Accelerating Agriculture Productivity Improvement (AAPI)

Integrating Greenhouse Gas (GHG) Emissions Mitigation into the Feed the Future Bangladesh Fertilizer Deep Placement Rice Intensification (GHG) Project

Quarterly Report

(July-September 2013)

Submitted to

USAID/Bangladesh
Cooperative Agreement Number AID-388-A-10-00002

by

IFDC

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List of Acronyms

AAPI	Accelerating Agriculture Productivity Improvement
AWD	Alternate Wetting and Drying
BAU	Bangladesh Agricultural University
BRRI	Bangladesh Rice Research Institute
CDCS	Country Development Cooperation Strategy
cm	centimeter
CSW	Continuous Standing Water
DAT	Days after transplanting
FDP	Fertilizer Deep Placement
FTF	Feed the Future
GCC	Global Climate Change
GCCI	Global Climate Change Initiative
GHG	Greenhouse Gas
h	hour
ha	hectare
IFDC	International Fertilizer Development Center
IRRI	International Rice Research Institute
kg	kilogram
m	meter
MDL	Minimum detection limit
MOP	Muriate of Potash
mt	metric ton
N_2	Nitrogen
N_2O	Nitrous Oxide
NH_4-N	Ammonium Nitrogen
NO	Nitric Oxide
NPK	Nitrogen, Phosphorus and Potassium
PDB	Power Development Board
pH	Measuring acidity in soil
psig	pound-force per square inch
PU	Prilled Urea
RCB	Randomized complete block
S	Sulfur
TSP	Triple Superphosphate
µg	microgram
UDP	Urea Deep Placement
USAID	United States Agency for International Development
Zn	Zinc

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Introduction

In October 2011, the United States Agency for International Development (USAID)/Bangladesh submitted a proposal for a Global Climate Change (GCC) integration pilot project. This project targeted the integration of two Presidential Initiatives: the Feed the Future (FTF) Initiative and the Global Climate Change Initiative (GCCI). It also reflected the integration of two development objectives in the Bangladesh Country Development Cooperation Strategy (CDCS) 2011-16.[1]

The activities of the proposed project allow for the quantification of environmental impacts, particularly nitrous oxide (N_2O) and nitric oxide (NO) emissions reduction through fertilizer deep placement (FDP) technology, provide opportunities for carbon credit payments and strengthen the capacity of the Bangladesh national research institutes. The activity was embedded within the Accelerating Agriculture Productivity Improvement (AAPI) project being implemented by IFDC within the FTF portfolio and intended to enhance and extend the impact of the AAPI project. The proposal was accepted in February 2012. This led to an AAPI contract addendum signed on September 25, 2012.

This progress report is part of the AAPI 12th quarterly report and is intended to brief stakeholders on the progress of the Integrating Greenhouse Gas (GHG) Emissions Mitigation

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[1] Development Objective 2: Food Security Improved; and Development Objective 4: Responsiveness to Climate Change Improved.

into the Feed the Future Bangladesh Fertilizer Deep Placement Rice Intensification Project (GHG Project) in its fourth quarter, July-September 2013.

Project Description

The GHG Project will measure GHG fluxes and other nitrogen losses associated with urea fertilizer applied to rice crops at two sites:

1. The Bangladesh Agricultural University (BAU) at Mymensingh.
2. The Bangladesh Rice Research Institute (BRRI) at Gazipur.

Working within these institutions will enhance their capacity, enabling them to achieve excellence in research that addresses climate change issues and improves understanding of the dynamics that impact climate change.

The project is designed in two phases:
Phase I: Quantification of N losses and capacity building.
Phase II: Effect of enhanced efficiency technologies on N emissions and yield.

The Project Timeframe

The Program Description Addendum proposes a timeframe over six seasons, starting with *Boro* 2012-2013 (see Table 1).

Table 1. Timeline and Milestones

Project	Integrating GHG Emissions Mitigation into the Feed the Future Bangladesh Fertilizer Deep Placement Rice Intensification Project											
Objective	To quantify N losses using standardized procedures and capacity building on the measurement of GHG fluxes and mitigation of these fluxes with enhanced efficiency nutrient and water technologies.											
Phase I: Capacity Building on the Quantification of N Losses												
	Boro-1				*Aus*-1				*T. Aman*-1			
• Procurement, calibration and shipment												
• Setup and installation at relevant institutes with scientists												
• Initial soil characterization												
• Establishment of field trial with GHG monitoring												
• N fluxes measurement from chambers												
• Soil and air temperature and soil moisture data												
• Runoff and leaching data												
• Operating manual for GHG measurement												
• Training of Bangladeshi scientists for GHG measurement												
Phase II: Effect of Enhanced Efficiency Technologies on N Emissions and Yield												
	Boro-2				*Aus*-2				*T. Aman*-2			
• Establishment of water regime x FDP trials												
• Comparison of N emissions: urea vs. FDP												
• Comparison of N emissions: flooded vs. reduced water use												
• Comparison of N emissions: rice vs. fallow vs. non-rice												
• Quantification of runoff and leaching loss in above systems												
• Quantification of volatilization loss in above systems												
• Assessment of impact of FDP on yield and N emission												
• Assessment of impact of drying on yield and N emission												
• Highly qualified and trained staff for GHG measurement												

Source: Attachment 2 – Program Description Addendum. Modification No. 3.

Progress Against the Timeframe

The project signed the project addendum during September 2012. After that, the *Boro* 2013 and *Aus* 2013 crops were harvested and the *Aman* crop was planted during the third week of August (BAU) and the last week of August (BRRI) 2013.

Table 2. Progress Against Timeline

Phase I: Capacity Building on the Quantification of N Losses												
	Boro-1						*Aus*-1			*T. Aman*-1		
	Dec 2012	Jan 2013	Feb 2013	Mar 2013	Apr 2013	May 2013	Jun 2013	Jul 2013	Aug 2013	Sep 2013	Oct 2013	Nov 2013
• Procurement, calibration and shipment					Complete							
• Setup and installation at relevant institutes with scientists							Complete					
• Initial soil characterization	Completed in 2012											
• Establishment of field trial with GHG monitoring				*Boro* complete			*Aus* complete			*Aman*		
• N fluxes measurement from chambers												
• Collection of soil and air temperature and soil moisture data												
• Collection of runoff and leaching data (collection and analysis of water samples for NH_4)				Complete			*Aus* complete			*Aman*		
• Development of operating manual for GHG measurement												
• Training of Bangladeshi scientists for GHG measurement					USA	within Bangladesh						
Phase II: Effect of Enhanced Efficiency Technologies on N Emissions and Yield												
	Boro-2				*Aus*-2				*T. Aman*-2			
	Dec 2013	Jan 2014	Feb 2014	Mar 2014	Apr 2014	May 2014	Jun 2014	Jul 2014	Aug 2014	Sep 2014	Oct 2014	Nov 2014
• Establishment of water regime x FDP trials												
• Comparison of N emissions: urea vs. FDP												
• Comparison of N emissions: flooded vs. reduced water use												
• Comparison of N emissions: rice vs. fallow vs. non-rice												
• Quantification of runoff and leaching loss in above systems												
• Quantification of volatilization loss in above systems												
• Assessment of impact of FDP on yield and N emission												
• Assessment of impact of drying on yield and N emission												
• Highly qualified and trained staff for GHG measurement												

Activity completion   Expected completion

Table 2 shows progress against the timeline. All activities began on time but have stretched beyond their timelines. Phase I has many components that are interdependent and need to be synchronized to obtain measurements in the field.

Phase I: Capacity Building on the Quantification of N Losses

Only **Phase I** will be reported herein. Phase II is scheduled for the second year, although much of the data required in Phase II will be collected in Phase I.

All the activities assigned for the fourth quarter of Phase I of the project are progressing as per time line. The activities until third quarter such as appointment of staff, procurement, calibration and shipment of equipment, setup and installation at the relevant institutes with scientists, establishment of field laboratories and installation of equipment have been completed on time.

Establishment of Field Trial with GHG Monitoring (*Aus* 2013)

Two field experiments were conducted during the *Aus* season, 2013 at each of the locations (BAU and BRRI). In each location, one experiment was conducted under continuous standing water (CSW) condition and the other under alternate wetting and drying (AWD) condition. The objectives of the studies were to observe the effects of broadcasting prilled urea, deep placement of urea briquette and NPK briquette on: (i) NH_4-N concentration in floodwater; (ii) emissions of N_2O and NO; (iii) rice yield; and (iv) N uptake by rice. The experiments were conducted in randomized complete block (RCB) design with three replications at both the locations. The unit plot size is 5.6 meters (m) x 3.6 m at BAU and 4.8 m x 3.2 m at BRRI. Modern rice varieties, i.e., BRRI dhan 48 at BAU and BRRI dhan 43 at BRRI, were used as the test crop. There were eight treatments in each of the experiments as shown in Table 3.

All the treatments except T6 and T8 received 16 kilograms (kg) of phosphorus (P)/ha and 42 kg of potassium (K)/ha from triple superphosphate (TSP) and muriate of potash (MOP), respectively. Treatments T6 (13 kg P/ha and 32 kg K/ha) and T8 (16 kg P/ha and 42 kg K/ha) received P and K from NPK briquettes. Sulfur (S) and zinc (Zn) were applied to all plots at the rate of 20 kg S/ha as gypsum and 3 kg Zn/ha as zinc oxide at BAU but not in BRRI. Thirty-day (BAU) to 40-day (BRRI) old rice seedlings were transplanted at spacing of 20 centimeters (cm) x 20 cm in both the experiments at both the locations. The seedlings were transplanted on May 24, 2013, at BAU and on June 10, 2013, at BRRI. Prilled urea was broadcasted in two equal splits at 10 and 31 days after transplanting (DAT) at BAU and 9 and 34 DAT at BRRI. Urea briquettes and NPK briquettes were applied at 10 and 9 DAT at BAU and BRRI, respectively.

The briquettes were placed at a depth of 8-10 cm between four hills at the alternate rows. Before application of N fertilizer, water was drained out from the field.

Table 3. Treatment Description for Greenhouse Gas Emission Trial During *Aus* Season 2013

Trt. No.	Description	N Rate	P Rate	K Rate	Basal/Deep-Placed N	1st Topdress N	2nd Topdress N
		(kg/ha)					
1	Check	0	16[a]	42[b]	0	0	0
2	Urea briquette (one 1.8-g)	52	16[a]	42[b]	52	0	0
3	Urea briquette (one 2.7-g)	78	16[a]	42[b]	78	0	0
4	Prilled urea	104	16[a]	42[b]	35	35	34
5	Urea briquette (two 1.8-g)	104	16[a]	42[b]	104	0	0
6	NPK briquette (one 3.4-g)	51	13[c]	32[c]	51	0	0
7	Prilled urea	78	16[a]	42[b]	26	26	26
8	NPK briquette (two 2.4-g)	78	16[d]	42[d]	78	0	0

a. Applied as triple superphosphate.
b. Applied as muriate of potash (KCl).
c. P and K are applied as NPK briquette (Treatment 6).
d. P and K are applied as NPK briquette (Treatment 8).

In CSW plots, irrigation water was applied (when necessary) up to a height of about 6-9 cm to keep the plots under continuously standing water condition. Water depth was monitored. In AWD plots, 25 cm long perforated (up to 15 cm) PVC pipes of 10 cm diameter were inserted (perforated end) into the soil up to a depth of 15 cm leaving 10 cm above the ground. Soils inside the pipes were removed to make a hole of 15 cm depth. Water depth in the PVC pipes was kept under close observation and irrigation water was applied to a height of about 6-9 cm immediately when water inside the pipes became invisible. The AWD treatment started 15 DAT and continued until one week before flowering stage of the crop.

Water sampling was done twice, the first one after basal application of PU and deep placement of urea briquette and NPK briquettes, the second ones after topdressing of PU. In each sampling, the first sample was collected two hours after the application of fertilizers and the subsequent samplings were done for seven consecutive days. Samples were collected once a day (in the morning) in acid-washed plastic bottles and brought to the laboratory to measure pH and NH_4-N.

The *Aus* rice was harvested on August 16, 2013, at BAU and on August 27, 2013, at BRRI. The grain and straw yields were recorded. Two additional harvests were also done both from AWD and CSW plots at the panicle initiation (PI) and heading stages. A total of 16 hills (BRRI) and 30 hills (BAU) were harvested at each stage and the biomass weight and N content were determined.

Automated Gas Sampling and Measurement

Installation of gas chambers and related instruments has already been reported in the previous quarterly report (April-June 2013). In short, 12 gas chambers were placed in each location. Gas chambers were placed in experimental plots of three treatments (T1, T2 and T7 – see Table 3). Nine gas chambers are being used for continuously flooded fields (three replicates for each treatment), while three chambers are being used for AWD fields for the same treatments but without replication. Each chamber was connected with Teflon tubes for gas sampling, nylon tubes (with compressed air) for opening and closing of chambers, temperature and moisture sensors and electric wire for fan that is used inside the chamber to mix air uniformly. All the tubes and wires were passed through 0.75″ diameter PVC pipes for better management and to protect them from unwanted damage in the field. All those tubes, sensors and wires were connected to a control box inside the laboratory. The sampling tubes inside the laboratory room and any exposed part near the chambers in the field were wrapped with the insulating materials to prevent moisture condensation. The system control box, data logger and gas analyzers were all interconnected as per design.

The calibration gas cylinders (N_2, NO and N_2O) were installed in the laboratories (kept upright with the wall and fixed with clamps) and connected to the specified gas dilutors for routine calibration of gas analyzers.

An air compressor was installed in the generator room of the lab building, and the outlet was connected with the control box then with gas chambers in the field using nylon tubes. The compressed air is required for opening and closing the chamber tops at specified times controlled by the software.

Installation of equipment and gas chambers was completed at BAU on June 3 and at BRRI on June 9, 2013. The laboratory of BAU was formally inaugurated on June 4, 2013, by Prof. Dr. Md. Abdul Khaleque Patwary, Dean, Faculty of Agriculture, BAU on behalf of Vice Chancellor, BAU. The GHG machines at both the locations are running well with no major difficulties. The machines have to be calibrated once a week with the standard gases of known concentration. Gas samples from the closed chamber are being collected and analyzed (automatically) continuously for 24 hours a day and seven days a week. One crop (*Aus* rice) has been completed so far for gas measurement. The preliminary results are incorporated here in this report.

Results

Bangladesh Agricultural University

Ammonium N Concentration in Floodwater

The results on the NH_4-N concentration in floodwater samples in different fertilizer treatments are presented in Figure 1. The NH_4- N concentration in floodwater of broadcast prilled urea treated plots (**T4: N_{104} and T7: N_{78}**) varied widely at both sampling times under both CSW and AWD conditions. In both the samplings, the highest NH_4- N concentration was observed in broadcast urea treated plots on day 2 of application of prilled urea and then decreased steadily with time and became almost similar with other treatments at days 6-7. The NH_4- N concentration in floodwater increased with increasing amount of urea application (**T4: N_{104} > T7: N_{78}**). On the other hand, the NH_4- N concentrations in the urea briquette treated plots (T2, T3 and T5) and NPK briquette treated plots (T6 and T8) were very low at both samplings and remained almost stable throughout the sampling time of one week. In fact, the concentrations of those briquette treated plots were almost similar with the control treatment, irrespective of the amount of briquette.

The higher concentration of NH_4-N in floodwater in urea treated plots may be due to rapid dissolution of surface applied prilled urea. While, the deep point placed urea briquettes and NPK briquettes did not come in direct contact with the floodwater; thus, briquettes were dissolved less in the floodwater. Due to this less dissolution, NH_4-N concentrations in briquette applied plots were significantly lower. The results are in full agreement with Kapoor et al. (2008), where they also found highest NH_4-N concentration in floodwater on day 2 of broadcast prilled urea application.

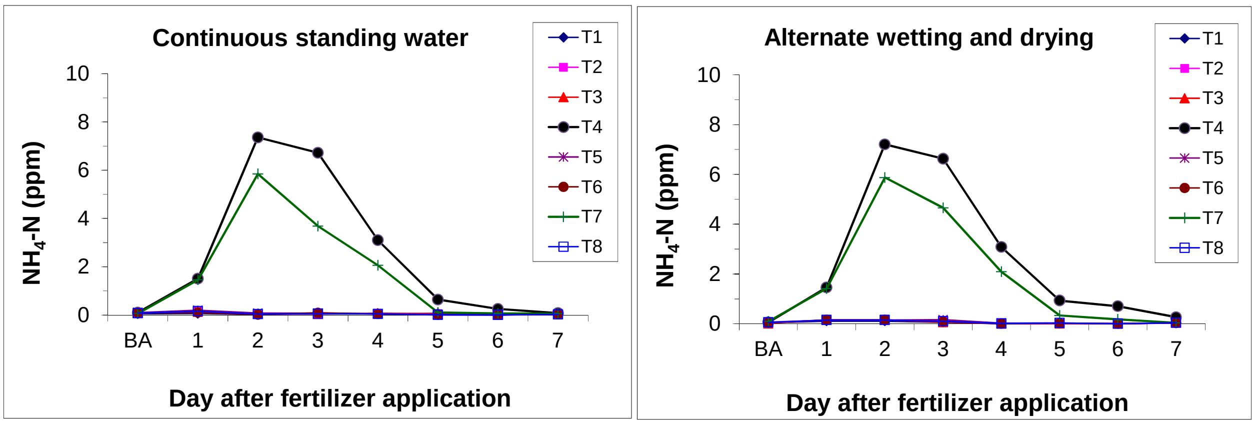

Figure 1. Changes in NH_4-N Concentration of Floodwater in CSW and AWD Conditions at Different Treatments After Basal Application of Fertilizers (First Sampling), BA in X-Axis Indicates Before Application of Fertilizer

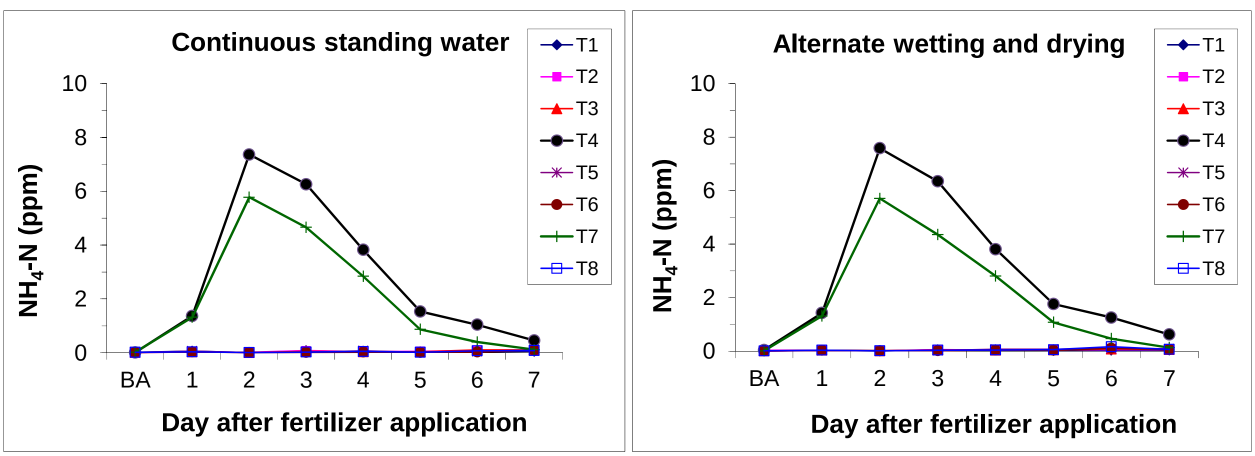

Figure 2. Changes in NH_4-N Concentration of Water in CSW and AWD Conditions at Different Treatments After First Topdressing of Prilled Urea (Second Sampling), BA in X-Axis Indicates Before Application of Fertilizer

Biomass and Rice Yield

Biomass weights at panicle initiation (PI) and heading stages and grain and straw yield of *Aus* rice as influenced by different fertilizer treatments under CSW and AWD condition have been depicted in Table 4-Table 5.

Biomass Weight at PI Stage

The biomass weight (oven dry) at panicle initiation (PI) stage under AWD condition was found higher than that observed under CSW condition irrespective of fertilizer treatments. Biomass weight at PI stage ranged from 1.15 (T1) to 1.72 (T5) mt/ha under CSW condition (Table 4) and 1.37 (T1) to 2.21 (T5) mt/ha in AWD condition (Table 5). In both CSW and AWD conditions, T5 (urea briquette-N_{104}) had significantly higher biomass.

Table 4. Effect of Prilled Urea, Urea Briquette and NPK Briquette on the Biomass Yield of *Aus* Rice (BRRI dhan 48) Under CSW Condition

Treatment			Biomass Weight (t/ha)		Straw Yield (mt/ha)	Grain Yield (mt/ha)
No.	Description	N Rate (kg/ha)	PI	Heading		
T1	Check	0	1.15c	3.28b	3.72c	3.51c
T2	Urea briquette (one 1.8-g briq.)	52	1.46b	4.17ab	4.64ab	4.57a
T3	Urea briquette (one 2.7-g briq.)	78	1.56ab	4.30a	4.71ab	4.59a
T4	Prilled urea	104	1.45b	4.25ab	4.90a	4.49a
T5	Urea briquette (two 1.8-g briq.)	104	1.72a	4.41a	4.63ab	3.85bc
T6	NPK briquette (one 3.4-g briq.)	51	1.44b	3.96ab	4.26b	4.23ab
T7	Prilled urea	78	1.39b	3.96ab	4.69ab	4.41a
T8	NPK briquette (two 2.4-g briq.)	78	1.51b	4.58a	4.63ab	4.12ab
CV (%)			7.59	12.52	5.42	6.15

Within a column, numbers followed by the same letters are not significantly different at the 5% level of significance, CV (%) = Coefficient of variation.

Table 5. Effect of Prilled Urea, Urea Briquette and NPK Briquette on the Biomass Yield of *Aus* Rice (BRRI dhan 48) Under AWD Condition

Treatment			Biomass Weight (t/ha)		Straw Yield (mt/ha)	Grain Yield (mt/ha)
No.	Description	N Rate (kg/ha)	PI	Heading		
T1	Check	0	1.37d	3.31b	4.20b	3.85b
T2	Urea briquette (one 1.8-g briq.)	52	1.81bc	4.53ab	5.42a	4.97a
T3	Urea briquette (one 2.7-g briq.)	78	1.94b	4.79a	5.32a	5.04a
T4	Prilled urea	104	1.75bc	4.85a	5.30a	4.92a
T5	Urea briquette (two 1.8-g briq.)	104	2.21a	4.83a	5.59a	5.22a
T6	NPK briquette (one 3.4-g briq.)	51	1.75bc	4.44ab	4.82ab	4.83a
T7	Prilled urea	78	1.61cd	4.52ab	5.22a	4.81a
T8	NPK briquette (two 2.4-g briq.)	78	1.89b	4.38ab	5.29a	4.87a
CV (%)			8.52	15.91	7.82	4.75

Within a column, numbers followed by the same letters are not significantly different at the 5% level of significance, CV (%) = Coefficient of variation.

Biomass Weight at Heading Stage

Biomass at heading stage ranged from 3.28 mt/ha in T1 treatment to 4.58 mt/ha in T8 treatment under CSW condition (Table 4) and from 3.31 mt/ha (T1) to 4.85 mt/ha (T4) under AWD conditions (Table 5). The highest yield was observed in T8 (NPK briquette-N_{78}) under CSW and T4 (prilled urea-N_{104}) under AWD condition. Crop response to fertilizer at the heading stage was found different from that at the PI stage. At the heading stage, there were no statistical differences among fertilizer treatments under both CSW and AWD conditions. All the fertilizer treatments except control (T1) produced similar biomass yield ranging from 4.38 to 4.85 mt/ha. Nevertheless, irrespective of fertilizer treatments, biomass weight was relatively higher under AWD conditions compared to that of CSW.

Grain and Straw Yield

Both straw and grain yield were statistically identical across fertilizer treatments. The grain yield ranged from 3.5 (T1) to 4.59 mt/ha (T3: Urea briquette N_{78}) under CSW and from 3.85 (T1) to 5.22 mt/ha (T5, urea briquette-N_{104}) under AWD conditions. Similarly, the straw yield under CSW ranged from 3.72 to 4.90 mt/ha, while it ranged 4.20 to 5.59 mt/ha under AWD conditions. As for biomass weight at PI and heading stages, both grain and straw yields were higher under AWD conditions.

Based on grain yield results, the *Aus* recommendation for urea briquette, i.e., 52 kg N/ha and NPK briquette at 52 kg N/ha could continue. As increasing amount of N did not increase the grain yield significantly, the increase in N amount may not be an economic option.

Nitrogen Uptake

N content of plant samples are being analyzed.

Bangladesh Rice Research Institute

Ammonium N Concentration in Floodwater

The NH_4-N concentration in floodwater samples under different fertilizer treatments at BRRI is shown in Figure 3-Figure 4. As in BAU, NH_4-N concentration in floodwater was observed higher under plots with broadcast prilled urea (T4 and T7). In both samplings, the highest NH_4-N concentration was observed on day 2 of prilled urea application and then decreased steadily over time. The highest NH_4-N concentration was observed with 104 kg N/ha (T4) followed by 78 kg N/ha (T7). This highest concentration reduced drastically within another 2 days and was almost similar to that with other treatments on day 4-7. NH_4-N concentration in floodwater was found much lower both in urea briquette and NPK briquette deep placement plots. This indicates that broadcast application of prilled urea in rice field produces higher NH_4-N concentration in floodwater, which consequently causes higher N loss and more water pollution compared to urea briquette and NPK briquette deep placement.

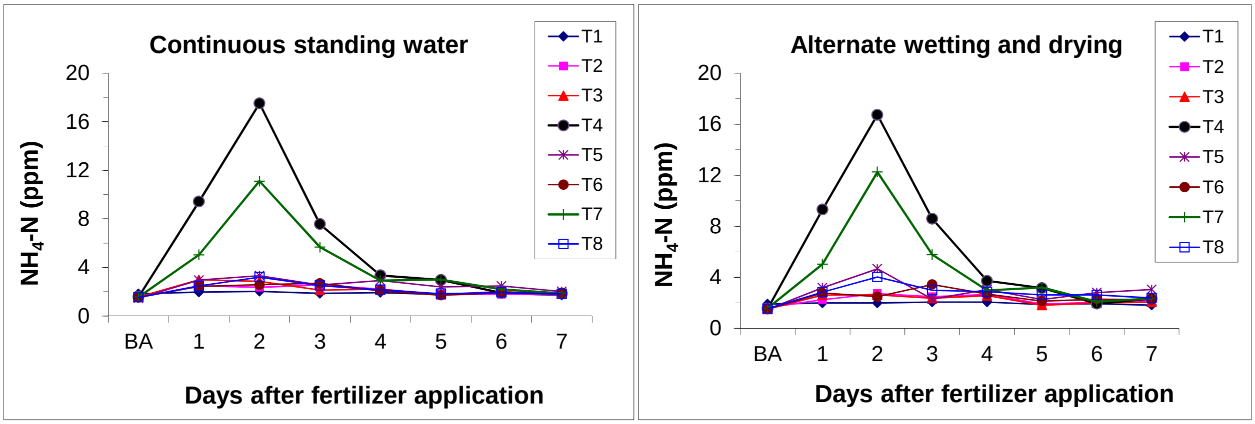

Figure 3. Changes in NH_4-N Concentration of Floodwater in CSW and AWD Conditions After Basal Application of Fertilizer (First Sampling), BA in X-Axis Indicates Before Fertilizer Application

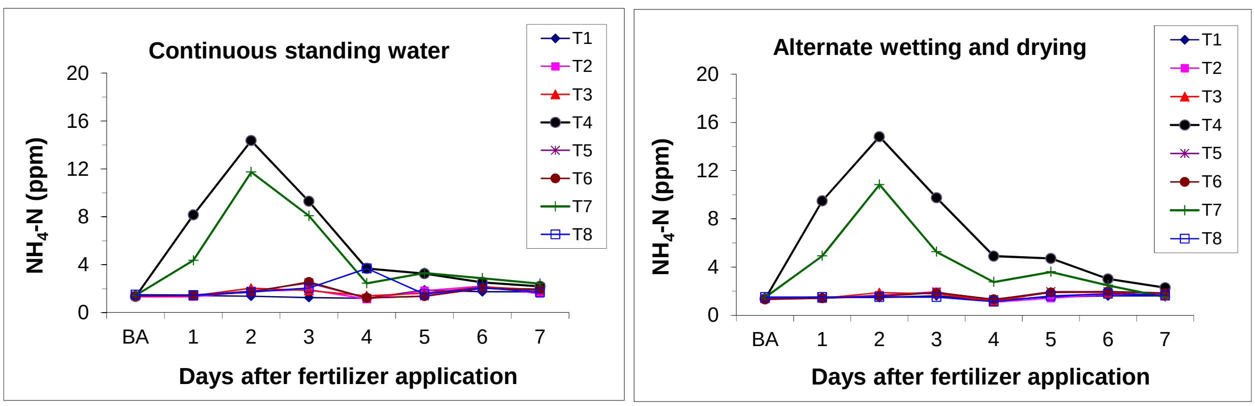

Figure 4. Changes in NH_4-N Concentration of Water in CSW and AWD Conditions After Application of Urea Briquette and NPK Briquette (Second Sampling); BA in X-Axis Indicates Before Fertilizer Application

Biomass and Rice Yield

Biomass weight at panicle initiation (PI) and heading stages and grain and straw yield at maturity stage of *Aus* rice as influenced by different fertilizer treatments under both AWD and CSW are shown in Table 6-Table 7.

Biomass Weight at PI Stage

As in BAU, the biomass weight (oven dry) at panicle initiation (PI) stage under AWD condition was found higher than that observed under CSW condition irrespective of fertilizer treatments. Biomass weight at PI stage ranged from 2.43 (T1) to 3.34 (T5, T6) mt/ha under CSW condition

(Table 6) and 2.57 (T1) to 4.17 (T6, NPK briquette-N_{51}) mt/ha in AWD condition (Table 7). Under CSW, T6 (NPK briquette-N_{51}) and T5 (urea briquette-N_{104}) had higher biomass. However, the biomass weight was statistically similar with other fertilizer treatments except T1 and T7 (prilled urea-N_{78}). Under AWD conditions, NPK briquette (T6, NPK briquette-N_{51}) yielded highest biomass.

Biomass Weight at Heading Stage

With increase of crop age, response of the crop to fertilizer was found different. At the heading stage under both CSW conditions, biomass yield of all the fertilizer treated plots (ranging from 5.39 to 6.15 mt/ha) were found statistically similar and only superior to that of the control (T1) plot (4.37 mt/ha). Similarly, biomass yield under AWD followed the same trend as of the CSW treatments. Biomass yield of rice at heading stage from all the fertilizer treated plots were statistically similar and were significantly higher than that of control treatment.

Table 6. Effect of Prilled Urea, Urea Briquette and NPK Briquette on the Biomass and Grain Yield of *Aus* Rice (BRRI dhan 43) Under CSW Condition

Treatment			Biomass Weight (t/ha)		Straw Yield (mt/ha)	Grain Yield (mt/ha)
No.	Description	N Rate (kg/ha)	PI	Heading		
T1	Check	0	2.43c	4.37b	3.84b	3.05c
T2	Urea briquette (one 1.8-g briq.)	52	3.08ab	6.15a	4.35ab	3.92a
T3	Urea briquette (one 2.7-g briq.)	78	3.27a	5.95a	4.89a	3.69ab
T4	Prilled urea	104	3.14ab	5.83a	4.53ab	3.32bc
T5	Urea briquette (two 1.8-g briq.)	104	3.34a	5.91a	4.28ab	3.80a
T6	NPK briquette (one 3.4-g briq.)	51	3.34a	5.99a	4.32ab	3.95a
T7	Prilled urea	78	2.73bc	5.39a	4.90a	3.93a
T8	NPK briquette (two 2.4-g briq.)	78	3.03ab	6.13a	5.01a	3.74ab
CV (%)			9.1	9.1	11.7	6.5

Within a column, numbers followed by the same letters are not significantly different at the 5% level of significance, CV (%) = Coefficient of variation.

Table 7. Effect of Prilled Urea, Urea Briquette and NPK Briquette on the Biomass and Grain Yield of *Aus* Rice (BRRI dhan 43) Under AWD Condition

Treatment			Biomass Weight (t/ha)		Straw Yield (mt/ha)	Grain Yield (mt/ha)
No.	Description	N Rate (kg/ha)	PI	Heading		
T1	Check	0	2.75c	4.91b	4.11b	2.92b
T2	Urea briquette (one 1.8-g briq.)	52	3.26bc	6.31a	5.19ab	3.96a
T3	Urea briquette (one 2.7-g briq.)	78	3.68ab	6.37a	4.44ab	3.76a
T4	Prilled urea	104	3.46ab	6.35a	5.30a	3.82a
T5	Urea briquette (two 1.8-g briq.)	104	3.83ab	6.26a	4.89ab	3.69a
T6	NPK briquette (one 3.4-g briq.)	51	4.17a	6.47a	4.70ba	4.02a
T7	Prilled urea	78	3.67ab	5.86ab	4.11b	3.67a
T8	NPK briquette (two 2.4-g briq.)	78	3.79ab	6.18a	4.79ab	3.93a
CV (%)			9.1	9.4	11.5	8.9

Within a column, numbers followed by the same letters are not significantly different at the 5% level of significance, CV (%) = Coefficient of variation.

Grain and Straw Yield

As observed in BAU, both straw and grain yields were statistically identical across fertilizer treatments under both CSW and AWD conditions. The grain yield ranged from 3.05 (T1) to 3.95 mt/ha (T6: NPK briquette N_{51}) under CSW and from 2.92 (T1) to 4.02 mt/ha (T6, NPK briquette-N_{51}) under AWD conditions. Similarly, the straw yield under CSW ranged from 3.84 to 5.01mt/ha, while it ranged from 4.11 to 5.30 mt/ha under AWD conditions. As for biomass weight at PI and heading stages, both grain and straw yields were higher under AWD conditions.

Based on grain yield results, the *Aus* recommendation for urea briquette, i.e., 52 kg N/ha could continue in BRRI as in BAU. As increasing amount of N didn’t have any yield advantages, the increase in N amount may not be an economic option to increase in rice grain yield.

Nitrogen Uptake

At PI stage, highest N uptake was observed in treatment T5 (Urea briquette-N_{104}) followed by T3 (Urea briquette-N_{78}) under both CSW and AWD conditions (Table 8-Table 9). Similarly, highest

N uptake was observed in T5 at heading stage also. Obviously, the highest uptake was observed due to higher N content of respective treatments. However, the uptake at heading stage was below statistical significance and all the fertilizer treatments were similar. Though there were no treatment differences, N uptake was observed higher in briquette treatments compared with broadcast prilled urea treatments. Under the AWD condition, the recommended UDP rate of 52 kg N/ha (T2) had significantly higher N uptake than the recommended rate of prilled urea applied as broadcast at 78 kg N/ha (T7). Higher uptake with increasing amount of N didn't have any yield advantage. Therefore, existing recommendation of briquette, i.e., N_{52} can perform well for this crop variety in this location.

Table 8. Effect of Prilled Urea, Urea Briquette and NPK Briquette on N Content and Uptake at PI and Heading Stages by *Aus* Rice (BRRI dhan 43) Under CSW Condition

Treatment			N Content (%)		N Uptake (kg/ha)	
No.	**Description**	**N Rate (kg/ha)**	**PI**	**Heading**	**PI**	**Heading**
T1	Check	0	1.04c	0.86	25.21d	37.75c
T2	Urea briquette (one 1.8-g briq.)	52	1.26bc	0.92	38.55cd	56.80ab
T3	Urea briquette (one 2.7-g briq.)	78	1.67ab	0.99	54.66ab	59.00ab
T4	Prilled urea	104	1.37bc	1.02	42.82bc	58.55ab
T5	Urea briquette (two 1.8-g briq.)	104	1.83a	1.06	61.04a	61.96a
T6	NPK briquette (one 3.4-g briq.)	51	1.25bc	0.96	41.48bc	57.27ab
T7	Prilled urea	78	1.38bc	0.84	37.61cd	45.34bc
T8	NPK briquette (two 2.4-g briq.)	78	1.35bc	0.96	41.12bc	58.65ab
CV (%)			16.5	16.1	17.9	15.5

Within a column, numbers followed by the same letters are not significantly different at the 5% level of significance, CV (%) = Coefficient of variation.

Table 9. Effect of Prilled Urea, Urea Briquette and NPK Briquette on N Content and Uptake at PI and Heading Stages by *Aus* Rice (BRRI dhan 43) Under AWD Condition

Treatment			N Content (%)		N uptake (kg/ha)	
No.	Description	N rate (kg/ha)	PI	Heading	PI	Heading
T1	Check	0	0.97c	0.79c	26.48d	39.01d
T2	Urea briquette (one 1.8-g briq.)	52	1.59ab	1.12ab	51.71bc	70.52ab
T3	Urea briquette (one 2.7-g briq.)	78	1.73a	0.98bc	63.99ab	62.17abc
T4	Prilled urea	104	1.57ab	1.06ab	53.62abc	67.73ab
T5	Urea briquette (two 1.8-g briq.)	104	1.73a	1.21a	65.77a	75.47a
T6	NPK briquette (one 3.4-g briq.)	51	1.30bc	0.88c	53.26abc	56.80bc
T7	Prilled urea	78	1.37ab	0.83c	49.75c	48.44cd
T8	NPK briquette (two 2.4-g briq.)	78	1.48ab	1.13ab	55.89abc	69.86ab
CV (%)			14.6	10.5	13.1	13.2

Within a column, numbers followed by the same letters are not significantly different at the 5% level of significance, CV (%) = Coefficient of variation

Conclusions

It is evident from the results of *Boro* 2013 and *Aus* 2013 that alternate wetting and drying (AWD) might be a good option for growing rice in respect of water saving and yield benefits. Because of frequent rainfall throughout the growing season of the *Aus* crop, maximum benefit of the AWD technology could not be realized. Yet the results indicate positive effects of the technology on rice production in respect of water saving and yield benefits. Results of different fertilizer treatments indicate that deep placement of urea briquette and NPK briquette ensures continuous supply of N throughout the crop growth period. Since floodwater NH_4-N concentration of briquette applied treatments were drastically lower than that of broadcast application of prilled urea, briquettes could reduce possible N losses either from surface runoff or by ammonia volatilization. In other words, use of N can be improved by deep placement of briquettes, indicating lower requirement of N fertilizer compared to broadcast application of prilled urea in rice production.

Based on the grain yield results from BAU and BRRI, application of urea briquette at the rate of 52 kg N/ha showed better performance. The grain yield was statistically similar across different fertilizer treatments, indicating lower dose of N can still perform better for those rice varieties.

Establishment of Field Trial with GHG Monitoring (*Aman* 2013)

Two field experiments have been established during *Aman* season, 2013 at each location following the same protocol with *Aus* 2013. One experiment was conducted under continuous standing water (CSW) condition and the other under alternate wetting and drying (AWD) condition. The experiments are now in the field and the rice crop is at vegetative stage at both the locations. Treatments and experimental design are the same as *Aus* 2013 (see Table 3).

Treatments were arranged in a randomized complete block (RCB) design with three replications. Modern rice variety, BR 22 was used as the test crop at BAU and BRRI dhan 46 at BRRI. 33-day old rice seedlings were transplanted at BAU and 30-day old rice seedlings at BRRI. Transplanting was done at the spacing of 20 cm x 20 cm in both the experiments at both the locations. The seedlings were transplanted on August 22, 2013 at BAU and August 30, 2013 at BRRI. First topdressing of prilled urea and deep placement of briquettes (urea and NPK) were done on September 1 and 7, 2013 at BAU and BRRI, respectively.

In CSW plots, irrigation water is being applied (when necessary) up to a height of about 6-9 cm to keep the plots under continuously standing water condition. Water depth is being monitored. In AWD plots, 25 cm long perforated (up to 15 cm) PVC pipes of 10 cm diameter were inserted (perforated end) into the soil up to a depth of 15 cm leaving 10 cm above the ground. Soils inside the pipes were removed to make a hole up to the length (15 cm) of the pipe in the ground. Water depth inside the PVC pipes is being monitored and irrigation is being applied to a height of about 6-9 cm immediately when water inside the pipes becomes invisible. The AWD treatment started at 15 DAT and will be continued until one week before flowering stage of the crop.

N Fluxes Measurement from Chambers (*Aus* 2013)

Nitrous oxide (N_2O) and nitric oxide (NO) fluxes measurements were started from the beginning of *Aus* season at both BAU and BRRI. The gas sampling systems and gas analyzers are working smoothly in both sites. Calculation of N fluxes will be continued for the next rice growing seasons. Since this is the first measurement taken in this project, it would essentially be for settling the procedures and more stable system will be for *Aman* and *Boro* seasons. Seasonal assessment of NO and N_2O fluxes and comprehensive effect of urea deep placement on fluxes will be analyzed later. Only preliminary fluxes of N_2O and NO from BAU and BRRI are presented herein. In addition to comparison of fertilizer treatments, N fluxes are also compared between CSW and AWD conditions. However, it should be noted that the fluxes presented for AWD conditions were measured from non-replicated chambers.

It is important to consider the sampling and analytical error (precision of gas analyzer) while measuring gas fluxes. When a chamber is placed on the soil surface and made air tight, headspace gas concentration increases over time because of emissions from soil. On the other hand, if the gas flux is zero, then theoretically the headspace gas concentration remains the same. However, sampling/analytical error may result in a data pattern that shows an apparent flux (Parkin et al., 2012). Hence, to correct that error (variability during gas sampling and analysis), minimum detection limit (MDL) for the fluxes should be estimated. To estimate MDL, ambient air samples were analyzed for 10 min. This data was used to calculate the standard deviation of the ambient concentrations of N_2O and NO at hyptothetical time points collected from a chamber over the 40 min deployment (closure) time based on the measurement precision of gas analyzers and size of gas chambers used (56.7 L volume, 0.146 m^2 area). Theoretically, the concentration data used to calculate fluxes within a population of ambient air samples should be zero. Any difference from zero would essentially be due to sampling and analytical error. Therefore the variability of the flux estimated from the ambient air samples is considered as MDL for the fluxes. The fluxes below MDL are considered negligible becasuse those are merely due to sampling and analysis error.

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Temporal variation of N_2O fluxes (Figure 5) shows the temporal variations in N_2O fluxes. During rice growing season, N_2O fluxes from all the treatments show similar temporal variations. Magnitude of fluxes were very low throughout the growing season. In fact, fluxes were below MDL (21.9 µg/m^2/h). Since fluxes were below MDL, differences among treatments were considered negligible.

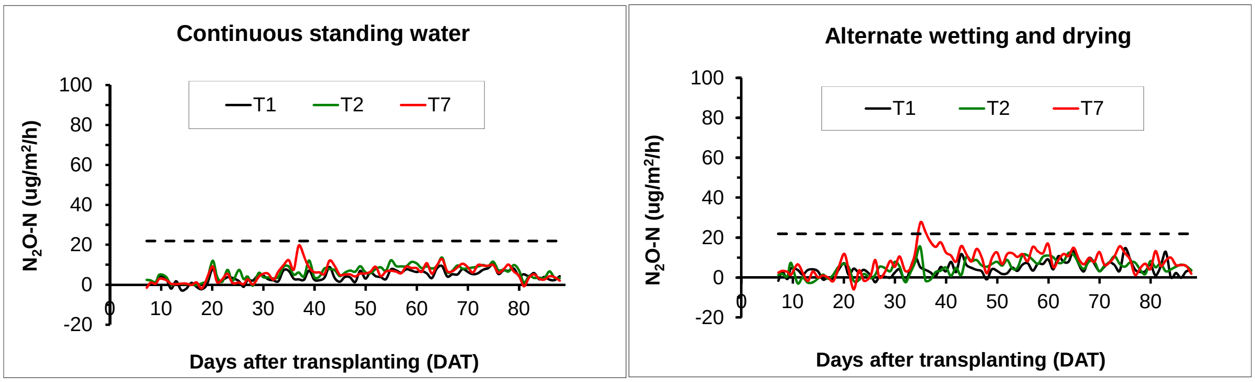

Figure 5. N_2O Fluxes in Control (T1: N_0), Deep-Placed Urea Briquette (T2: N_{52}) and Broadcast Prilled Urea (T7: N_{78}) Plots Under Both CSW and AWD Condition at BAU for *Aus* 2013; Dashed Line Indicates the Minimum Detection Limit (MDL) for the Fluxes

Emissions of N_2O occur in soils during both nitrification and denitrification (Bouwman, 1998). Emissions mostly regulated by the mositure content and amount of nitrogen (N fertilization and soil N content). N_2O is an intermediate product during both nitrification and denitrification. The final product of nitrification is nitrate (NO_3^-) and denitrification is N_2. Therefore fluxes are negligible when the field is continuously flooded (Gaihre et al., 2013), probably due to reduction of N_2O to N_2. However, the emission peaks appear when the rice fields become alternately wet and dry. Hence, high N_2O emissions occur when rice field is drained (Pittelkow et al., 2013). Seasonal average emission rates from CSW plots were 4.14, 6.08 and 5.69 µg/m^2/h for control, urea briquette and prilled urea, respectively. Similarly, seasonal average emission rates from AWD plots were 4.35, 5.07 and 8.16 µg/m^2/h for control, urea briquette and prilled urea, respectively. Those fluxes were below the MDL (21.9 µg/m^2/h) and considered neglible. Small emission peaks were observed from 35-40 DAT under both CSW and AWD conditions. This peak emission was higher in prilled urea than urea briquette treatments. The peak emission was observed after topdressing of prilled urea at 31 DAT. AWD plots remained continuously flooded due to frequent rainfall; thus, there were similar emisssions pattern between CSW and AWD conditions.

Total cumulative N_2O emissions were estimated from the sum of hourly emission rates. Since fluxes were below MDL, cumulative emission was also considered as negligible. However, total emissions of *Aus* season were estimated which were 78, 114 and 107 g/ha for control, urea briquette and prilled urea treatments, respectively under CSW conditions (Figure 6). Differences between the control, urea briquette and prilled urea treatments were negligible. This suggests that the loss of N as N_2O is negligible from flooded rice field. Emissions under AWD conditions were also similar with CSW with total emissions of 82, 95 and 154 g/ha, respectively for control, urea briquette and prilled urea treatments. Unlike in CSW condition, prilled urea emitted relatively higher than that of urea briquette under AWD condition. However, these results were from single replicate and need more replicated measurements to verify the result.

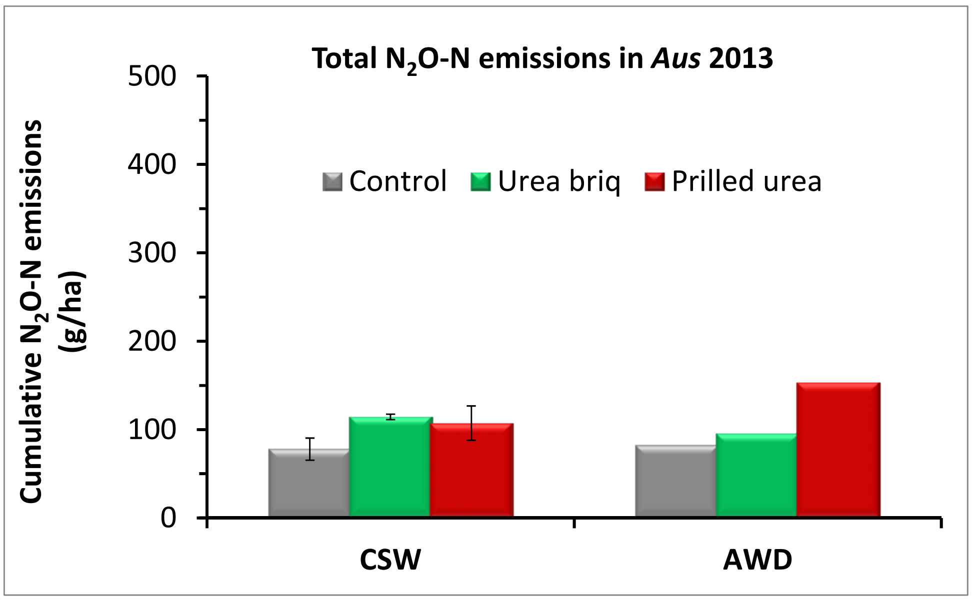

Figure 6. Cumulative N_2O Emissions in Control (T1: N_0), Deep-Placed Urea Briquette (T2: N_{52}) and Broadcast Prilled Urea (T7: N_{78}) Plots Under Both CSW and AWD Condition at BAU for *Aus* 2013; Vertical Bars Indicate Standard Deviation of Means (n=3)

Temporal Variation of NO Fluxes

NO fluxes from all the treatments were very low under both CSW and AWD conditions. On average, the NO fluxes from control, urea briquette and prilled urea plots during rice growing period were 0.16, 0.13 and 0.15 µg/m^2/h, respectively under CSW conditions. Similarly, average seasonal fluxes in AWD conditions were 0.18, 0.08 and 0.28 µg/m^2/h, respectively for control, urea briquette and prilled urea plots. However, those fluxes were below MDL (1.23 µg/m^2/h) and were considered negligible. It is reported that most of the NO fluxes occur during the drainage period, probably due to nitrification (Zhou et al., 2010). But in this experiment, all the plots under both CSW and AWD remained flooded during whole rice growing period. This might be the reason for low emission rates.

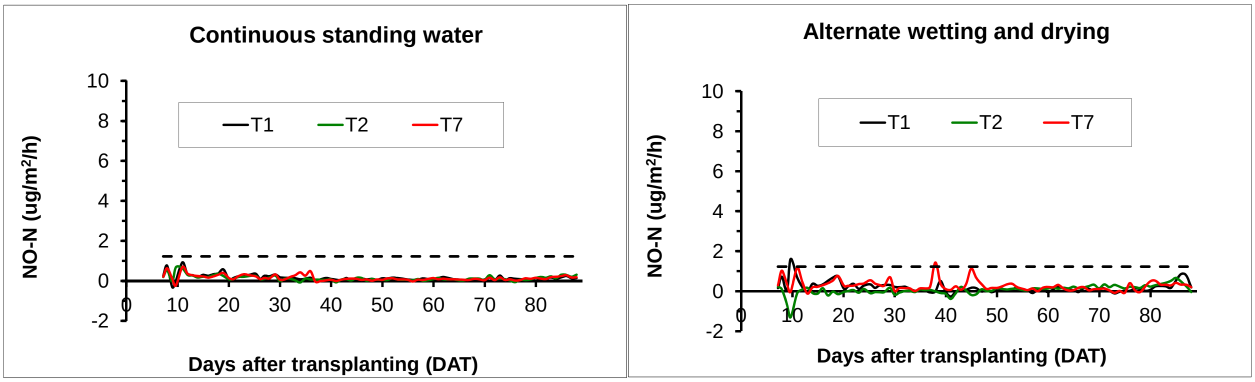

Figure 7. NO Fluxes in Control (T1: N_0), Deep-Placed Urea Briquette (T2: N_{52}) and Broadcast Prilled Urea (T7: N_{78}) Plots Under Both CSW and AWD Condition at BAU for *Aus* 2013; Dashed Line Indicates the Minimum Detection Limit (MDL) for the Fluxes

On average, total seasonal emissions in *Aus* season were 2.99, 2.48 and 2.8 g/ha for control, urea briquette and prilled urea treatments, respectively under CSW conditions (Figure 8). Similarly, total emissions from control, urea briquette and prilled urea under AWD conditions were 3.36, 1.49 and 5.18 g/ha, respectively. Since fluxes were below MDL, total NO emissions were also negligible.

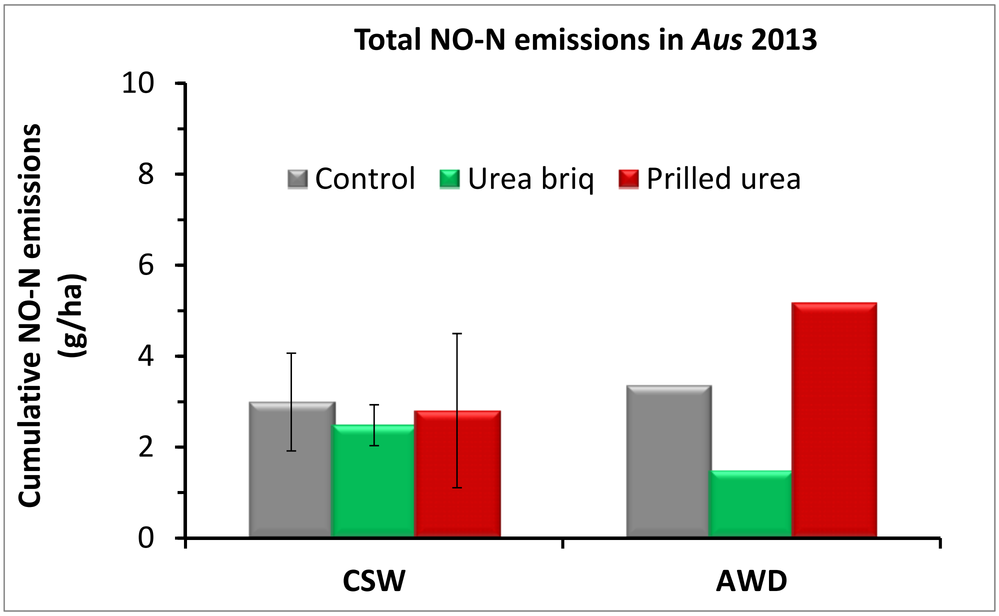

Figure 8. Cumulative NO Emissions in Control (T1: N_0), Deep-Placed Urea Briquette (T2: N_{52}) and Broadcast Prilled Urea (T7: N_{78}) Plots Under Both CSW and AWD Condition at BAU for *Aus* 2013; Vertical Bars Indicate Standard Deviation of Means (n=3)

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Temporal variation of N_2O fluxes

Figure 9 shows the seasonal variations in N_2O fluxes. During rice growing season, N_2O fluxes from all the treatments under CSW show similar seasonal variations. Magnitude of fluxes were below MDL throughout the growing season under CSW condition. Some emission peaks were observed (65-75 DAT) when field was drained for the final harvest. In general, high emission peaks are observed when field is drained probably due to rapid nitrification process. However, differences among treatments were negligible. Seasonal average emission rates from CSW plots were 7.17, 4.91 and 5.79 µg/m^2/h for control, urea briquette and prilled urea treatments, respectively.

On the other hand, under AWD condition, the emissions patterns were different among treatments compared with CSW condition. Peak emissions were observed from 25-40 DAT when field was under dry cycle. Relatively higher emissions were observed in urea briquette treatment compared with prilled urea. This might be due to longer retention of NH_4^+ in root zone in deep-placed urea briquette treatment. When field is dry, the available NH_4^+ may undergo rapid nitrification, thus enhancing higher N_2O emissions. Smaller peak emissions at 40 DAT from prilled urea treated plots may be due to its topdressing at 34 DAT. Seasonal average emission rates from AWD plots were 7.56, 18.11 and 9.77 μg/m$^{2/}$h for control, urea briquette and prilled urea treatments, respectively. In addition to mid season peak emissions during 25-40 DAT, small emission peaks were also observed during 65-75 DAT from all the treatments when the field was drained for final harvest of rice. All the emission peaks were observed during dry periods. Emissions were negligible from all the treatments when AWD plots remained continuously flooded. This clearly suggests that the emission of N_2O is higher when the field remained under AWD condition compared to that under CSW condition. As mentioned above, however, results from AWD plots were from single measurment and need to conduct replicated measurement for further verification.

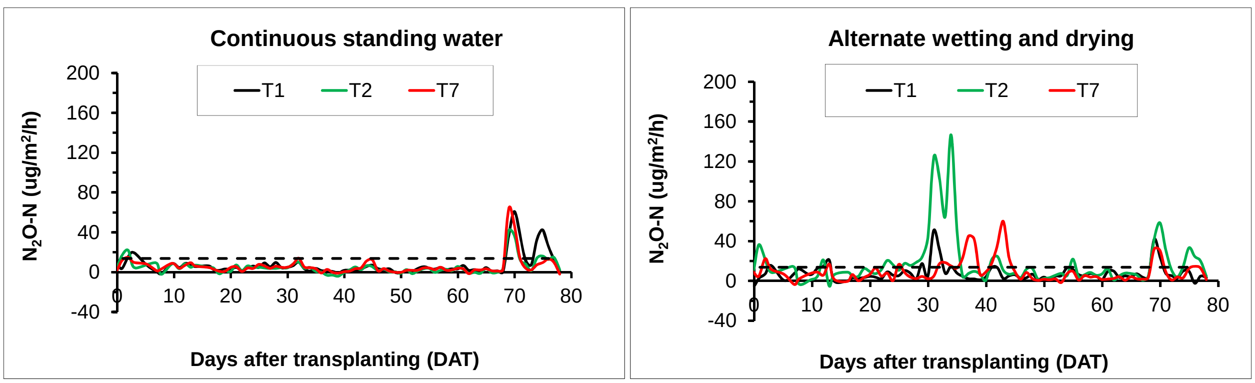

Figure 9. N_2O Fluxes in Control (T1: N_0), Deep-Placed Urea Briquette (T2: N_{52}) and Broadcast Prilled Urea (T7: N_{78}) Plots Under Both CSW and AWD Condition at BRRI for *Aus* 2013; Dashed Line Indicates the Minimum Detection Limit (MDL) for the Fluxes

The total cumulative N_2O emissions from *Aus* season are shown in Figure 10. Under CSW condition, total emissions were 125, 85 and 101 g/ha for control, urea briquette and prilled urea treatments, respectively. As in BAU, emissions were not significantly different among treatments. This further suggest that the rice field is not a significant source of N_2O when the field is continuously flooded irrespective of fertilizer treeatments. On the other hand, emissions under AWD conditions were slightly higher than that under CSW with total emissions of 132, 316 and 170 g/ha, respectively for control, urea briquette and prilled urea treatments. Urea briquette emitted relatively higher N_2O than that of prilled urea. However, this result was from single chamber measurement, it cannot be tested statistically. Unlike in BRRI, BAU had lower emissions from AWD plots because AWD plots remained continuously flooded throughout the growing season.

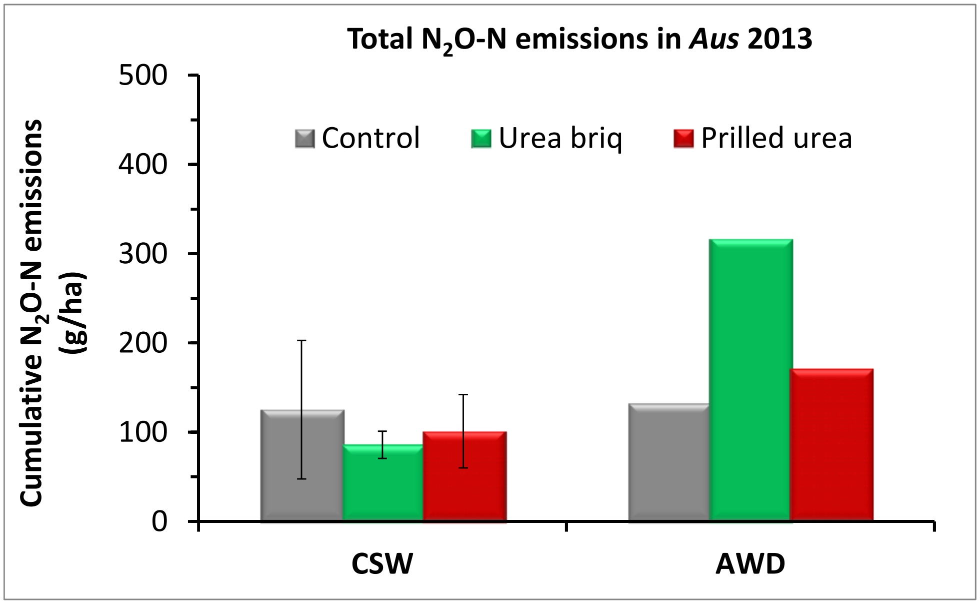

Figure 10. Cumulative N_2O Emissions in Control (T1: N_0), Deep-Placed Urea Briquette (T2: N_{52}) and Broadcast Prilled Urea (T7: N_{78}) Plots Under Both CSW and AWD Condition at BRRI for *Aus* 2013; Vertical Bars Indicate Standard Deviation of Means (n=3)

Temporal Variation of NO Fluxes

NO fluxes from all the treatments were very low under both CSW and AWD conditions. On average, the NO fluxes from control, urea briquette and prilled urea plots during rice growing period were 0.06, 0.06 and 0.04 µg/m^2/h, respectively, under CSW conditions. Similarly, average seasonal fluxes in AWD conditions were 0.007, 0.18 and 0.19 µg/m^2/h, respectively, for control, urea briquette and prilled urea treated plots. Those fluxes were also below the MDL (0.53 µg/m^2/h). Differences among fertilizer treatments were also negligible. Unlike in BAU, AWD plots were dry for some periods (25-40 DAT and 65-70 DAT) and some fluxes were observed when plots were dry.

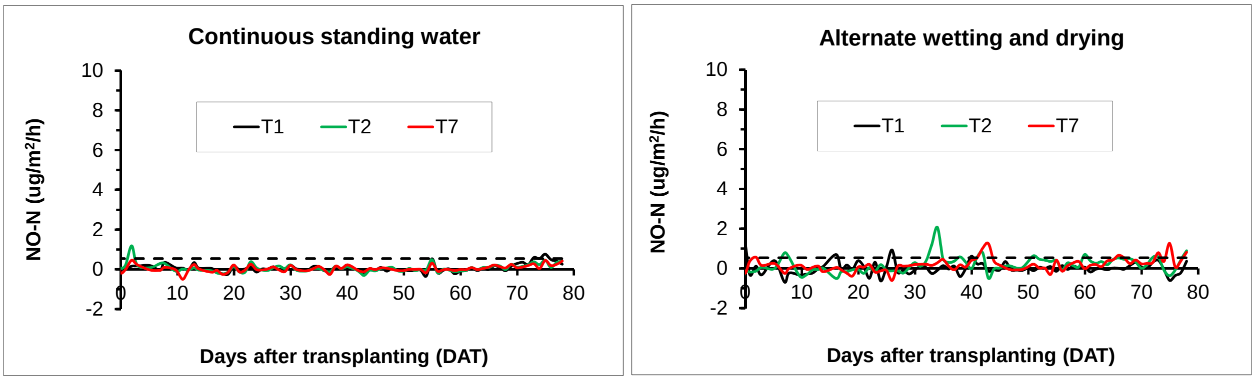

Figure 11. NO Fluxes in Control (T1: N_0), Deep-Placed Urea Briquette (T2: N_{52}) and Broadcast Prilled Urea (T7: N_{78}) Plots Under Both CSW and AWD Condition at BRRI for *Aus* 2013

On average, total seasonal emissions in *Aus* season were 1.11, 1.10 and 0.69 g/ha for control, urea briquette and prilled urea treatments, respectively under CSW conditions (Figure 12). Similarly, total emissions from control, urea briquette and prilled urea treatments under AWD conditions were 0.14, 3.13 and 3.47 g/ha, respectively. Total NO emissions showed negligible (CSW) to smaller differences (AWD) among treatments. However, relatively higher emissions were observed under AWD conditions compared to CSW conditions. Slightly higher emissions from AWD plots may be due to increased nitrification when plots were dry.

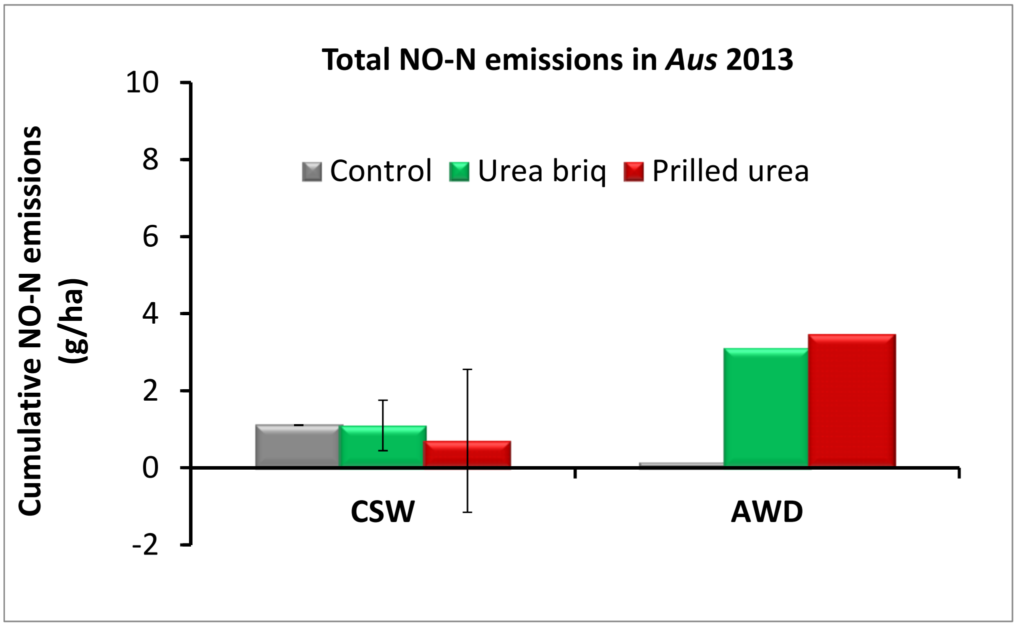

Figure 12. Cumulative NO Emissions in Control (T1: N_0), Deep-Placed Urea Briquette (T2: N_{52}) and Broadcast Prilled Urea (T7: N_{78}) Plots Under Both CSW and AWD Condition at BRRI for *Aus* 2013

Conclusions

Aus season results show that emissions of both N_2O and NO from all the treatments were negligible when field was continuously flooded. This result clearly suggests that the loss of N as N_2O and NO is negligible from flooded rice field. Since there was no significant emission, differences between surface applied prilled urea and deep-placed urea briquette (*Guti* urea) was not apparent under CSW conditions.

On the other hand, some emissions were observed in BRRI under AWD conditions when plots were dry. However, there were no significant emissions at BAU, because AWD plots remained continuously flooded throughout the growing season. In BRRI, slightly higher N_2O emissions were observed from urea briquette under AWD conditions. This may be due to longer retention of NH_4^+ in root zone, which enhanced nitrification while plots were dry as described above. Nevertheless, slight increase in N_2O emission could be offset by reduction of methane emissions (Pittelkow et al., 2013) which is not measured in this experiment.

These preliminary results indicate that losses of nitrogen as N_2O and NO emissions are negligible under CSW conditions irrespective of fertilizer treatments. But some emissions were observed under AWD conditions particularly during dry cycles. However, adoption of AWD has potential to mitigate overall global warming potential from rice field. It is because the rice field is the major source of methane, a second important greenhouse gas which contributes 90% to the total greenhouse gas emissions from rice fields (Pittelkow et al., 2013). Therefore, while making strategies to mitigate greenhouse gas emissions from AWD, measurement of methane emission should give equal emphasis together with N_2O and NO measurement. It is expected that the reduction of methane may offset the slight increase of N_2O during AWD conditions. Overall, AWD may mitigate global warming potential compared with continuous flooding. However, in this study, N_2O and NO fluxes measurements from AWD fields were not replicated, thus statistical test couldn't be performed. More studies with replicated measurements (under AWD conditions) are needed to support these preliminary findings. Since there was no significant emissions of N_2O and NO under CSW, use of urea briquette is environmentally safe under CSW conditions based on previously reported benefit (increased rice yield and reduced N losses).

Soil and Air Temperature and Soil Moisture Data

Soil and air temperature and soil moisture data are also monitored along with gas sampling. Air temperature data were used to calculate the emission rates of NO and N_2O. Soil temperature and moisture data are being processed.

Runoff and Leaching Data

Since *Boro* 2012 (December 2011), AAPI has collaborated with BAU and BRRI to establish trials under the GHG Project protocols. These trials collected agronomic data, and NH_4-N was measured in floodwater in each treatment after fertilizer application. The procedure for sampling water in flooded fields was provided by the USAID mission environment officer, and the analysis took place in the laboratory of each institution.

Results for NH_4-N in floodwater during *Aus* season 2013 are presented in Figure 1-Figure 4.

Operating Manual for GHG Measurement

This is under preparation and will be published by IFDC headquarters.

Bangladeshi Scientists Trained for GHG Measurement

Training on 'installation of gas chambers and related instrument and their operating procedure' was held in IFDC headquarters from April 6 to May 4, 2013. Two junior scientists, one each from BAU and one from BRRI, attended that program. The local environment specialist and post-doctoral scientist also joined training from April 12 and April 22, respectively. In-country training and capacity development of junior scientis is going on continously in their respctive institute with IFDC experts.

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