Effects of nitrogen fertilizer types and alternate wetting and drying irrigation on rice yield and nitrous oxide emission in rice cultivation

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Article info.	ABSTRACT

Improvements on nitrogen (N) efficiency in rice cultivation have been increasingly concerned with using new types of N fertilizer. The aims of the study were to investigate the effect of N fertilizer types and alternate wetting and drying irrigation on rice yield and N_2O emission in rice cultivation in the Mekong Delta of Vietnam. The design of experiment was split plot with two water management regimes in main plots including (1) alternate wetting and drying (AWD) and (2) farmer practice (FP); and four N fertilizer types in sub-plots as (1) urea, (2) N-(n-butyl) thiophosphoric triamide (nBTPT) urease inhibitor, (3) NPK briquette deep placement technique, and (4) isobutylidene diurea (IBDU) slow N-release. N_2O emission was investigated every three days from 10 to 60 days after sowing. The results showed that AWD treatment had higher rice yields (5.14 t.ha^{-1}) than FP treatment (4.68 t.ha^{-1}), but rice yields of the new fertilizer type treatments were not significantly different compared with those of urea treatment. Concentrations of N_2O increased after broadcasting fertilizer in treatments of urea and urea-nBTPT and decreased thereafter in both FP and AWD irrigations. In treatments of NPK briquette and NPK IBDU, N_2O fluxes remained low throughout crop although the fluxes increased in times of soil drainage under AWD regime. Cumulative N_2O emissions of urea-nBTPT, NPK briquette and NPK IBDU treatments (1.67, 1.47 and 1.29 kgN_2O.ha^{-1}, respectively) were significantly lower than those of urea treatment (2.47 kgN_2O.ha^{-1}). The results suggested that application of urea-nBTPT, NPK briquette and NPK IBDU was effective in mitigating N_2O emission in rice fields which contributes to attenuating the greenhouse effect.

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1 INTRODUCTION

Nitrogen use efficiency in paddy soil is usually low due to NH_3 volatilization on surface soil of broadcasted urea and due to N_2O emission when NO_3^- was leached down and denitrificated. Recently, the attention has been paid to the use of nBTPT with trade name "Agrotain" to increase rice yields by an average of 40% over prilled urea and its effectiveness in retarding urea hydrolysis (Chien *et al.*, 2009). The studies of Cuu Long Delta Rice Research Institute confirmed the benefits of Agrotain

in improving nitrogen use efficiency (NUE) by approximately 32% and the increase in rice yields by 6% in paddy soil in the Mekong Delta, Vietnam (Chu and Le, 2007). Isobutylidene diurea (IBDU) was another type of N fertilizer which improved NUE by slow releasing N to plant during irrigated rice cropping (Trenkel, 2010). IBDU fertilizer can minimize environmental impacts due to reduction of N_2O emission (Ussiri and Lal, 2013). However, IBDU was ineffective in increasing nitrogen use efficiency in rice fields (Carreres *et al*., 2003). The International Fertilizer Development Center (IFDC) has recently developed fertilizer deep placement (FDP) technology as an innovative, proven fertilizer application technology that achieves average yield increases while reduces fertilizer use (IFDC, 2013). A report of United States Agency for International Development (USAID) on deep placement NPK briquettes in Bangladesh showed that NPK briquettes increased rice yields from 4 to 36 % and provided more complete nutrition for crops and contributed to long-term soil fertility compared to urea (AAPI, 2013). Deep placement NPK briquettes in Northern of Vietnam have also increased rice yields up to 20% change to over the conventional method (Codespa Foundation, 2011).

The use of urea-nBTPT, IBDU and other slow N release was also reported to reduce N_2O emission in comparison to urea for upland crops such as barley, corn or pasture grass (Snyder *et al.,* 2009). However, the studies on the effects of new fertilizer types such as NPK briquette, NPK IBDU and urea-nBTPT in N_2O emission from rice field, especially in the Mekong Delta were limited

Optimum use of irrigated water is also another concern today due to the increase of drought as a result of climate change. AWD irrigation was recommended by International Rice Research Institute (IRRI) as an effective technique to minimize this effect. It is reported that the use of AWD technique can save 15-30% amount of water for irrigation without loss in rice yield (Bouman *et al.,* 2007). However, applying of AWD irrigation with urea broadcasting may increase N_2O emission in rice field. Lagomarsino *et al.* (2013) found that N_2O emission in AWD field with traditional urea application was 1/5 higher than that of flooded field. Therefore, the hypothesis of this study was that N_2O emission in AWD field may be reduced with the use of new fertilizer types. The objectives of this study were to assess the effect of new fertilizer types on rice yield in two water management regimes AWD and FP, and to estimate N_2O emission of these treatments.

2 MATERIALS AND METHODS

2.1 The field experiment design

The experiment was conducted in farmer fields at My Loc commune, Tam Binh district, Vinh Long province, Vietnam in Summer-Autumn season 2014. The field located at 10°04'52"N, 106°00'52"E in triple rice cropping region in Vietnam. The experiment soil was classified as Endo-ProtoThionic Gleysols. Soil characteristics (0 - 20 cm) at the study site were shown in Table 1.

The field trial was laid out in two-factors, split-plots experimental design, with four replications. Main plots were water management regimes consisting of alternate wetting and drying irrigation and famer irrigation practice. Subplots were types of N fertilizers including urea, urea-nBTPT, NPK briquette and NPK IBDU. The plot size was 20 m^2 (5 m x 4 m).

Table 1: Soil characteristics (0 - 20 cm) at the study site in the beginning

Soil parameters	Value
Soil particle size distribution, %	
Sand	3.5
Silt	57.9
Clay	38.6
pH $_{(H2O)}$ 1:2.5	4.50
Electrical conductivity, mS.cm^{-1}	0.48
Cation exchange capacity, meq.$100g^{-1}$	9.74
Total organic matter, %	4.83
Total N, %	0.18
Exchangeable NH_4^+, mg.kg^{-1}	8.97
Exchangeable NO_3^-, mg.kg^{-1}	8.82
Total P, %P_2O_5	0.13
Available P (Bray 1), mg.kg^{-1}	4.15
Exchangeable K (unbuffered $BaCl_2$ extraction), meq.$100g^{-1}$	0.19

OM6976 variety rice cultivar with growing duration of 95 - 97 days was used in the study. Row seeding with 120 kg.ha^{-1} was practiced at 20 cm in between rows on 5th April, 2014 and rice crop was harvested on 15th July, 2014.

2.2 Fertilizers and method of fertilizer application

The study used Phu My urea 46 %N, Dau Trau 46A$^+$ (46 %N with 0,2 % agrotain coated), NPK briquettes 28-11-10 produced by briquetting of urea, diammonium phosphate (DAP) and potassium chloride (KCl), and NPK IBDU 12-6-6 by JCAM Agri. Co., Ltd. The average weight of NPK briquettes and NPK IBDU is 2.72 g and 6.20 g per briquette, respectively. Fertilisers rate of 80-40-40 kg N-P_2O_5-K_2O.ha^{-1}, respectively was applied.

Urea or urea-nBTPT, DAP and KCl were applied at 10, 20 and 40 days after sowing (DAS) with the rate of 16-8-20, 32-16-0 and 32-16-20 kg N-P_2O_5-K_2O.ha^{-1}, respectively. NPK briquette and NPK IBDU were deeply placed at the first topdressing (10 DAS). NPK briquettes and NPK IBDU were deeply placed at 7 - 10 cm depth and at 40 cm × 40 cm spacing every alternate row by hand. Total 120 and 108 briquettes of NPK and NPK IBDU respectively were applied in 20 m^2 plot area in order to meet fertiliser N formula of 80 kgN.ha^{-1}.

2.3 Water management and measurement

AWD method was started at 10 DAS until 15 days before harvest stage, with water irrigation to 5 cm depth above soil surface. When water level dropped to -15 cm below the soil surface, irrigation had to be applied to re-flood the field to 5 cm water depth. Surface water of 5 cm depth was kept at 1 week before and after flowering. After flowering, during grain filling and ripening, the water level could drop again to -15 cm below the surface before re-irrigation in favour for harvesting. For fertilizers application, water was applied before each application. For measuring water table depth in the field, the Polyvinyl Chloride (PVC) tube was embedded into the soil in each plot to a depth of 25 cm below soil surface. Each tube had a 40-cm-long and 14-cm-diameter, perforated with 1-cm-diameter holes at 3-cm-intervals around the half side (Bouman *et al.*, 2007).

In farmer irrigation practice, the field was irrigated to water depth of 7 - 10 cm. When this water was dried out (just a few days), then water was again added to 7 - 10 cm water depth. The fields were usually irrigated again before fertilization or when surface water was dried out. This irrigation method was practiced by farmers in the region.

2.4 Grain yields measurement

At physiological maturity, grain yields were assessed by a 2.5 × 2 m sampling frame, grain moisture content was measured with a moisture meter. Grain yields were calculated in t.ha^{-1}, which was adjusted to 14% moisture content.

2.5 Nitrous oxide sampling and measurement

The closed chamber method was used for measurement of N$_2$O flux from paddy fields (Parkin and Ventera, 2010). The sampling chambers were made of PVC with 125-liter-volume having conical frustum shape (radii: R_1 = 27 cm and R_2 = 22 cm and slant height h = 65 cm). Each chamber was equipped with a thermometer and a 9 V battery operated fan on top for air mixing inside. A rubber stopple was inserted into the chamber from one side. The plastic chamber bases, which had the same radius R_1 of the sampling chamber, were installed 3 DAS in the plots and permanently in the field throughout rice crop. The 30-cm height bases were inserted into the soil at 20 cm below soil surface. A 60-mL syringe with 2-directional valve was used to draw air samples every 10-minute interval through the stopper. At each time point, chamber headspace gas samples (10 mL) were collected then immediately injected into 5 mL glass vial that had butyl rubber septa (Parkin and Hatfield, 2014). The air samples were stored in vials for analysis.

N$_2$O fluxes were determined by measuring temporal increase of N$_2$O concentration inside the chamber. Gas samplings were done right after putting chamber on the base. From each chamber, four air samplings were collected at every 10-minute interval (0, 10, 20, and 30 minutes) during 9 - 11 am. N$_2$O samples were collected at 3 consecutive days from 10 to 50 DAS, then at 5 consecutive days for last two samplings in 55 and 60 DAS.

The N$_2$O concentrations were analysed in the laboratory of Cuu Long Delta Rice Research Institute using gas chromatograph (SRI 8610C) equipped with an electron capture detector (310ºC), Hayesep-N column (60ºC) and N$_2$ as the carrier gas.

The N$_2$O fluxes were calculated from the slope (positive) of the linear model fitted to the concentration of N$_2$O against sampling time (Parkin *et al.*, 2012). Daily N$_2$O fluxes were calculated for each treatment based on the increase in concentration from the initial N$_2$O chamber concentration (at T0min) to the final N$_2$O chamber concentration (at T30min).

$$F_{daily} = \frac{\Delta C}{\Delta t} \frac{MW \times 60 \times 24}{R \times (273 + T) \times 10^6} \frac{V}{A}$$

Where,

F_{daily} is emission N$_2$O concentration (mg N$_2$O.m^{-2}.d^{-1}),

$\Delta C/\Delta t$ is the slope of the line for T0 to T30 (ΔC is the change in gas concentration in the chamber headspace during the enclosure period in ppb and Δt is the enclosure period expressed in minutes),

MW is the molecular weight of the respective N$_2$O gas (44 g.mol^{-1}),

60 is conversion factor for time (min.h^{-1}),

24 is calculation for a day (h.d^{-1}),

R is the gas law constant (0.08206 L.atm.mol^{-1}.K^{-1}),

273 is conversion factor from degrees Celsius to Kelvin (K),

T is the temperature inside the chamber ($^{\circ}$C),

$10^6 = 1 \times 10^{-9}$L/Lx 10^3 (g.mg^{-1})

V is the volume of the gas chamber and

A is the area covered by chamber (0.229 m^2).

Cumulative N$_2$O emissions during the study period of 60 days were estimated using linear interpolation of the daily fluxes.

During N$_2$O emission monitoring, the temperature inside the chambers was also measured by using mercury thermometers. Soil redox (Eh) at a 5-cm depth was measured in situ with a redox meter (Hanna HI 9025) and oxidation reduction potential (ORP) electrodes.

2.6 Data analysis

The analysis of variance (ANOVA) was performed with a generalized linear model of split-plot design. Based on normality and variance homogeneity tests for the errors, the normal distribution was used as the probability distribution. The effects of the water regime, nitrogen fertilizer and the interactions from these two factors on rice yield and N$_2$O emission were analysed as fixed effects. All pairwise comparisons of treatment means from either significant interactions or simple effects were performed with the Tukey test by Minitab v.16 software.

3 RESULTS AND DISCUSSION

3.1 Effect of nitrogen fertilizer types and water management on grain yield

3.1.1 The water level in AWD water management field

Water levels in AWD treatments ranged from -15.6 cm to 5.5 cm. During the experiment, there were only four times at 20, 35, 62, 83 DAS that water level dropped down to 10 - 15 cm below the soil surface. In other cases, the water level dropped only to about 5 cm below the soil surface due to raining (at 50 DAS).

Water management regime greatly affects N$_2$O emissions due to its effect on nitrification and denitrification processes. During the dried soil period, higher NO$_3^-$ concentration was accumulated due to nitrification, and after that it is reduced by denitrification process when the soil is re-flooded. Therefore, AWD in rice fields may trigger substantial amount of N$_2$O emissions in contrast with FP by increasing the amount of available N for microbial transformation (Ussiri and Lal, 2013).
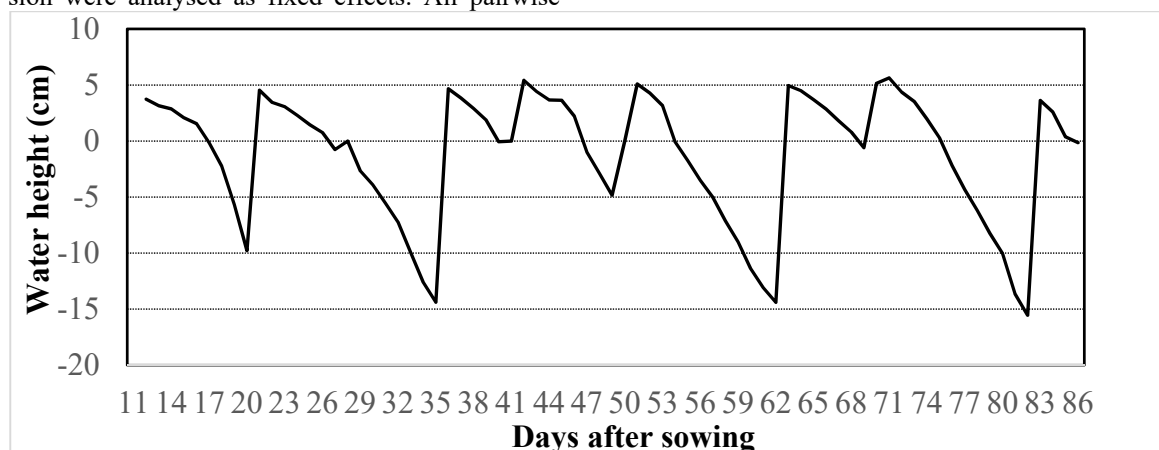

Fig. 1: Seasonal variation of water level in paddy fields under alternate wetting and drying regime

3.1.2 Effects of nitrogen fertilizer types on grain yield

The results showed that grain yields of N fertilizer type treatments were not significantly different (Table 2). According to Christianson *et al*. (1990) and Freney *et al*. (1995), nBTPT becomes active to retard urea hydrolysis in the soil when it is converted to oxygen-analog form [nBPT(O)], and this conversion may be impaired under flooded conditions. Therefore, nBTPT may not be strongly effective in these experiments because urea-nBTPT was broadcasted in flooded condition. NH$_3$ loss in urea-nBTPT, NPK briquette and NPK IBDU treatments were found insignificantly different as compared with urea applied treatment (Vo Thanh Phong *et al*., 2015). In addition, the field water pH in floodwater were low, hence it conduced to the reduction of N loss by NH$_3$ volatilization even in urea treatment. This resulted in the insignificant increase in grain yields of urea-nBTPT, NPK briquette and NPK IBDU treatment in comparison to urea treatment.

The low NH_3 gas losses might also be due to the acidity of the studied soil (pH = 4.5) and the easy running out of water in the field, so it was not suitable for the growth of algae which reduced switching of ammonium-N to NH_3 (Ferguson *et al.*, 1984). Carreres *et al.* (2003) also reported that IBDU fertilizers was the best nitrogen source for improving recovery efficiency and grain yields, but the significant difference was not found between IBDU and urea.

Table 2: Grain yields in different fertilizers and water regimes

Treatment		Mean yield (t.ha^{-1})
Nitrogen fertilizers (A)	Urea	4.88
	Urea-nBTPT	5.00
	NPK briquette	4.84
	NPK IBDU	4.92
Water regimes (B)	Farmer practice	4.68 [b]
	Alternate wetting and drying	5.14 [a]
F(A)		*ns*
F(B)		*
F(A X B)		*ns*
CV (%)		*7.0*

Means that do not have the same letter are significantly different at P < 0.05 level by Tukey's test.
IBDU: Isobutylidene diurea; nBTPT: N-(n-butyl) thiophosphoric triamideEffects of water management on grain yields

AWD irrigation regime showed a significantly higher grain yields than FP irrigation (Table 2). Implementation AWD irrigation could increase grain yields thanks to accelerating nitrogen mineralization to available N for rice uptake, improve the oxygen content in the soil for root growth, root respiration, nutrient absorption, and reduce the accumulation of the soil toxics such as Fe^{2+}, Mn^{2+} or H_2S. Appling AWD irrigation also increased the root penetrating with depth, so it helped plants cope with water shortages and reduce the incidence of lodging. According to Belder *et al.* (2004) and Liu *et al.* (2013), grain yields were significantly higher under the AWD than those under FP.

3.2 Effects of nitrogen fertilizer types and water regimes on nitrous oxide emission

3.2.1 Soil redox potential

The emission of N_2O from paddy fields is affected greatly by the oxidation-reduction condition of the soil, which depends on irrigation and drainage practices. The N_2O emission is reported at soil redox levels below +200 mV to -100 mV during denitrification reactions (Masscheleyn *et al.,* 1993).

Soil Eh values in the AWD treatments were found higher than those in the FP treatments for the most part of rice growing period (Figure 2). Soil Eh values during rice growing season ranged from -121.0 to +275.5 mV (in AWD) and -114.1 to +213.5 mV (in FP).

In AWD treatments, soil Eh values increased rapidly with time during drying periods and decreased immediately following reflooding. Eh in AWD field was higher than that of FP field at 20, 35 and 60DAS (+42.0 mV, 79.8 mV, and +275.5 mV, respectively, which is corresponding to the lowest water level in AWD field.

In FP treatments, soil Eh values decreased gradually due to continuously saturation condition in soil, except for the sharp increase to +213.5 and 275.5 mV for the last sampling (60 DAS) in both AWD and FP field due to insufficient irrigation water.
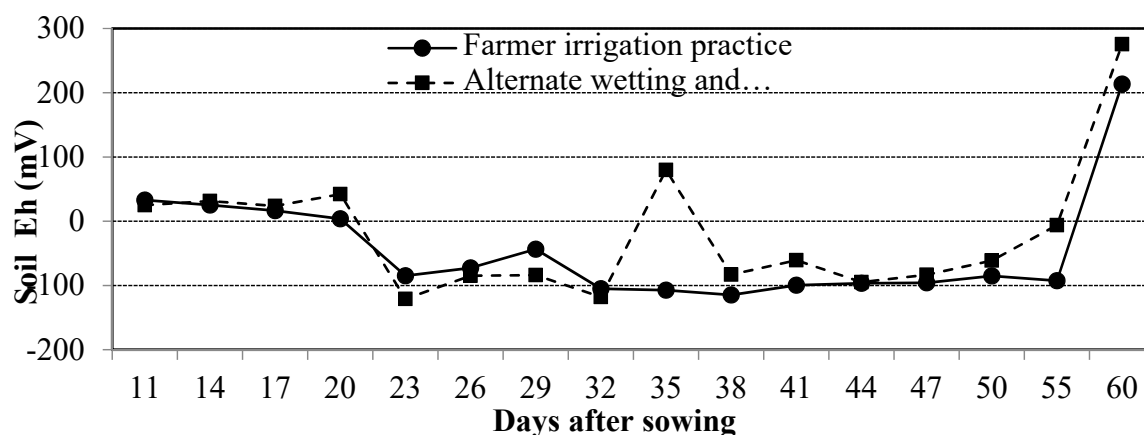

Fig. 2: Seasonal variation of soil Eh at -5cm depth in the fields under two water regimes

3.2.2 The effects of nitrogen fertilizer types on N₂O flux under farmer irrigation practice

Nitrous oxide fluxes of different nitrogen fertilizers types in FP regime were shown in Figure 3. Generally, N₂O fluxes of urea treatments were higher than those of urea-nBTPT treatments for few days after N application, especially days after the third N application. N₂O fluxes in urea treatment were shown significantly high at 7 days after fertilization (DAF) of the first application, 6 DAF of the second

application and 1 DAF of the third application, respectively (equivalent to 17, 26 and 41 DAS). The concentration of NH_4^+ in flood water and in soil surface at 0-3 mm depth in urea treatments was observed higher than urea-nBTPT treatments following each fertilizer application (Vo *et al*., 2015). The high NH_4^+ concentration in urea treatment enhanced the rates of both heterotrophic and autotrophic nitrification processes and therefore increased N₂O flux (Dalal and Allen, 2008).
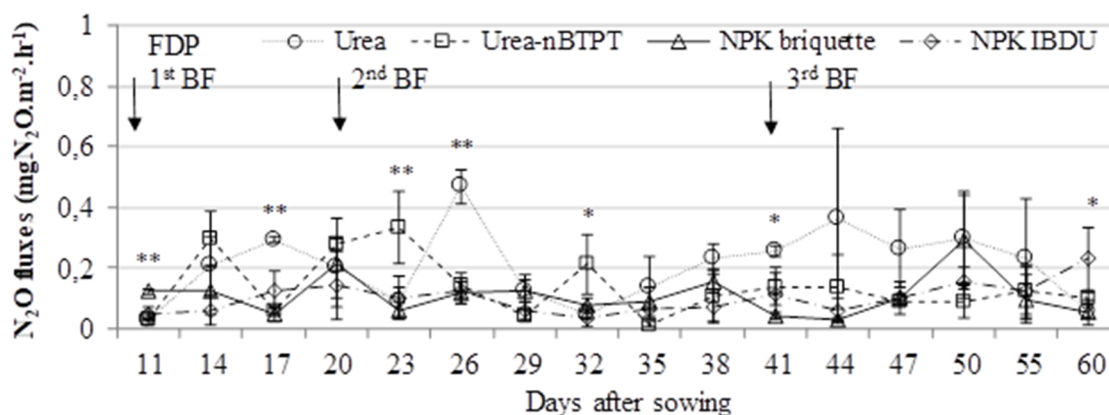

Fig. 3: Nitrous oxide fluxes in different N fertilizer type treatments in the fields under farmer irrigation practice

Data was shown in mean ± SE. Standard errors are denoted by vertical bars.

Significant at P<0.01 (**) or P < 0.05 (*). BF: Broadcasting fertilizer, FDP: Fertilizer deep placement. IBDU: Isobutylidene diurea, nBTPT: N-(n-butyl) thiophosphoric triamide.

Vertical arrows denote time of fertilizer applications.

In contrast, the increase in N₂O fluxes in urea-nBTPT treatments was 23, 32 DAS, so it was later than urea treatment. This may be due to the delay of urea hydrolysis and denitrification process.

N₂O fluxes of NPK briquette and NPK IBDU treatments were remained low during rice season, ranging from 0.03 to 0.29 mgN₂O.h⁻¹.m⁻² and from 0.03 to 0.23 mgN₂O.h⁻¹.m⁻², respectively. Deep placement of these fertilizers in continuously saturated soil decreased N₂O fluxes because the oxidation of NH_4^+ to NO_3^- was limited. N₂O fluxes of NPK briquette were significantly high at 11 DAS (or 1 DAF). The reason was that NPK briquette fertilizers were applied only once with large amount of N and just at 1 DAF, so N content in soil is high, leading to increase of N₂O emission. Moreover, NPK briquettes are produced by me-

chanical briquetting, so they are solubilized more easily than NPK IBDU.

In general, the N₂O fluxes of urea and urea-nBTPT were high because broadcasting fertilizer having high concentration of NH_4^+ in flood water and surface soil. For deep placement NPK briquette or NPK IBDU, N₂O fluxes were low and changed little during rice growth stage due to the activity of urease inhibitor in urea-nBTPT and the deep placement method in NPK briquette and NPK IBDU treatments.

3.2.3 The effects of nitrogen fertilizer types on N₂O flux under AWD regime

The result of N₂O fluxes in different nitrogen fertilizer treatments under AWD regime was shown in Figure 4. N₂O fluxes of broadcasting urea and urea-nBTPT treatments tended to be higher at few days following N applications than those of deep placement NPK briquette and NPK IBDU treatments.

For urea treatments, N₂O fluxes ranged from 0.06 to 0.68 mgN₂O.h⁻¹.m⁻² with two peaks. The first peak of N₂O flux at 38 DAS could be associated with mid-season aeration and re-flooded stages which stimulated N₂O emission (Xing *et al*., 2009; Peng *et al*., 2011). The second peak of N₂O flux

occurred at 44 DAS (4 DAF of the third N application). This peak could be related to the increase in NH_4^+ and NO_3^- after N application and subsequent denitrification to N_2O (Gaihre *et al.*, 2015).

The N_2O flux concentrations of urea-nBTPT treatments were low (0.03 to 0.40 $mgN_2O.h^{-1}.m^{-2}$). Nevertheless, after broadcasting fertilizer or mid-season drainage and following re-waterlogging, these fluxes increased slightly.

In NPK briquette treatments, N_2O fluxes were lowest from 0.01 to 0.26 $mgN_2O.h^{-1}.m^{-2}$. The high fluxes by NPK briquette application were shown at 32, 55 and 60 DAS corresponding to drainage time. N_2O fluxes of NPK IBDU varied from 0.01 to 0.24 $mgN_2O.h^{-1}.m^{-2}$, reached the highest at 17 DAS (7 days after deep fertilizer placement) but were lower in other stages. Generally, the N_2O fluxes of NPK briquette or NPK IBDU treatments were lower than those of urea treatments under AWD regime.
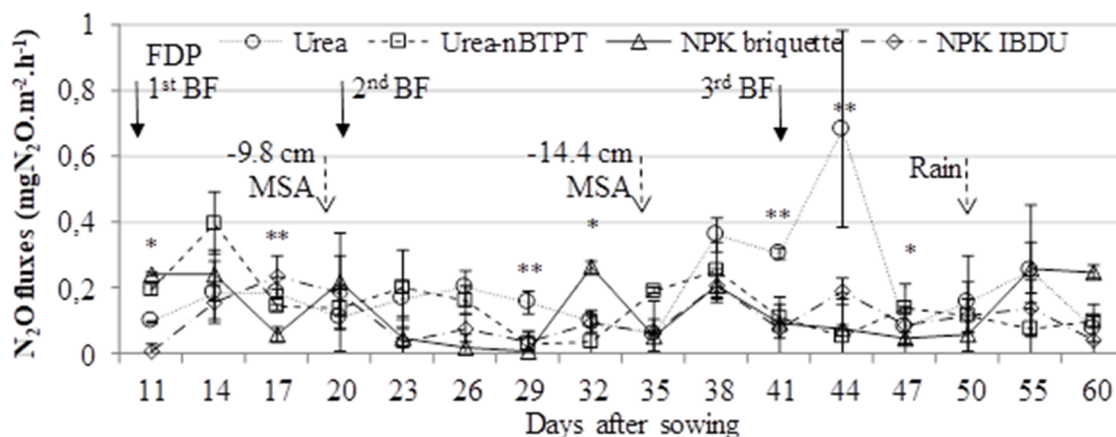

Fig. 4: Nitrous oxide fluxes of different N fertilizer type treatments in the field under alternate wetting and drying regime

Data was shown in mean ± SE. Standard errors are denoted by vertical bars.

Significant at P<0.01 (**) or P < 0.05 (*). BF: Broadcasting fertilizer, FDP: Fertilizer deep placement. MSA: Mid-season aeration. IBDU: Isobutylidene diurea, nBTPT: N-(n-butyl) thiophosphoric triamide. Solid vertical arrows denote time of fertilizer applications and dashed vertical arrows indicate the midseason drainage phase.

In general, the N_2O fluxes of urea and urea-nBTPT increased after fertilizer applications or mid-season aeration and then re-flooded. However, the N_2O concentrations of urea-nBTPT treatments were lower than those of urea treatments during rice crop. N_2O fluxes of NPK briquette and NPK IBDU were lowest, except for the slight increases due to soil drainage in AWD regime.

3.2.4 Cumulative N_2O emission during rice season

The cumulative N_2O emissions in 50 days from 10 - 60 DAS affected by nitrogen fertilizer types and water management regimes were shown in Table 3.

Table 3: Cumulative nitrous oxide emissions from rice field as affected by nitrogen fertilizer types and water management regimes

Treatment		N_2O emission (+) ($kgN_2O.ha^{-1}$)
Nitrogen fertilizers (A)	Urea	2.47 [a]
	Urea-nBTPT	1.67 [b]
	NPK briquette	1.47 [b]
	NPK IBDU	1.29 [b]
Water regimes (B)	Farm irrigation practice	1.69
	Alternate wetting and drying	1.77
F (A)		**
F (B)		*ns*
F (A X B)		*ns*

(+): The cumulative N_2O emissions were calculated in 50 days from 10 to 60 DAS

(**): Means that have the same letter are significantly different at P < 0.01 by Tukey's test.
IBDU: Isobutylidene diurea; nBTPT: N-(n-butyl) thiophosphoric triamide

The highest cumulative N_2O emissions were found in the urea treatments (2.47 kg.ha^{-1}). Meanwhile, application of urea-nBTPT, NPK briquette and NPK IBDU reduced significantly cumulative N_2O emissions (1.67, 1.47 and 1.29 kg.ha^{-1}, respectively).

Cumulative N_2O emissions of AWD irrigation were not significantly higher than those of FP irrigation (Table 3). Alternating wet and dry in paddy soil was reported to stimulate N_2O emission as compared to continuous flooding (Xing *et al*., 2009). However, in this study, during FP irrigation, rice field was not always flooded, but it was dried out to saturated condition before the next irrigation. Therefore, N_2O emission in AWD was as similar as that in FP irrigation, which should be recommended for rice cultivation in the Mekong Delta of Vietnam.

4 CONCLUSIONS

The application of urea-nBTPT, NPK briquette or NPK IBDU did not significantly increase rice yields but reduced N_2O emission in comparison to traditional urea application. New N types could be highlighted as a critical issue in mitigating greenhouse gas emission in rice cultivation in the Mekong Delta of Vietnam. The N_2O fluxes pattern of urea and urea-nBTPT treatments increased after fertilization under FP irrigation, whereas N_2O fluxes of NPK briquette and NPK IBDU were maintained low during rice season. However, the fluxes increased at soil drainage under AWD water management.

Alternate wetting and drying water management technique is proved to increase rice yields, which should be applied in rice cultivation. Moreover, N_2O flux concentration of AWD technique is as similar as that of farmer irrigation practice, hence this technique can also be accepted in terms of increases in grain yield.

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