O_5-K_2O kg/ha as urea, single super phosphate and muriate of potash + farm yard manure). Whereas, lowest emission was recorded in T_2 (35:18:18 N-P_2O_5-K_2O kg/ha as urea, single super phosphate and muriate of potash). N_2O emission also showed significant positive correlations with soil nitrate-N and soil organic carbon. The fertilizer dose N, P_2O_5, K_2O @ 40: 20: 20 kg/ha as urea, single super phosphate and muriate of potash (T_1) without farm yard manure was found to be suitable for sustaining productivity and lower N_2O emission in this zone.

Keywords: Fertilizer Dose, Farm Yard Manure, N_2O Emission, Grain Yield, Rice

1. Introduction

The main greenhouse gases that contribute to global warming and climate change are water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). Since the industrial revolution, the concentration of N_2O in the atmosphere has increased from around 270 ± 7 ppb in 1750, to 319 ± 0.12 ppb in 2005 [1]. Fertilizers or manures applied to agricultural soils are direct sources of N_2O and atmospheric nitrogen depositions, sewage and loss of nitrogen from agricultural fields through leaching and runoff are indirect sources. Several studies have indicated that N_2O emissions are influenced by the rate and type of fertilizers applied [2], [3]. Higher nitrogen and phosphorous fertilizer doses were found to emit higher N_2O fluxes from the interaction of N and P fertilizers under an irrigated rice system [4]. N_2O emissions double to 10 kg N_2O-N/ha/year when N applied at 400 kg N/ha/year [5]. Recent investigations have showed that when annual fertilizer rates increased from 270 to 430, from 270 to 650, and from 270 to 850 kg N/ha/year, cumulative N_2O emissions increased from 35-115% [6]. With increasing N application rates total N_2O emission during the wheat growing period increased linearly from 32 to 164 % [7]. Significant increase in cumulative N_2O emissions with increasing N application rates were reported during potato and corn growing season [8], [9]. Although few studies on effect of fertilizer rates on N_2O emission from different cropping systems in India are reported but no such studies were conducted in North Bank Plain Agroclimatic Zone of Assam of India where rice is the major cereal crop grown throughout the year under different ecosystem. Therefore, present study was conducted with an objective to find out the temporal and seasonal variations in N_2O emissions from rice field under different doses of fertilizer treatments and to identify the best fertilizer combination for lower N_2O emission and adequate yield potential in rice ecosystem of North Bank Plain Agroclimatic Zone of Assam.

2. Study Area

The study was conducted in North Bank Plain Agroclimatic Zone (NBPAZ) of Assam at Tezpur, India (Figure 1). The experimental area is located at 26°41′ N latitude and 92°50′ E longitude in a farmer's field at about 6 km distance from Tezpur Central University, Assam. The average weekly precipitation and maximum and minimum average air temperature recorded during the experimental period are shown in Figure 2. This zone is characterized by light textured loamy alluvial soils. Prior to inception of treatments experimental site soils contained 29.02% sand, 40.69% silt, 30.29% clay, 377 kg/ha available nitrogen, 35 kg/ ha available phosphorus and 240 kg/ha available potassium, 0.91% organic carbon, soil pH 5.2.

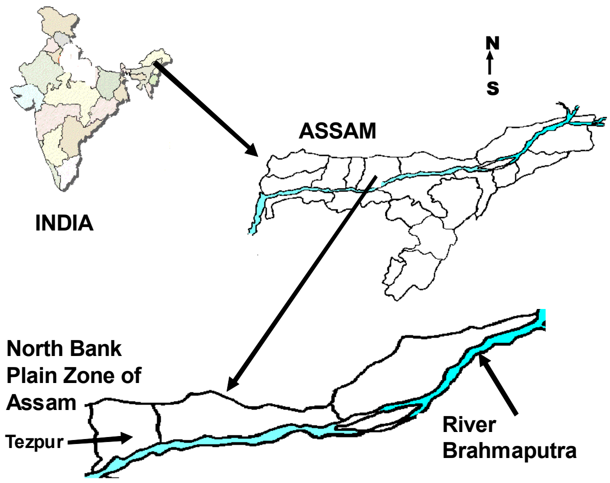


Figure 1. *Experimental site at North Bank Plain Agroclimatic Zone*

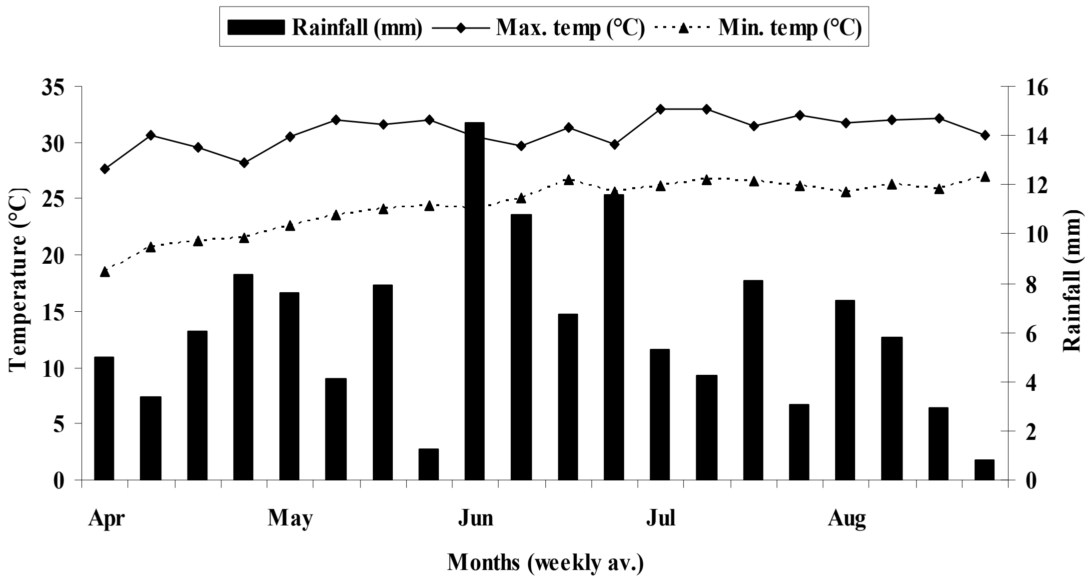


Figure 2. *Meteorological parameters during the experimental period*

3. Methods

Two popularly grown rice varieties namely Phorma and Luit were selected for this experiment. Luit is a high yielding, semi-dwarf, white kernelled photoperiod insensitive variety. Phorma is an indigenous traditional rice cultivar. Plants are of medium height with strong culm and good tillering ability. The seedlings of these varieties were transplanted in well prepared plots (area = 2 m × 2 m) comprising of nine different fertilizer treatment combinations, each replicated three times in randomized block design on May, 17, 2008. The form and doses of fertilizer treatments are T_1: N, P_2O_5, K_2O @ 40: 20: 20 kg/ha as Urea, SSP (Single Super Phosphate) and MOP (Muriate of Potash), T_2: N, P_2O_5, K_2O @ 35:18:18 kg /ha as Urea, SSP, MOP, T_3: N, P_2O_5, K_2O @ 45:22:22 kg/ha as Urea, SSP, MOP, T_4: N, P_2O_5, K_2O @ 40:20:20 kg/ha as Urea, DAP (Diammonium Phosphate), MOP, T_5: N, P_2O_5, K_2O @ 35:18:18 kg/ha as Urea, DAP, MOP, T_6: N, P_2O_5, K_2O @ 45:22:22 kg/ha as Urea, DAP, MOP, T_7: N, P_2O_5, K_2O @ 40:20:20 kg/ha as Urea, SSP, MOP + farm yard manure (FYM), T_8: N, P_2O_5, K_2O @ 35:18:18 kg/ha as Urea, SSP, MOP + FYM, T_9: N, P_2O_5, K_2O @ 45:22:22 kg/ha as Urea, SSP, MOP + FYM. One third of total dose of N was applied at the time of final puddling before transplanting along with full dose of P_2O_5 and K_2O. The second and third doses of N were applied at tillering and panicle initiation stages, i.e. at 30 and 47 days after transplanting (DAT) of the crop. FYM was applied in treatments T_7, T_8 and T_9 @ 10 t/ha along with other fertilizers at the time of final land preparation. Crop was harvested on 4 th August, 2008. Gas samples were collected by a closed chamber technique. The collected gas samples analyzed for N_2O fluxes, using a Varian model 3800 gas chromatograph (USA) fitted with an electron capture detector (ECD). N_2O flux was calculated as described earlier [10]. Cumulative N_2O emission for the entire crop growth period was computed by the method given by [11]. Cumulative N_2O emission is expressed as seasonal integrated flux (E_{sif}) in mg N_2O-N/m^2. Soil samples were randomly collected from each plot from a depth of 15 cm using a core sampler. Soil nitrogen content was determined by Kjeldahl's method [12]. Phosphorus and potassium content in soil were determined by Bray's I method and Flame photometric method, respectively [13]. Soil pH was measured at 1:2.5 soils to water ratio using a digital pH meter (Systronics Griph model D pH meter). Organic carbon of the soil at weekly interval was estimated by wet digestion method [14]. Soil nitrate nitrogen content was determined on each N_2O flux measurement day at weekly interval by Phenol disulphonic acid method [15]. Rice yield was determined from the total plot area by harvesting all the hills excluding the hills bordering the plots.

The statistical package SPSS version 11.5 was used to calculate the correlation (Pearson correlation) coefficient. The significant variations within treatments in each rice variety were analyzed by one-way ANOVA and subsequently by Duncans's multiple range tests. Two- way ANOVA was carried out to analyze whether the seasonal mean values differ within two varieties.

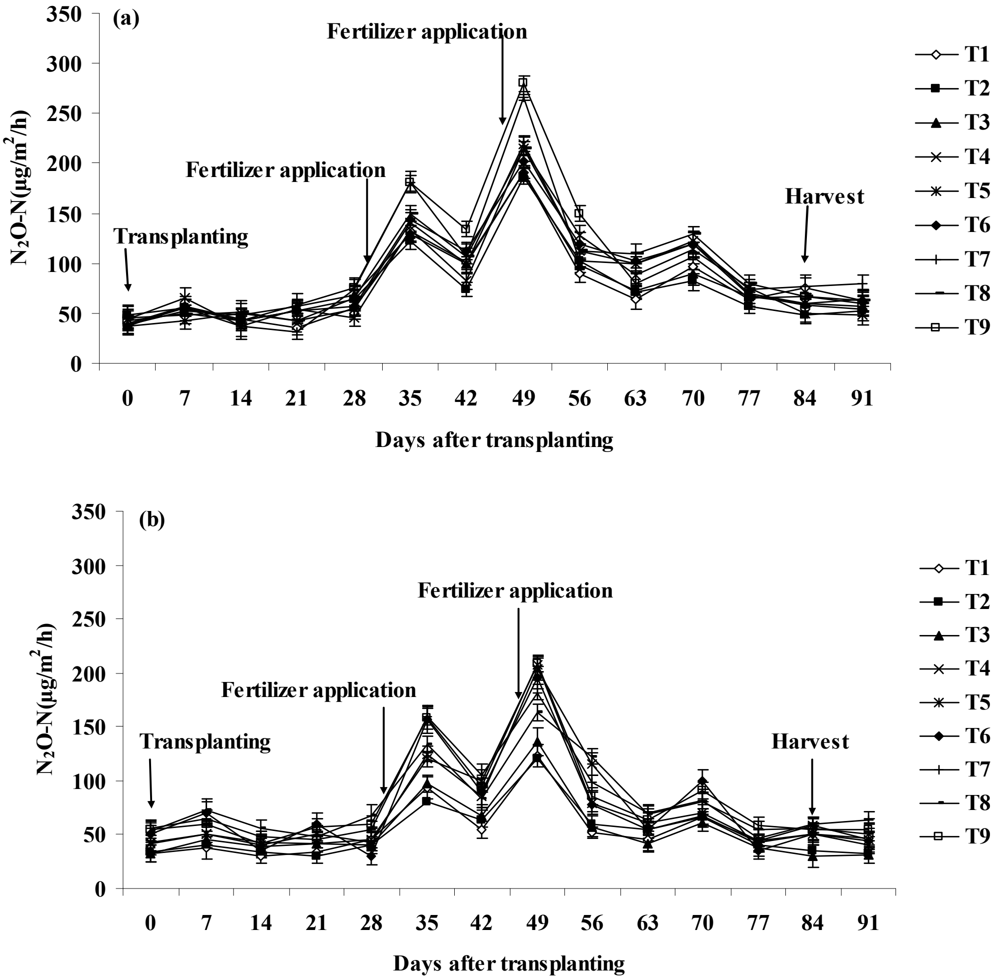


Figure 3. *Nitrous oxide fluxes N_2O-N (µg/m^2/h) from rice variety Phorma (a) and Luit (b) respectively, under different fertilizer treatments. Vertical bars represent standard error of three replications. The arrows indicate the time of application of fertilizers and day of harvest*

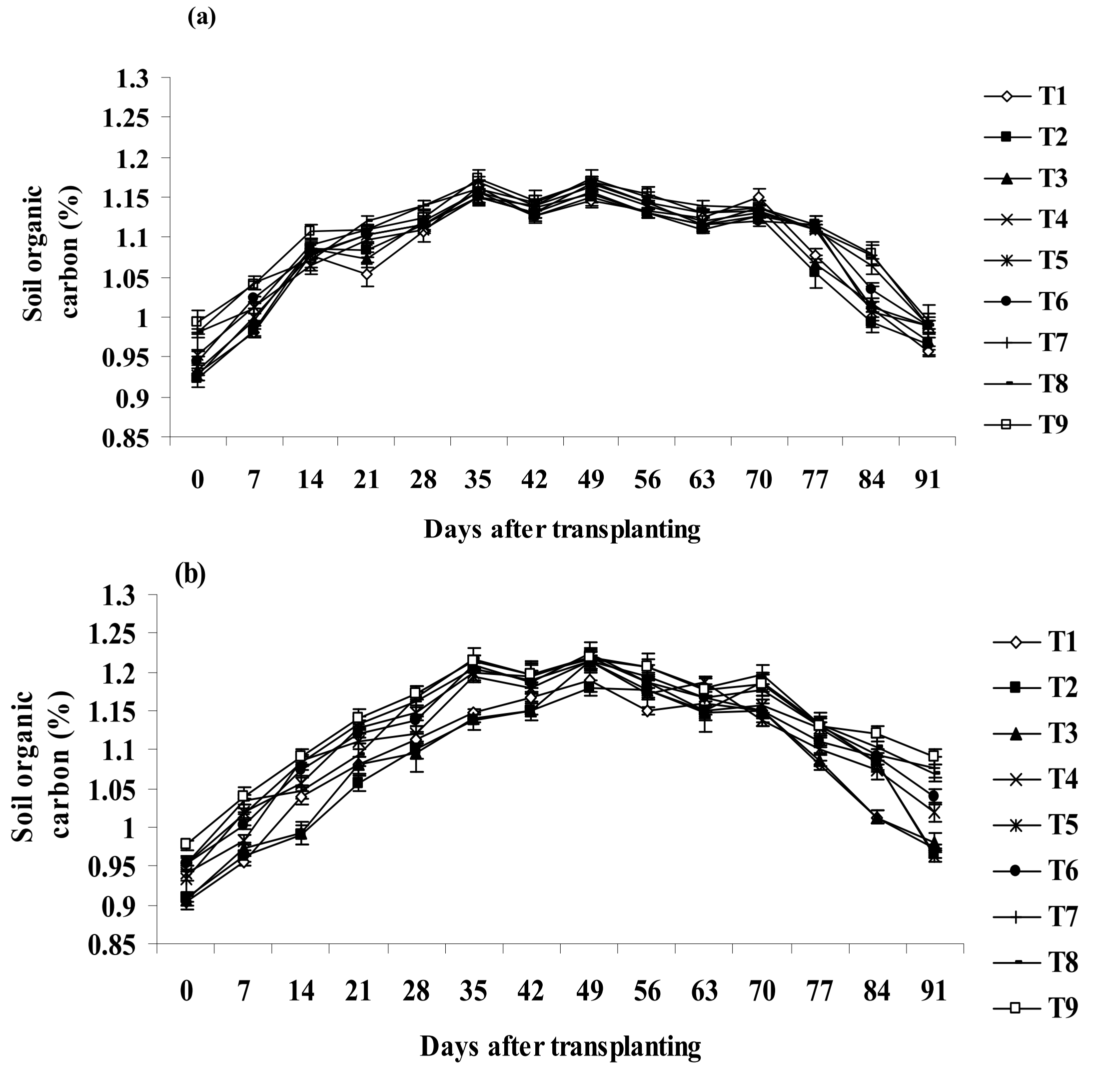
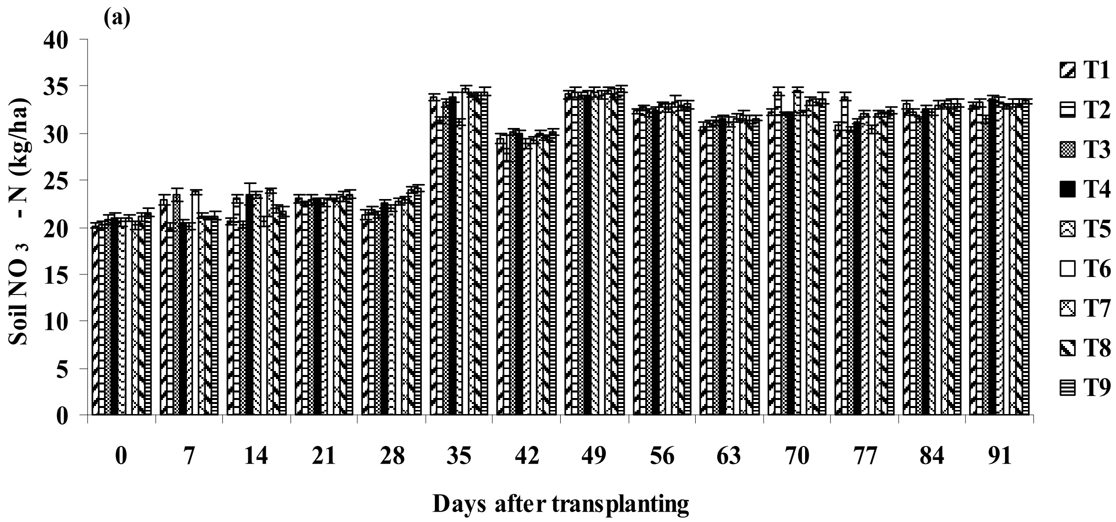


Figure 4. *Soil organic carbon (%) of the experimental field with rice variety Phorma (a) and Luit (b) respectively, under different fertilizer treatments. Vertical bars represent standard error of three replications*



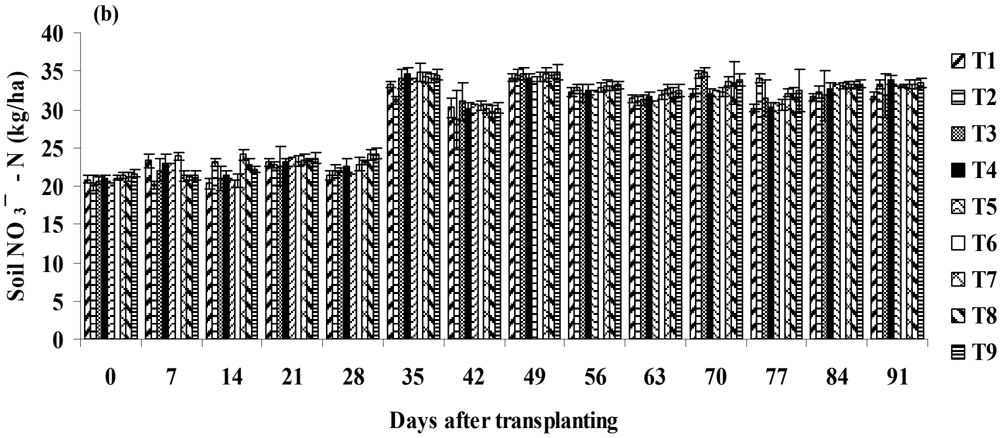


Figure 5. *Soil NO_3^- - N (kg/ha) of the experimental field with rice variety Phorma (a) and Luit (b) respectively, under different fertilizer treatments. Vertical bars represent standard error of three replications*

4. Results

Mean N_2O flux of 41 and 44 µg N_2O-N/m^2/h was observed in varieties Phorma and Luit, respectively at the time of transplanting (Figure 3). After fertilizer application at 30 DAT (days after transplanting) the mean N_2O fluxes increased to 146 µg N_2O-N/m^2/h in Phorma and 125 µg N_2O-N/m^2/h in Luit at 35 DAT. Again at 49 DAT elevated N_2O fluxes were observed in both the varieties after fertilizer application at 47 DAT. Maximum flux values of 280 µg N_2O-N/m^2/h and 209 µg N_2O-N/m^2/h was observed in T_9 (N, P_2O_5, K_2O @ 45:22:22 kg/ha as Urea, SSP, MOP + FYM) at 49 DAT in variety Phorma and Luit, respectively. Further, at 70 DAT mean N_2O fluxes increased up to 109 µg N_2O-N/m^2/h in Phorma and 70 µg N_2O-N/m^2/h in Luit, respectively. We observed higher seasonal N_2O emissions (Table 2) when N, P_2O_5, K_2O at the rate of 45:22:22 kg/ ha (T_9) in the form of Urea, SSP, MOP + FYM (farm yard manure) was applied followed by T_7 (N, P_2O_5, K_2O @ 40:20:20 kg/ha as Urea, SSP, MOP + FYM) and T_8 (N, P_2O_5, K_2O @ 35:18:18 kg/ha as Urea, SSP, MOP + FYM). Whereas, lowest emission was recorded when rice varieties were grown in T_2 (N, P_2O_5, K_2O @ 35:18:18 kg/ha as Urea, SSP, MOP). Variety Phorma showed higher seasonal emissions compared to Luit (Table 2). The mean seasonal N_2O emissions differed significantly within two varieties ($P < 0.0001$).

Figure 4 represents the soil organic carbon (SOC) of the experimental field with rice varieties subjected to various fertilizer treatments. Significant positive correlations between SOC and N_2O emission is observed in present investigation (Table 1). SOC of the treated plots were initially low and increased during maximum tillering, panicle initiation and crop ripening stage. Observed SOC is significantly higher in treatments T_7, T_8 and T_9 in both the varieties (P<0.05). Seasonal mean SOC differ significantly within varieties (P<0.0001). The soil NO_3^--N content showed significant positive correlation with N_2O emission (Table 1). Soil NO_3^--N of the experimental field with the variety Phorma and Luit grown at different level of fertilizer treatments are shown in Figure 5. Soil NO_3^--N content was initially low and increased rapidly from 35 DAT onwards till crop ripening. High soil NO_3^- content was recorded in treatment T_9 followed by T_7 and T_8 in both the varieties. Seasonal mean soil NO_3^- content varied significantly within varieties (P<0.0001).

Rice varieties at different levels of fertilizers recorded maximum yield in T_7 followed by T_1, T_4, T_6, T_3, T_9, T_8, T_5 and T_2 (Table 2). Compared to Phorma variety Luit had higher yield potential. Variety Luit also recorded higher thousand grain weights compared to Phorma. Higher grain sterility (%) was observed in treatment T_2 followed by T_5, T_8, T_9, T_3, T_6, T_4, T_1 and T_7 in both the varieties. variations in length of panicle within the treatments were not significant. Phorma recorded more number of panicle/unit area (square meter land area).

5. Discussion

The observed N_2O emission peaks after fertilizer applications at active vegetative (35 DAT) and panicle initiation stages (49 DAT) after topdressing of nitrogenous fertilizer in the form of urea at 30 DAT and 47 DAT, are attributed to increased substrate (NO_3^--N) which is evident from increased soil nitrate content of the experimental field at these stages (Figure 5). The emission peaks at 70 DAT in both varieties (Figure 3) is associated with high N_2O production in the rice rhizosphere as a result of decomposition of leaf litters and crop roots. It is reported that incorporation of plant residues in soils increases the denitrification enzyme activity and influence the composition and diversity of the denitrifying community and thus effects N_2O emissions [16]. Similar mechanism might have promoted higher N_2O flux at reproductive stage (70 DAT) under the influence of different doses of fertilizer applied in rice field. Higher seasonal N_2O emission in T_9 is attributed to more substrate availability (NH_4^+ and NO_3^-) for nitrifying and denitrifying microorganisms, which is contributed by higher dose of applied N in the form of urea. Applied FYM along with urea might have provided additional C and N substrates of nitrification and denitrification in T_9. Similar results of higher N_2O emission after application of N fertilizers along with manure is reported by [17]. It was reported that emission of N_2 and N_2O was greater with alkaline-producing fertilizers than with acidic fertilizers [18]. In our study relatively lower seasonal N_2O emission recorded at T_6, T_4 and T_5 is primarily due to lower soil alkalinity caused by T_6, T_4 and T_5 compared to T_9, T_7 and T_8 a mechanism suggested by [18]. It is reported that more alkaline-producing fertilizers may promote denitrification under waterlogged conditions, either because of an increase in the supply of oxidizable C or because of a direct effect on microbial activity [19]. Similar mechanisms may have resulted increased N_2O emissions in T_9, T_7 and T_8 in the present investigation. Efficient use of nutrients by rice plants can be a cause for observed lower seasonal emission in treatment T_1 and T_2 [20]. The observed significant differences in seasonal N_2O emission within varieties are attributed to variations in soil C input by root turnover and exudates as suggested in some earlier findings [21], [22].

In present study significant positive correlations of N_2O emission with soil organic carbon (SOC) of the experimental fields is due to influence of SOC on denitrifying and nitrifying microorganisms. Since, nitrification is strongly influenced by CO_2, while denitrification is driven by easily oxidizable C sources hence; both nitrification and denitrification are supported by the availability of C [23], [24]. Increased SOC at active vegetative growth stage in our study is attributed to availability of a large quantity of decomposable organic matter and carbon from root exudates with increasing root biomass of the plants. The increased N_2O emissions with increasing SOC at active vegetative growth stages of rice is because of increased C in rhizosphere contributed by increased rate of plant growth parameters like roots, leaves and tillers. Higher mean SOC observed in the field treated with T_9, T_7 and T_8 are attributed to application of farm yard manure along with fertilizer N (urea) which might have increased SOC and stimulated N_2O emission. Our results are in agreement with earlier findings [25], [26]. It was reported that an increase in N_2O emission from 3.11 kg N/ha/year to 4.43 kg N/ha/year was because of increased soil organic carbon from 0.5% to 2%, in summer maize ecosystem [25]. In a laboratory incubation experiment higher N_2O emission was observed from farm yard manure treated soils [26]. It was suggested that the long-term application of farmyard manure and the associated increase in soil organic carbon and nitrogen stocks promote emissions of N_2O [25], [26].

Soil NO_3^--N and N_2O emission in present investigation are found to be significantly correlated (Table 1). This is because the main substrates for nitrification and denitrification in soils are NH_4^+ and NO_3^-, which may be derived from either decomposition of organic matter or the addition of fertilizers [6]. Relatively low soil NO_3^- (Figure 5) of the fields observed in our study at initial period is due to loss of NO_3^- through denitrification under submerged soil condition (standing water level more than 3 cm). Increased soil NO_3^--N at active vegetative and panicle initiation stages is contributed by fertilizer urea topdressing at these stages in rice. Higher soil NO_3^--N at crop ripening and maturity stages were due to increased availability of mineralized soil organic nitrogen in soil as a result of decomposition of senesced older leaves and roots.

Maximum yield was recorded in T_7 followed by T_1, T_4, T_6, T_3, T_9, T_8, T_5 and T_2 (Table 2). Although no significant difference in yield was observed in T_7 and T_1 in both rice varieties (Table 2), the seasonal N_2O emission is significantly reduced due to treatment T_1 compared to T_7. Similarly there is no significant difference in yield between the treatments T_4 and T_6, but seasonal N_2O emission is significantly lower in T_4 than T_6 (Table 2). Our results are in agreement with earlier study which reported that a significant reduction in N_2O emissions from the soil would be possible by reducing N fertilizer application in the order of 50% without critically altering grain yield or quality [5]. Similarly difference in yield in the treatments T_3, T_9 and T_8 are not significant but differences in seasonal N_2O emission were observed which might be due to differences in fertilizer doses and combinations.

Table 1. *Correlation of soil parameters with nitrous oxide emission*

Varieties/Parameters	Correlation coefficient								
	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**T_8**	**T_9**
Phorma									
Soil organic carbon (%)	0.643* P = 0.033	0.622* P= 0.041	0.686* P= 0.020	0.665* P = 0.026	0.669* P = 0.025	0.754** P = 0.007	0.659* P= 0.027	0.747** P = 0.008	0.762** P = 0.006
Soil NO_3^- - N (kg/ha)	0.754** P = 0.007	0.603* P= 0.050	0.723* P= 0.012	0.783** P = 0.004	0.787** P = 0.004	0.855** P = 0.001	0.725* P= 0.012	0.831** P = 0.002	0.706* P = 0.015
Luit									
Soil organic carbon (%)	0.618* P = 0.043	0.625* P= 0.040	0.631* P= 0.037	0.648* P = 0.031	0.680* P = 0.021	0.625* P = 0.040	0.637* P= 0.035	0.669* P = 0.024	0.651* P = 0.030
Soil NO_3^- - N (kg/ha)	0.709* P = 0.015	0.644* P= 0.032	0.607* P= 0.047	0.665* P = 0.026	0.650* P = 0.030	0.675* P = 0.023	0.645* P= 0.032	0.641* P = 0.034	0.641* P = 0.034

* Correlation is significant at the 0.05 level of significance
** Correlation is significant at the 0.01 level of significance

Table 2. *Yield and yield attributing parameters of rice varieties and seasonal integrated nitrous oxide emission flux (E_{sif})*

Rice varieties/ Parameters	Panicle/square meter	Panicle length (cm)	Sterility (%)	Thousand grainweight (g)	Yield (q/ha)	Esif(mg N2O-N/m2)
Phorma						
T 1	253.00ab	22.70a	8.12dab	19.80a	26.10ab	175.56 h
T 2	251.67ab	22.97a	11.57a	19.15c	25.29 e	169.34 i
T 3	252.00ab	22.93a	10.85ab	19.84a	25.77abcd	179.81g
T 4	253.33ab	22.37a	9.76c	19.95a	26.07ab	190.28 f
T 5	250.00b	22.43a	11.39ab	19.26c	25.50 de	192.86 e
T 6	252.67ab	22.47a	10.65ab	19.80a	25.97abc	196.84 d
T 7	254.33ab	22.13a	8.06d	19.71a	26.17 a	212.29 b
T 8	255.67a	22.63a	11.19ab	19.48b	25.57 cde	205.46 c
T 9	252.33ab	22.63a	11.00ab	19.79a	25.70bcde	224.05 a
Luit						
T 1	236.00ab	21.77a	4.63g	23.92a	29.03 a	118.94 g
T 2	232.00c	20.97a	7.30a	23.12b	28.17 c	117.54 g
T 3	233.67abc	20.80a	5.70e	23.73a	28.83 abc	121.85 f
T 4	235.00abc	20.90a	4.70g	23.74a	28.97 ab	162.79 e
T 5	232.33bc	20.90a	6.80b	23.18b	28.27 bc	161.61 e
T 6	234.33abc	21.43a	5.00f	23.87a	28.93 ab	168.67 d
T 7	236.33a	21.57a	4.54g	23.89a	29.10 a	179.98 b
T 8	232.67abc	21.20a	6.50c	23.64a	28.37 abc	177.74 c
T 9	233.00abc	20.67a	6.27d	23.67a	28.77 abc	182.16 a

In each column, means with the similar letters are not significantly different at $P < 0.05$ level by Duncan's multiple range test

6. Conclusions

Present study showed that fertilizer dose and combination significantly influences temporal and seasonal N_2O emission. N_2O emission estimation under the influence of different level of fertilizer application revealed that T_1 (N, P_2O_5, K_2O @ 40: 20: 20 kg/ha as Urea, SSP, MOP without any organic amendment) with yield potential of 26.10 q/ha (in Phorma) and 29.03 q/ha (in Luit) can be suitably used at North Bank Plain Agroclimatic Zone of Assam for sustaining productivity and as well for lower N_2O emission.

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