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EFFECTS OF DIFFERENT NITROGEN FERTILIZERS ON N_2O EMISSION, NH_3 VOLATILIZATION AND RICE YIELD IN RICE CULTIVATION IN THE MEKONG DELTA

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LIST OF PUBLICATIONS OF AUTHOR RELATED TO THE STUDY

1. Vo Thanh Phong, Nguyen Thi Ca and Nguyen My Hoa (2014). Effects of urea-nBTPT (nbutyl thiophosphoric triamide) and NPK briquette on N distribution in soil and rice yield in Cau Ke District - Tra Vinh Province. Can Tho University Journal of Science. Vol. Agriculture 2014(3)117-123. (in Vietnamese).

2. Vo Thanh Phong, Tran Thanh Phong, Nguyen Minh Dong and Nguyen My Hoa (2015). Effects of different nitrogen fertilizers on ammonium distribution in soil and ammonia volatilization in rice cultivation in Tam Binh district - Vinh Long province. Can Tho University Journal of Science. Vol. 40 (2015) 128-135. (in Vietnamese).

3. Vo Thanh Phong, Nguyen Xuan Du, Nguyen Thi Kim Phuong and Nguyen My Hoa (2015). Effects of nitrogen fertilizers on nitrous oxide emission in rice soil in Tam Binh district - Vinh Long province. Journal of Natural Resources and Environment. Vol. 15 (211) 31-34. (in Vietnamese).

CHAPTER 1: INTRODUCTION

1.1 Research rationale

The reduction of greenhouse gas (GHG) emissions, especially N_2O gas, is very important in mitigating the impact of the climate change. According to the Intergovernmental Panel on Climate Change (IPCC) and the World Meteorological Organization (WMO), emissions of N_2O into the atmosphere range from 8.5 to 27.7 million tons per year. These N_2O emissions continue to increase by 0.25% per year (Denman *et al*., 2007; WMO, 2011). It is reported that agricultural activities generate the largest amount of N_2O emissions (1.7 - 4.8 million tons N_2O per year). Among them, nitrogen fertilizers have significantly caused direct N_2O emissions with 1.7 million tons N_2O per year (Ussiri & Lal, 2013). Application of urea on rice also emitted 1.38 $kgN_2O.ha^{-1}$ per season (Ussiri & Lal, 2013).

Consequently, many studies on improving nitrogen fertilizer have been done to slow down urea hydrolysis, N release rate, and reduce nitrification. These will lead to reduce N_2O emission and NH_3 volatilization, and increase nitrogen use efficiency and crop yields. Acording to Majumdar (2013), deep placement of urea (prill urea or urea super granular - USG) reduces N_2O emission. In addition, application N slow-release fertilizer such as neem coated urea (NCU), sulfur coated urea (SCU) or nitrification inhibitor including Dicyadiamide, encapsulated calcium carbide (ECC), Hydroquinone, Thiosulfate (except Nitrapyrin) contributes to reduce N_2O emission.

However, there have not been many studies which carried out on N_2O emission by application of uera-nBTPT [N-(n-butyl) thiophosphoric triamide], NPK briquette, and IBDU (Isobutidene diurea) in rice cultivation. Similarly, in the Mekong Delta, studies on N_2O emission realating to new nitrogen fertilizer types such as urea-NBTPT, NPK briquette, and IBDU in condition of alternate wetting and drying (AWD) irrigation in rice cultivation have not been conducted.

Besides, most of studies on ammonia volatilization were concentrated in urea and USG, but there was not much research on NPK briquette (Hayashi, 2013). In Vietnam, Watanabe *et al*. (2009) studied NH_3 volatilization from urea fertilizer application in Bac Giang, Ha Noi and Can Tho provinces. In the Mekong Delta, Ngo Ngoc Hung (2009) and Dong *et al*. (2012) had been studied about NH_3 volatilization from urea under water saving irrigation conditions. Effect of urea-NBTPT, NPK briquette, and NPK IBDU on ammonia volatilization have not been investigated in rice cultivation in the Mekong Delta.

Application urea-NBTPT, NPK briquette and NPK IBDU contributed to increase in nitrogen use efficiency (NUE), however the effect on rice yield depended on soil types and cultivar conditions (Carreres *et al*., 2003; Chien *et al*., 2009; IFDC, 2013). The experiments of Nguyen Thi Lan & Do Thi Huong (2009) in the North of Vietnam showed that deep placement of NPK briquette had increased NUE and reduced the amount of N fertilizer, but rice yield had not been discussed. In the Mekong Delta, the experiments of Chu Van Hach & Le Van Banh (2007) showed that application urea-NBTPT fertilizer gave increases in NUE but rice yield did not increase considerable compared to urea fertilizer. Deep placement of NPK briquette has not been applied in the Mekong Delta yet. Althought NPK briquettes were only deep placement once thoughout each cropping season, rice plant might uptake nutrients. Therefore, is necessary to investigate nitrogen in the soil due to this application. Beside rice yields, studies on the distribution of nitrogen (NH_4^+ and NO_3^-) in soil and in floodwater following urea-nBTPT and NPK briquette application have not been studied in the Mekong Delta.

In summary, it is necessary to carry out the study on effects of application of new nitrogen fertilizer types such as urea-nBTPT, NPK briquette and NPK IBDU fertilizers on N_2O emission and rice yield in AWD irigation regime in order to cope with water scarcity and reduce greenhouse gas emissions from rice cultivation in the Mekong Delta. The impacts of nitrogen fertilizer types on ammonia volatilization after fertilizer application were also studied to evaluate the efectiveness of diferrent N fertilizer type in reducing nitrogen loss and minimize the negative environmental impact. Effects of application urea fertilizer amended nBPTP and NPK briquette deep placement on rice yield and nitrogen use efficiency were also investigated in rice cultivation in the Mekong Delta. The thesis results could provide specific scientific basis about effects of new nitrogen fertilizers on N_2O emission, NH_3 volatilization, and rice yield.

1.2 General objective of research

The objective of the research was to evaluate the effects of different nitrogen fertilizers on nitrous oxide emission, ammonia volatilization, and rice yield in rice cultivation in the Mekong Delta.

1.3 Subjects and scope of research

The research was done on the potential acid sulphate soil (Endo ProtoThionic Gleysols) in Tam Binh - Vinh Long and the Mekong river alluvial soil (Dystric - Rhodic Gleysols) in Cau Ke district - Tra Vinh province under the alluvial soils. In the Mekong Delta, the Gleysols soil group occupies 1.9 million ha (48% of the total area of the delta). The soil group is used by farmers for rice cultivation with three rice crop per year.

All new fertilizers including urea-nBTPT, NPK briquette and NPK IBDU were used in the experiments on N_2O emission and NH_3 volatilization. In the researches on concentration of nitrogen in soil and floodwater, and the research on rice yield and NUE, only three N fertilizer types were used including: urea, urea-nBTPT and NPK briquette because IBDU fertilizer had not been provided in time for using in those experiments.

OM 6976 which is a hybrid rice variety with high Fe content in milled rice (6 - 8 mgFe.kg^{-1}) was used in the experiments. In recent years, this variety has been widely cultivated by local famers.

The sampling gases were collected directly in field conditions by closed chamber method for N_2O emissions and dynamic chamber method for NH_3 volatilization.

Two NUE indices were used in this study including agronomic efficiency of applied N (AE_N) and recovery efficiency of applied N (RE_N). The data of RE_N are only implemented in the summer-autumn rice crop due to the limited budget so it was also a limitation of the research.

The on-farm experiments were conducted on farmers' rice fields. The randomized complete block design for single factor experiments or the split plot design for two-factor experiments were randomized and layout with 3 or 4 replications.

Nitrogen transformations processes such as nitrification, denitrification, had not been studied in the dissertation.

1.4 New findings of the research

The study showed that application of new nitrogen fertilizer types such as urea-nBTPT, NPK briquette and NPK IBDU decreased significantly N_2O emission compared to urea. These are important implications for farmers in applying new nitrogen fertilizers that aim to effectively reduce greenhouse gas emissions from rice cultivation in the Mekong Delta, contribute to the effort in reducing the impact of climate change.

The result also showed that alternate wetting and drying irrigation increased rice yield and nitrogen recovery efficiency compared to farmers' irrigation practice, and reduced N_2O emissions when new fertilizer types were applied. This is new and significant findings in recommending farmers in the Mekong Delta to apply AWD technique in rice cultivation for increasing rice yield and saving irrigation water to cope with water scarcity in the area.

Furthermore, the study result indicated that in potential acid sulfate soil with soil pH = 4.5, the application of N fertilizer in the presence of water and floodwater pH $\leq$ 7, therefore the ammonia volatilization of urea treatment was rather low. The research also found out that high ammonium concentration in floodwater after broadcasting urea and urea-nBTPT enhanced NH_3 volatilization flux compared to NPK NPK briquette and NPK IBDU treatments. This could lead to N loss by N leaching and NH_3 volatilization. High NH_4^+ concentration in 10 cm soil depth in NPK briquette deep placement treatments was found. Therefore, rice plants could uptake nitrogen effectively throughout the season, although NPK briquettes were deep placed once at 10 days after sowing.

Last but not least, rice yields were high at the rate of 80 kgN.ha^{-1} equivalent to this of 100 kgN.ha^{-1} in Winter-Spring and Summer-Autumn season on potential acid sulfate soil and alluvial soil in the Mekong Delta. Therefore the rate of 80 kgN.ha^{-1} was recommended to reduce both fertilizer costs and environmental impact.

Application of urea-nBTPT or NPK briquette increased efficiency of N uptake in rice plants compared to urea application, but rice yield in these treatment was similar to urea application treatment. Rice yield in NPK briquette and NPK IBDU treatments was maintained although they were applied only one time at the beginning of the crop. Fertilizer deep placement can be an effective method if mechanization was applied in applying of fertilizer.

In conclusion, although the rice yield did not increase considerably, new nitrogen fertilizers contributed effectively to reduce N_2O emission and increase straw and grain N uptake so it should be recommended to farmers in the Mekong Delta.

CHAPTER 2: METHODOLOGY

2.1 Research 1: Investigating the dissolve and hydrolysis of nitrogen fertilizer types

Determination of the solution and hydrolysis of the nitrogen fertilizer types was carried out in the laboratory conditions to evaluate nitrogen release from diferent nitrogen fertilizers over time in accordance with the document of Keerthisinghe & Freney (1994) and Carson & Ozores-Hampton (2012).

2.2 Research 2: Investigating the concentration of nitrogen in soil and in floodwater following nitrogen fertilizer application

Microplots of this experiment were performed on the field trial of the research 4. The experiment was designed in randomized complete blocks including 3 treatments with 3 repetitions. Microplots (empty rice) 1 m^2 area were settled on the same rate and type of nitrogen fertilizers in the field trial. Observation indicates such as:

- pH, $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ dissolved in floodwater over following 1, 2, 3, 5 DAF of fertilizer application 10, 20, 40 DAS.

- Contentration of $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ in soil (depth: topsoil 0-3 mm, 5 cm, 10 cm, 20 cm and width: 5 cm , 10 cm) at time 1, 2, 3, 5 DAF of fertilizer application 10, 20, 40 DAS.

2.3 Research 3: Research on nitrous oxide emission and ammonia volatilization in rice cultivation

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

2.3.1.1 Experiment design

The research investigated effects of nitrogen fertilizer types (urea, urea-nBTPT, NPK briquette and NPK IBDU) and alternate wetting and drying (AWD) irrigation on nitrous oxide emission and rice yield in rice cultivation. An experiment was conducted on potential acid sulphate soil (Endo ProtoThionic Gleysols) in the area of triple rice cropping in Loc Tuong commune - Tam Binh district - Vinh Long province. An on-farm experiment of the research was done in Summer-Autumn season 2014.

2.3.1.2 Method of irrigation water management

The experiment was conducted under water managements including farmer's practice (FP) irrigation and alternate wetting and drying (AWD) irrigation. According to IRRI (2009), when applying AWD, the ponded water has dropped to -15 cm.

2.3.1.3 Nitrous oxide sampling and measurement

The closed chamber method was used to measure nitrous oxide flux from paddy fields into the atmosphere (Parkin and Ventera, 2010). N_2O gas samples emitted from soil surface and throught rice plant were collected.

In order to determine N_2O gas concentration in these samples, SRI 8610C gas chromatograph column electron capture detector (ECD) Hayesep-N (available in the Cuu Long Delta Rice Research Institute) was used.

Nitrous oxide emissions were measured basing on N_2O gas concentration increases continuously (0, 10, 20, 30 minutes) by the formula of Parkin *et al.* (2012). Cumulative N_2O emissions during the study period of 50 days (from 10 to 60 DAF) were estimated by using linear interpolation of the daily fluxes.

2.3.2 Impacts of nitrogen fertilizer types on ammonia volatilization after fertilizer application

The experiment was carried out to investigate impacts of 4 nitrogen fertilizer types on ammonia volatilization - the largest global emission into the atmosphere among reactive nitrogen in the rice fields. NH_3 volatilization samples were collected in the rice field under FP irrigation in the same site with the research N_2O emission.

Ammonia volatilization from the surface of paddy field during rice cultivation was measured by using the dynamic chamber method suggested by Hayashi *et al.* (2006). Ammonium concentration extracted from NH_3 volatilization samples following N application (1, 3, 5 and 7 DAF) was used to calculate the NH_3 volatilization flux and cumulative NH_3 volatilization.

2.4 Research 4: Effects of different nitrogen fertilizers on rice yield and nitrogen use efficiency

The research focused on rice yield and nitrogen use efficiency with 3 N fertilizer types (urea, urea-nBTPT, NPK briquette) with 3 N fertilizer rates (60, 80, 100 $kgN.ha^{-1}$). The experiments were performed on 2 locations in triple rice cropping cultivation areas:

1) Chau Dien commune - Cau Ke district - Tra Vinh province on alluvial soil of the Mekong River Delta (Dystric - Rhodic Gleysols) in Winter-Spring season 2012/2013 and in Summer-Autumn season 2013.

2) My Loc commune - Tam Binh district - Vinh Long province on potential acid sulphate soil (Endo- ProtoThionic Gleysols) in Winter-Spring season 2013/2014.

CHAPTER 3: RESULTS AND DISCUSSION

3.1 Research 1: Investigating the dissolve and hydrolysis of nitrogen fertilizer types

All of urea concentration in urea fertilizer and urea-nBTPT fertilizer immediately dissolved in water after an hour meanwhile NPK briquette fertilizer went into solution after a day. However, NPK IBDU fertilizer only dissolved 26.2% amount of total urea during 3-month incubation. Hydrolysed urea in fertilizers: urea, urea-nBTPT and NPK briquette was formed ammonium 8 days after incubation. The rate of urea hydrolysis from urea-nBTPT fertilizer (39.6%) was lower than that from urea fertilizer (49.3%) in 1st day after incubation. It is clear that the effective urease inhibitor in urea-nBTPT fertilizer was retarded slightly by the addition of nBPTP. Otherwise, the hydrolysis of IBDU fertilizer was very low (17.3%) following 2-month incubation due to 90% of the N in water-insoluble form. The fast rate of urea solution and hydrolysis was formed the high amount of ammoniacal-N present to potential N loss. NPK briquettes were deeply placed so NH_4^+-N remains in the soil by absorption.

Most of the N (90%) in NPK IBDU fertilizer is water-insoluble form so the hydrolysis ratio of IBDU is very slow. After 2 months of incubation, amount of N in IBDU fertilizer was hydrolysed only 17.3%. Acording to findings of the field studies IBDU fertilizer is considered as N sources application for rice.

3.2 Research 2: Investigating the concentration of nitrogen in soil and in floodwater following nitrogen fertilizer application

3.2.1 The concentration of nitrogen in rice floodwater following broadcasting nitrogen fertilizer application

Experimental results showed that concentration of NH_4^+ for urea treatment within 1-3 DAF was high (13.44 - 21.32 mg.l^{-1}). Similarly, NH_4^+ concentration of urea-nBTPT treatment presented in floodwater within 1-3 DAF was also high (12.13 - 12.64 $mg.l^{-1}$). The high NH_4^+ concentration of urea and urea-NBPT treatments occurred within 1-3 DAF and then showed decline on 5 DAF. Meanwhile, NH_4^+ concentration in floodwater in the case of NPK briquette treatments was low (3.23 - 8.24 $mg.l^{-1}$) and remained during the stage of the survey.

In general, NH_4^+ concentration at the depth of 5 cm and 10 cm was high following broadcasting application urea or urea-nBTPT. This can be explained by the rapid dissolution and hydrolysis of both urea and urea-nBTPT fertilizers on the rice field. In the lab experiments, urea and urea-nBTPT hydrolysed 83.2% and 81.5% NH_4^+-N after 3 days of incubation. For NPK briquette treatment, NH_4^+ concentration in floodwater occurred in low level due to deep placement of NPK briquettes at the depth of 7 - 10 cm that may increase adsorption of NH_4^+ by soil.

Moreover, high NH_4^+ concentration in floodwater of urea and urea-nBTPT treatments occrured following fertilizer application. This may increase N loss through NH_3 volatilization, leaching, runoff. In contrast, deep placement of NPK briquettes may lead to nitrogen accumulation in the soil and minimize the N loss through evaporation or runoff.

The result of the experiment in Chau Dien commune - Cau Ke district - Tra Vinh province in Winter-Spring season 2012/2013 also showed that nitrate concentration in floodwater was very low (<0.25 $mg.l^{-1}$) in all types of nitrogen fertilizer: urea, urea-nBTPT and NPK briquette. This may be due to the activities of microorganisms that promote nitrification and that is usually lower in submerged soil.

3.2.2 The concentration of nitrogen in rice soil following broadcasting nitrogen fertilizer application

The result of the experiment in My Loc commune - Tam Binh district - Vinh Long province in Winter-Spring season 2013/2014 also showed that NH_4^+-N concentration in topsoil (0-3 mm from surface) tended to be higher in broadcast application prill urea treatment (32.94 $mg.kg^{-1}$) and urea-nBTPT treatment (28.10 $mg.kg^{-1}$) NPK briquette (9.66 $mg.kg^{-1}$). At the depth of 5 cm and 10 cm, NH_4^+ concentration of NPK briquette treatments (were high 12.72 and 14.95 $mg.kg^{-1}$, respectively) but those of urea or urea-nBTPT treatments were low (4.79 and 2.13 $mg.kg^{-1}$, respectively or 5.48 and 2.86 $mg.kg^{-1}$, respectively) .

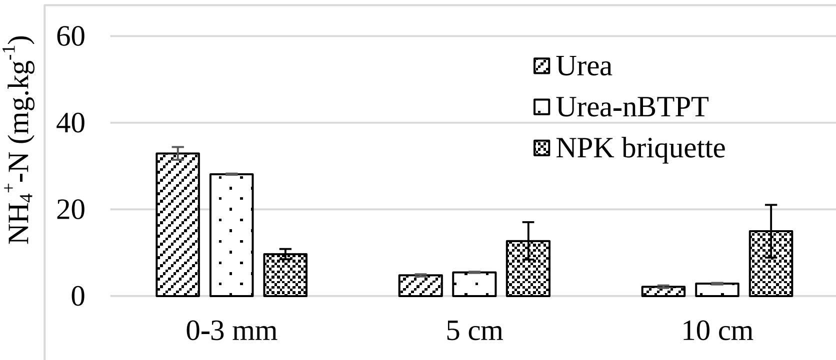

Figure 3.1: Ammonium concentration in soil depth folowing fertilizer application in My Loc commune - Tam Binh district - Vinh Long in Winter-Spring season 2013/2014

Note: Data was shown in mean ± SE. Standard errors are denoted by vertical bars. (**): Means that have the same letter are significantly different at $P < 0.01$ by Tukey's test. ns: not significant. nBTPT: N-(n-butyl) thiophosphoric triamide.

In summary, deep placement fertilizer could directly provide nutrients to the root zone, so plant easily absorbed them. Besides, this method reduces nitrogen move into floodwater, which may cause more greenhouse gas emission.

3.3 Research 3: Research on nitrous oxide emission and ammonia volatilization in rice cultivation

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

3.3.1.1 Cumulative nitrous oxide emission

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 3.1. 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 (α = 1%) cumulative N_2O emissions (1.67, 1.47 and 1.29 $kg.ha^{-1}$, respectively).

Table 3.1: Cumulative nitrous oxide emissions from rice field as affected by nitrogen fertilizer types and water management regimes

N_2O emission ($^+$) ($kgN_2O.ha^{-1}$)				
		Water regimes (A)		Average of N fertilizers
		FP	AWD	
Nitrogen fertilizers (B)	Urea	2.54	2.40	**2.47^a**
	Urea-nBTPT	1.64	1.70	**1.67^b**
	NPK briquette	1.33	1.62	**1.47^b**
	NPK IBDU	1.25	1.35	**1.29^b**
Average of water regimes		**1.69**	**1.77**	

F_A = ns, F_B = ** và F_{AB} = ns

Note: ($^+$): The cumulative nitrous oxide 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. ns: not significant. IBDU: Isobutylidene diurea; nBTPT: N-(n-butyl) thiophosphoric triamide. AWD: Alternate wetting and drying. FP: Farmer irrigation practice.

It is clear that the urease inhibitor in urea-nBTPT fertilizer was retarded slightly hydrolysis of urea, plant could uptake more nitrogen. As a result, N_2O emissions by amended nBPTP fertilizer were significantly lower than unamended-urea fertilizer. Deep placement of NPK briquette had higher NH_4^+ and NO_3^- in subsoil, so plant root might uptake directly nitrogen therefore it reduced N_2O emissions. Nutrients from IBDU (low-release) fertilizer becomes available to plants through hydrolysis however 90% of the N in water-insoluble form releases nitrogen gradually to limit N_2O emissions.

Cumulative N_2O emissions of AWD irrigation were not significantly higher than those of FP irrigation (Table 3.1). Alternate wetting and drying in paddy soil was reported to stimulate N_2O emission compared to continuous flooding. However in this study, during FP irrigation, water was not always keep flooded, it was dried out to saturated condition before the next irrigation.

These are important implications for farmers in applying new nitrogen fertilizers (urea-nBTPT, NPK briquette and NPK IBDU) that aim to effectively reduce greenhouse gas emissions from rice cultivation, contribute to the effort in reducing the impact of climate change.

3.3.1.2 Effects of nitrogen fertilizer types on grain yield and recovery efficiency

Results from Table 3.2 showed that nitrogen application increased rice yield compared to non-fertilizer N supply. Grain yields in N fertilizer type treatments (4.84 - 5.00 $t.ha^{-1}$) were not significantly different. On the contrary, grain yields under AWD irrigation regime (4.71 $t.ha^{-1}$) were significantly higher than these under FP irrigation regime (4.31 $t.ha^{-1}$).

Implementation AWD irrigation could increase grain yields thanks to accelerating nitrogen mineralization which was available N for rice uptake, improve the oxygen content in the soil for root growth, root respiration, nutrient absorption and also reduce the accumulation of toxins in the soil. AWD also increased the root distribution with depth so it helped plants cope with water shortages and reduce incidence of lodging.

Table 3.2: Grain yield as affected by nitrogen fertilizer types and water management regimes

Grain yield (t.ha^{-1})				
		Water regimes (A)		Average of N fertilizers
		FP	AWD	
Nitrogen fertilizers (B)	N0	2.81	2.97	**2.89^{b}**
	Urea	4.66	5.10	**4.88^{a}**
	Urea-nBTPT	4.59	5.42	**5.00^{a}**
	NPK briquette	4.67	5.02	**4.84^{a}**
	NPK IBDU	4.82	5.02	**4.92^{a}**
Average of water regimes		**4.31^{b}**	**4.71^{a}**	

F_A = **, F_B = ** và F_{AB} = ns

Note: (**): Significantly different at P < 0.01 by Tukey's test. ns: not significant. IBDU: Isobutylidene diurea; nBTPT: N-(n-butyl) thiophosphoric triamide. AWD: Alternate wetting and drying. FP: Farmer irrigation practice.

The results in Table 3.3 also showed that the recovery efficiency of nitrogen fertilizer application treaments (urea, urea-nBTPT, NPK briquette and NPK IBDU) was not significantly different (0.37% - 0.48%). However, nitrogen recovery efficiency under AWD irrigation (0.47%) was higher than that under FP irrigation (0.39%).

Table 3.3: Recovery efficiency as affected by nitrogen fertilizer types and water management regimes

recovery efficiency (%)				
		Water regimes (A)		Average of N fertilizers
		FP	AWD	
Nitrogen fertilizers (B)	Urea	24^{b}	49^{a}	**37**
	Urea-nBTPT	49	45	**47**
	NPK briquette	41	38	**39**
	NPK IBDU	41	55	**48**
Average of water regimes		**39^{b}**	**47^{a}**	

F_A = *, F_B = ns và F_{AB} = *

Note: (*): Significantly different at P < 0.05 by Tukey's test. ns: not significant. IBDU: Isobutylidene diurea; nBTPT: N-(n-butyl) thiophosphoric triamide. AWD: Alternate wetting and drying. FP: Farmer irrigation practice.

Similarly, total N uptake in straw and in grain under AWD irrigation regime (0.82% and 1.11%%, respectively). was higher than that under FP irrigation regime (0.77% and 1.04%, respectively).

It is clear that implementation AWD irrigation could increase grain yield, total N uptake in rice plant and nitrogen recovery efficiency.

3.3.2 Impacts of nitrogen fertilizer types on ammonia volatilization after nitrogen application

Correlation analysis results between NH_3 volatilization flux and NH_4^+ concentration in floodwater showed a significant correlation (P = 0.009). High NH_4^+ concentration in floodwater after top-dressing application of urea and urea-nBTPT enhanced NH_3 volatilization. In experimental conditions, soil pH low and intermittent flooding limited the growth of algae that could affect the floodwater pH values only neutral or lower. The results also indicated that increasing concentration of NH_4^+ in floodwater influenced on NH_3 volatilization in the experimental conditions.

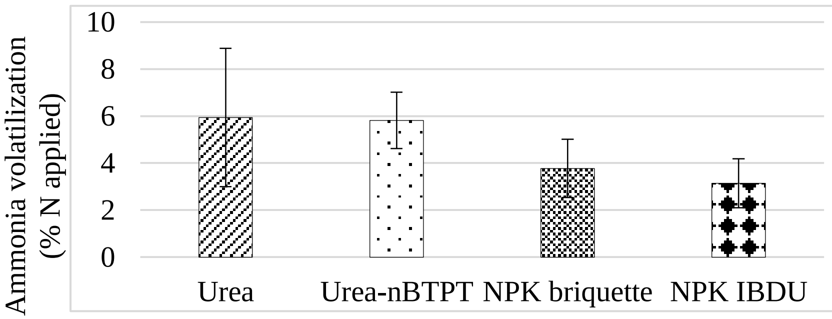

Figure 3.2: Cumulative ammonia volatilization

Note: Data was shown in mean ± SE. Standard errors are denoted by vertical bars. IBDU: Isobutidene diurea. nBTPT: n-butyl thiphosphoric triamide.

Another experimental result indicated that cumulative NH_3 volatilization of urea, urea-nBTPT, NPK briquette and

NPK IBDU treatments was rather low (3.14% - 5.94% of applied N fertilizer). In conditions of low soil pH, application N fertilizer just after irrigation and water pH near neutral or lower level almost certainly reduced NH_3 volatilization.

The urea-nBTPT fertilizer was not significantly in reducing NH_3 volatilization compared to urea fertilizer. Much of urea has been hydrolyzed before sufficient conversion of nBTPT to its oxygen analogue (nBTPO) in submerged conditions of rice fields (Christianson *et al.*, 1990; Freney *et al.*, 1995). Besides, when the water pH values got under 7, evaporation NH_3 was low and NH_3 loss of urea-nBTPT treaments was not different from that of urea. Apparently, application of NPK briquette and NPK IBDU reduced NH_4^+ in floodwater, and tended to reduce NH_3 volatilization in the conditions of the experiment.

3.4 Research 4: Effects of different nitrogen fertilizers on rice yield and nitrogen use efficiency

3.4.1 Effects of rates of nitrogen application and nitrogen fertilizer types on rice yield

Table 3.4 presented average rice yields by rates of nitrogen application and nitrogen fertilizer types. The statistic data set of rice yield in three seasons was analysed in a combined analysis of data.

The result showed that application of urea-nBTPT and NPK briquette tended to increase rice yields (5.80 $t.ha^{-1}$ and 5.77 $t.ha^{-1}$, respectively) compared to urea treatment (5.17 $t.ha^{-1}$) at the rate of 80 $kgN.ha^{-1}$. Moreover, the rice yields of urea-nBTPT and NPK briquette at the rate of 80 $kgN.ha^{-1}$ were higher than those of urea treatment at the rate of 100 $kgN.ha^{-1}$ (4.83 $t.ha^{-1}$).

Farmers usually applicate nitrogen for rice with high rates (more than 100 $kgN.ha^{-1}$), so the rate of 80 $kgN.ha^{-1}$ was recommended to reduce both fertilizer costs and environmental impact.

The effectiveness of urease inhibitor amended in urea-nBTPT fertilizer contributed to increase rice yield over 3 seasons. In the rice fields, submerged soil could limit conversion of nBTPT to nBTPO - an active urease inhibitor. Besides, fertilizer use efficicecy might be improved in the low floodwater pH condition and low NH_3 volatilization including efficiency of urea fertilizer.

Table 3.4: Rice yields between rates of nitrogen fertilizer and nitrogen fertilizer types in a combined analysis of data

Treatments	**Nitrogen fertilizer types**	**Rates of fertilzer application** (kg.ha^{-1})	**Rice yields** (t.ha^{-1})
N0	Non-fertilizer N	0-30-30	3.82^{c}
R1N1	Urea	60-30-30	4.74^{b}
R1N2	Urea-nBTPT	60-30-30	5.47^{ab}
R1N3	NPK briquette	60-30-30	5.74^{a}
R2N1	Urea	80-30-30	5.17^{ab}
R2N2	Urea-nBTPT	80-30-30	5.80^{a}
R2N3	NPK briquette	80-30-30	5.77^{a}
R3N1	Urea	100-30-30	4.83^{b}
R3N2	Urea-nBTPT	100-30-30	5.64^{a}
R3N3	NPK briquette	100-30-30	5.82^{a}
	F		**
	CV (%)		*24.6*

Note: (**): Means that have the same letter are significantly different at P < 0.01 by Tukey's test. ns: not significant. nBTPT: N-(n-butyl) thiophosphoric triamide.

Although deep placement of NPK briquette did not affect on rice yield in the 3 seasons, the NPK briquette contributed to the high concentration of NH_4^+-N at 5 cm and 10 cm depth and limited concentration of NH_4^+-N in floodwater and in topsoil. This contributed considerably to increase N uptake and reduce N losses.

3.4.2 Effects of rates of nitrogen application and nitrogen fertilizer types on nitrogen use efficiency

3.4.2.1 Nitrogen concentration in straw and in grain

Table 3.5 presented average nitrogen concentration in straw and in grain by rates of nitrogen application and nitrogen fertilizer types. The statistic data set of N concentration in straw and in grain in three seasons were analysed in a combined analysis of data.

The result showed that application of urea-nBTPT had higher N in straw and in grain at the rate of 80 $kgN.ha^{-1}$ (0.69% and 1.14%, respectively) than those at 60 $kgN.ha^{-1}$ (0.60% and 1.06%, respectively) but that N did not increase higher at the rate of 100 $kgN.ha^{-1}$ (0.66% and 1.17%, respectively). Similary, NPK briquette deep placement also had higher N in straw and in grain at both the rate of 80 $kgN.ha^{-1}$ (0.68% and 1.15%, respectively) and 100 $kgN.ha^{-1}$ (0.65% and 1.16%, respectively) compared to that at 60 $kgN.ha^{-1}$ (0.61% and 1.08%, respectively).

Nitrogen concentrations in straw and in grain were higher in two types of urea-nBTPT and NPK briquette (0.69% and 1.14%, respectively and 0.68% and 1.15%, respectively) than in urea (0.63% and 1.08%, respectively). It had a very significant difference at the rate of 80 $kgN.ha^{-1}$ (Table 3.5).

This result proved that the rice yields were equivalent to application nitrogen types but N concentrations in straw and in grain showed N uptake from urea-nBTPT and NPK briquette were more effective than from urea fertilizer at the rate of 80 $kgN.ha^{-1}$.

Table 3.5: Nitrogen concentration in straw and in grain between rates of nitrogen fertilizer and nitrogen fertilizer types in a combined analysis of data

Treatments	Nitrogen fertilizer types	Rates of fertilzer application ($kg.ha^{-1}$)	Nitrogen concentration (%)	
			in straw	**in grain**
N0	Non-fertilizer N	0-30-30	0.52^{d}	0.99^{f}
R1N1	Urea	60-30-30	0.59^{cd}	1.07^{de}
R1N2	Urea-nBTPT	60-30-30	0.60^{bc}	1.06^{e}
R1N3	NPK briquette	60-30-30	0.61^{bc}	1.08^{de}
R2N1	Urea	80-30-30	0.63^{bc}	1.08^{de}
R2N2	Urea-nBTPT	80-30-30	0.69^{a}	1.14^{abc}
R2N3	NPK briquette	80-30-30	0.68^{a}	1.15^{ab}
R3N1	Urea	100-30-30	0.61^{bc}	1.13^{abcd}
R3N2	Urea-nBTPT	100-30-30	0.66^{ab}	1.17^{a}
R3N3	NPK briquette	100-30-30	0.65^{ab}	1.16^{a}
	F		**	**
	CV (%)		*5.4*	*5.4*

Note: (**): Means that have the same letter are significantly different at P < 0.01 by Tukey's test. ns: not significant. nBTPT: N-(n-butyl) thiophosphoric triamide.

3.4.2.2 Recovery efficiency

Nitrogen recovery efficiency among different rates of nitrogen application and nitrogen fertilizer types of experiments in Chau Dien commune - Cau Ke district - Tra Vinh province in Summer-Autumn season 2013 were calculated and presented in Table 3.6.

The findings showed that nitrogen recovery efficiency was equivalent among rates of nitrogen application at 60, 80 and 100 $kgN.ha^{-1}$ when applying the same N fertilizer types.

For nitrogen fertilizer types, application urea-nBTPT got recovery efficiency higher at the rate of both 80 and 100 $kgN.ha^{-1}$ (0.44% and 0.46%, respectively) than urea (0.27% and 0.28%, respectively). Meanwhile, nitrogen recovery efficiency of NPK briquette (0.39% and 0.36%, respectively) did not differ from urea fertilizer at these N rates (Table 3.6).

Table 3.6: Recovery efficiency between rates of N application and nitrogen fertilizer types in Chau Dien commune - Cau Ke district - Tra Vinh province in summer-autumn season

Treatments	**Nitrogen fertilizer types**	**Rates of fertilzer application** ($kg.ha^{-1}$)	**Recovery efficiency** (%)
R1N1	Urea	60-30-30	34^{ab}
R1N2	Urea-nBTPT	60-30-30	39^{ab}
R1N3	NPK briquette	60-30-30	33^{ab}
R2N1	Urea	80-30-30	27^{b}
R2N2	Urea-nBTPT	80-30-30	44^{a}
R2N3	NPK briquette	80-30-30	39^{ab}
R3N1	Urea	100-30-30	28^{b}
R3N2	Urea-nBTPT	100-30-30	46^{a}
R3N3	NPK briquette	100-30-30	36^{ab}
	F		*
	CV (%)		*21,3*

Note: (**): Means that have the same letter are significantly different at P < 0.05 by Tukey’s test. ns: not significant. nBTPT: N-(n-butyl) thiophosphoric triamide.

In short, application at the rates of 100 $kgN.ha^{-1}$ did not increase nitrogen recovery efficiency compared to at the rates of 80 $kgN.ha^{-1}$. Besides, nitrogen recovery was high in both urea-nBTPT and NPK briquette but low in urea at the application at the rates of 80 and 100 $kgN.ha^{-1}$.

CHAPTER 4: CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The concentration of NH_4^+ in flood water was higher in broadcasting urea and urea-nBTPT than in NPK briquette treatments. This could lead nitrogen loss by leaching, NH_3 volatilization. High NH_4^+ concentration tended to be higher at topsoil in broadcasting urea and urea-nBTPT treatments and was high in 5 cm and 10 cm soil depth in NPK briquette treatments. Therefore, the rice could uptake nitrogen effectively throughout the season, although NPK briquettes were deep placement once in 10 days after sowing. Fertilizer deep placement technique was a very effective technique to reduce NH_3 volatilization because NH_4^+ concentration was low in topsoil.

The application new nitrogen fertilizer types such as urea-nBTPT, NPK briquette and NPK IBDU decreased considerably N_2O emission compared to urea. This is an important implications for farmer in applying new nitrogen fertilizers that aim to effectively reduce greenhouse gas emissions from agriculture, contribute to the reduction of the impact of climate change.

The AWD irrigation increased rice yield and nitrogen recovery efficiency compared to FP irrigation. Furthermore, it was proved that the application of AWD technique did not increase N_2O emissions in comparision to farmer practice when N fertilizer was applied. This is a new and significant findings in recommending farmers in the Mekong Delta to apply AWD technique in rice cultivation for increasing rice yield and saving irrigation water to cope with water scarcity in the area.

Furthermore, the study result indicated that in potential acid sulfate soil with soil pH = 4.5, the application of N fertilizer in the presence of water and floodwater pH $\leq$ 7, therefore the ammonia volatilization of urea treatments was rather low. The research also found that high ammonium concentration in floodwater after broadcasting urea and urea-nBTPT enhanced NH_3 volatilization flux compared to NPK briquette and NPK IBDU treatments. This could lead to N loss by N leaching and NH_3 volatilization.

Last but not least, rice yields were high at the rate of 80 $kgN.ha^{-1}$ equivalent to this of 100 $kgN.ha^{-1}$ in winter-spring and summer-autumn season on potential acid sulfate soil and alluvial soil in the Mekong river Delta. Therefore the rate of 80 $kgN.ha^{-1}$ was recommended to reduce both fertilizer costs and environmental impact.

Application of urea-nBTPT or NPK briquette increased efficiency of N uptake in rice plants in comparison to urea application, but rice yield in these treatment was similar to urea application treatment. Rice yield in NPK briquette and NPK IBDU treatments was maintained although they were applied only one time at the beginning of the crop. Fertilizer deep placement can be an effective method if mechanization was applied in applying of fertilizer.

4.2 Recommendations

The new nitrogen fertilizer types such as urea-nBTPT, NPK briquette and NPK IBDU decreased considerably N_2O emission compared to urea. This was important implications for farmer in applying new nitrogen fertilizers that aims to effectively reduce greenhouse gas emissions from agriculture in the Mekong Delta.

The application of AWD irrigation increases rice yield and nitrogen recovery efficiency but did not increase N_2O emissions compared to FP irrigation. Therefore it is recommended to apply in rice cultivation in the Mekong Delta to increase rice yield and save irrigation water to cope with water scarcity in the area.

Concentration of NH_4^+ in flood water was higher in broadcasting urea and urea-nBTPT than in NPK briquette and NPK IBDU treatments. This could lead to the nitrogen loss by leaching, NH_3 volatilization. More studies are needed to improve N fertilizer productions and fertilization methods to reduce N_2O emissions and increase N use efficiency.