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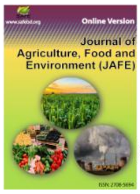

Original Article

Effects of nitrogenous fertilizers on rice yield under continuous flooding and alternate wetting and drying conditions

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A B S T R A C T

In rice cultivation, water and nitrogen saving strategies are becoming more crucial in order to identify efficient and useful crop production and management approaches. A study was conducted at the Soil Science Field Laboratory of Bangladesh Agricultural University, Mymensingh to examine the combined effects of irrigation method and nitrogen fertilizer on yield contributing traits and yield of rice cv. BRRI dhan29. The experiment was set up in a split-plot based on a randomized complete block design with 3 replications and 14 treatment combinations. Two irrigation methods such as continuous flooding (CF) and alternate wetting and drying (AWD) were the main factor while nitrogen fertilizers including prilled urea (PU) and urea super granule (USG) were the sub-factor. The treatment T_6 (USG at 7 DAT) generated the highest plant height (cm), no. of effective tillers hill^{-1}, panicle length (cm), no. of grains panicle^{-1}, grain yield and biological yield during AWD condition. In terms of grain yield, the treatment combinations AWD + T_6 and CF + T_7 were statistically equal. In comparison to control, all AWD + USG and CF + PU treatment combinations increased straw yield and harvest index. Under both AWD and CF conditions, USG increased more grain and straw yields compared to PU. So, farmers may be advised to apply USG (216 kg ha^{-1}) at 7 DAT under AWD conditions in order to improve rice yield and ensure food security.

Introduction

Every year challenges like the disappearance of fertile land, population increase, climate change, and poor management practices influence crop yields in Bangladesh (Mondal, 2010). Rice yield in emerging countries like Bangladesh must be more than doubled by 2050 to fulfill the requirement of an ever-increasing population (Kabir *et al.*, 2015). In 2020, Bangladesh produced 37.4 million tons of rice (BRRI, 2020). Rice specialists of Bangladesh believe that the country's rice production might increase to 40.7 million tons by 2030, 43.9 million tons by 2040, and 46.7 million tons by 2050 (Kabir *et al.*, 2021). Expanding the application of effective water-saving technology (WST) and fertilizer management strategies is a major element of the solution for improving yields in a sustainable way (Uddin and Dhar, 2020).

As the climate changes, effective fertilizers and irrigation systems are required for successful crop production (Djaman *et al.*, 2017). Due to climate change and upstream water control, the water shortage has become a serious issue in recent years. However, nitrogen loss in wet soils as ammonia volatilization varied from zero to over 60% of the provided nitrogen (Xing and Zhu, 2000). Various irrigation methods have already been developed to allow farmers to actively reduce irrigation and associated expenses, or to preserve water for other purposes (Bouman *et al.*, 2007). Alternate wetting and drying (AWD) is such a technology developed by the IRRI (International Rice Research Institute) in 1990 which can save up to 38% of water without affecting rice production (Price *et al.*, 2013). This approach permits the soil to dry up somewhat before re-irrigating because most wetland rice varieties can sustain a 30% drop in total irrigation flow without appreciably lowering production (Richards and Sander, 2014). Under AWD conditions, the soil is dried until the soil water level reaches 15 cm below the surface, then the field is re-irrigated to a standing water depth of around 5 cm to avoid production loss (Bouman and Lampayan, 2009). Tan *et al.* (2013) showed no significant yield loss under AWD conditions and a 17% increase in water efficiency as compared to continuous flooding irrigation.

Although the AWD approach has been proven to reduce water use as well as increasing crop yield, few investigations have been performed in Bangladesh to investigate potential water-saving strategies, especially when using different fertilizer rates and application times. Among the basic nutrients, nitrogen (N) is the most essential element for rice production. Farmers in Bangladesh utilize N fertilizer as prilled urea by broadcast or urea super granule (USG) by deep placement for rice cultivation. Dhane *et al.* (1989) reported that a few of the mechanisms include immobilization, denitrification, volatilization, leaching, and surface runoff that cause N fertilizer to be lost to the environment. The waste of prilled urea (PU) due to volatilization is extremely high, and farmers lose a lot of money on N fertilizer (Hossain *et al.,* 2019). As a result, lowering production costs must be prioritized in order to improve crop yield. However, urea deep placement (UDP) was already proven to reduce nitrogen losses by as much as 50% than the broadcast method (Huda *et al*., 2016). The concentration of NH_4-N in flood water decreases by the deep placement of USG than the broadcast application of PU (Hasan *et al.,* 2016). When compared to a split PU application, placing USG at 8-10 cm depth in the soil can save 30% nitrogen and enhance nutrient uptake, improve soil health, and eventually accelerates crop production (Rahman and Barmon, 2015; Islam *et al.*, 2019).

To fulfill the requirement for rice, researchers and policymakers should concentrate on the combination of irrigation and N fertilizer management under high-yielding rice cultivars. As a result, the experiment was undertaken to investigate the effects of nitrogenous fertilizers on rice yield under continuous flooding as well as alternate wetting and drying conditions.

Materials and methods

Location

The experiment was conducted at the Soil Science Field Laboratory of Bangladesh Agricultural University, Mymensingh (24.75^{0}N latitude, 90.5^{0}E longitude and 18 m height above the sea level) during the Boro season of 2019 to explore the effect of N fertilizers on the growth and yield of BRRI dhan29 under continuous flood (CF) and alternate wetting and drying (AWD) conditions.

Soil and climate

In the experiment site, the morphological, physical and chemical characteristics of soil were recorded before the experimental setup (Table 1 and Table 2). The weather information regarding temperature, rainfall, relative humidity and sunshine hours that prevailed at the experimental site from January 2019 to June 2019 had also been recorded (Figure 1 and Figure 2).

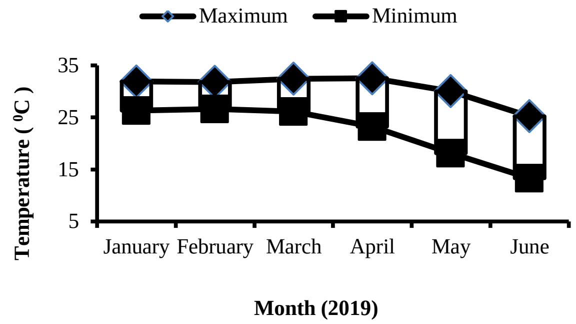

Figure 1. Maximum and minimum temperature during experiment period.

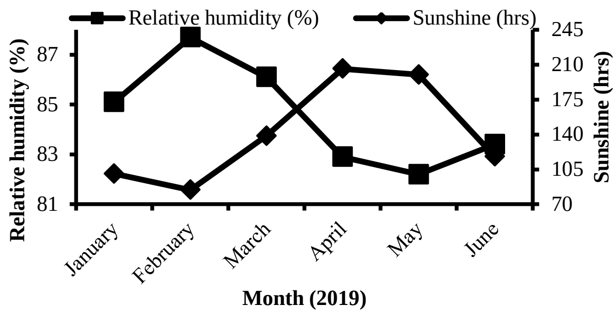

Figure 2. Relative humidity (%) and sunshine (hrs) during experiment period.

Experimental design and treatments

A split-plot design was used to layout the experiment where the study area was divided into 3 blocks representing the replications to minimize soil heterogeneity. Each block was further subdivided into two sub-blocks, each of which contained seven plots. There were two irrigation systems and 14 different treatment combinations (Table 3). A total of 42 plots were prepared for the experiment and the treatments were distributed to the unit plots in each block. There was a 1 m drain between the blocks that separated the blocks from each other.

Table 1. Morphological characteristics of the soil sample.

Morphology	Characteristics
Land Type	Medium high land
Topography	Fairly level
General Soil Type	Non-calcareous Dark Grey Floodplain
Soil Series	Sonatola
Agro-ecological zone	Old Brahmaputra Floodplain
Flood level	Above flood level

Table 2. Physical and chemical characteristics of the soil sample.

Characteristics	Value
Particle size analysis	
Sand (%)	3.64
Silt (%)	78.18
Clay (%)	18.18
Textural class	Silt loam
pH	6.27
Organic matter (%)	1.95
Total nitrogen (%)	0.14
Available phosphorus (mg kg^{-1})	8.16
Exchangeable K (meq/100 g soil)	0.11
Available sulphur (mg kg^{-1})	10.5

Table 3. Experimental treatment combinations.

Irrigation systems	Treatment combinations	Time of application	Amount of N fertilizer (kg ha^{-1})
1. Alternate wetting and drying (AWD)	AWD + T1	Control	No PU or USG
	AWD + T2	PU at 7 DAT + 27 DAT + 47 DAT	216
	AWD + T3	PU at 10 DAT + 30DAT + 50 DAT	216
	AWD + T4	PU at 15 DAT + 35 DAT + 55 DAT	216
	AWD + T5	USG at transplanting	216
	AWD + T6	USG at 7 DAT	216
	AWD + T7	USG at 10 DAT	216
2. Continuous flooding (CF)	CF + T1	Control	No PU or USG
	CF + T2	PU at 7 DAT + 27 DAT + 47 DAT	216
	CF + T3	PU at 10 DAT + 30DAT + 50 DAT	216
	CF + T4	PU at 15 DAT + 35 DAT + 55 DAT	216
	CF + T5	USG at transplanting	216
	CF + T6	USG at 7 DAT	216
	CF + T7	USG at 10 DAT	216

Here, PU: Prilled urea, USG: Urea super granule and DAT: Days after transplanting

Planting material and cultivation procedure

BRRI dhan29, a high yielding variety of rice was used as the test crop in this experiment. Forty days old seedlings were carefully uprooted from a seedling nursery bed and transplanted in the prepared plots on 4 February 2019 maintaining 20cm × 20cm spacing and three seedlings were transplanted in each hill. The fertilizers were applied as per treatment. As the basal doses, all the treatments received P, K, and S (21-60-8 kg ha^{-1}). The PU was applied in three equal splits. USG was placed at 8-10 cm depth between four hills at alternate rows. The excess water in the rice plots was drained out just before the application of N fertilizers. Intercultural operations like weeding, irrigation, drainage and plant protection actions were done as and when necessary for ensuring and maintaining a favorable environment for normal growth and development of crops. The crop was harvested when it was fully mature.

Data collection and analysis

The data on yield components including plant height, effective tillers per hill, panicle length, grain panicle^{-1}, 1000 grain weight, grain yield and straw yield of BRRI dhan29 were recorded. For statistical analysis, ANOVA was performed using MStatC software. Duncan's Multiple Range Test (DMRT) was used to assess the significant differences in mean values.

% Harvest index (HI) = (Biological yield/ Grain yield) × 100

Results and discussion

Plant height

Plant height of BRRI dhan29 responded positively to the deep placement USG compared to PU in both AWD and CF conditions. In comparison to the control (T_1), all treatments resulted in higher plant height. The plant height varied from 73.18 cm to 82.34 cm. The tallest plant (82.34 cm) was observed in treatment combination CF + T_6 (USG, 216 kg. ha^{-1}) and the shortest plant of (73.18 cm) was in AWD + T_1 (Control) (Table 4). Other studies pointed out (Mazumder *et al.*, 2019; Chen *et al.*, 2013) that N fertilization has a tendency to increase plant height since N is involved in cell division and cell elongation of plants. A previous study (Hien *et al.*, 2019; Yakubu *et al.*, 2019) confirmed that plant height increases in the combination of AWD and 90 kg ha^{-1} N because N fertilizer stimulates plants to grow taller as N is involved in cell division and cell elongation of plants. Recently, Zheng *et al.* (2020) exposed rice plants to water saving irrigation (WSI) treatments and discovered that WSI-treated rice plants were substantially shorter than CF treated rice plants. Because they discovered that WSI increased root dry matter weight but decreased stem dry matter weight when compared to CF.

Table 4. Effects of PU and USG on growth and yield contributing traits of BRRI dhan29 under both CF and AWD conditions.

Treatments	Plant height (cm)		Number of effective tillers hill^{-1}		Panicle length (cm)		Number of grains panicle^{-1}		1000-grain weight	
	AWD	CF	AWD	CF	AWD	CF	AWD	CF	AWD	CF
T1	73.18	75.22	10.00de	9.00e	17.57	18.33	116.67c	110.00c	19.93	19.50
T2	77.42	78.57	14.00bcd	13.00bcde	20.37	21.05	137.33ab	133.00ab	22.23	22.16
T3	81.31	79.25	14.33abcd	11.00cde	21.12	21.36	140.00ab	136.00ab	22.13	22.00
T4	80.04	79.31	17.00ab	12.00cde	19.21	20.41	137.00ab	132.33b	21.82	21.00
T5	81.45	82.3	15.00abc	15.00abc	20.80	20.97	140.67ab	137.33ab	21.86	21.96
T6	82.27	82.34	19.00a	17.00ab	21.99	20.53	143.00a	138.67ab	21.60	22.23
T7	80.72	80.48	14.33abcd	12.66bcde	20.21	22.16	139.67ab	138.00ab	22.40	21.80
SE (±)	1.20	0.93	1.05	0.99	0.54	0.45	3.37	3.81	0.31	0.37
CV (%)	4.01	3.08	18.83	20.37	7.10	5.75	6.53	7.63	3.83	4.56

Effective tillers hill^{-1}

The application of PU and USG had a significant influence on effective tillers hill^{-1} under both AWD and CF environments. In AWD situations, all treatments had greater effective tillers hill^{-1} than CF. The maximum number of effective tillers hill^{-1} (19.00) was recorded in AWD + T_6 (USG, 7 DAT) while the minimum value (9.00) was found in CF + T_1 (Control). Statistically similar effective tillers hill^{-1} was documented in AWD + T_2 (14.00), AWD + T_3 (14.33), CF + T_5 (15.00), AWD + T_5 (15.00) and AWD + T_7 (14.33) respectively (Table 5). Islam *et al.* (2017) recorded the maximum number of effective tillers hill^{-1} (15.00) in T_3

(USG, 130 kg N ha^{-1}) and minimum in control which is similar to the present investigation (Table 5). According to Norton *et al.* (2017), AWD promotes rice plants to grow stronger roots, allowing the root system to receive more oxygen and water during tiller development, resulting in more effective tillers. On the contrary, Oliver *et al.* (2008) recorded the highest number of effective tillers $hill^{-1}$ (10) under CF conditions compared to AWD. However, from the investigation of Afrad *et al.* (2018), the treatment combination AWD + BARC recommended fertilizers (300-112-127-75-11 kg ha^{-1} of Urea-TSP-MoP-$CaS0_4$-$ZnS0_4$) gave the maximum number of effective tillers $hill^{-1}$ (15.23) than CF + BARC recommended fertilizers treatment combinations which support the present findings. Both Kahimba *et al.* (2013) and Katambara *et al.* (2013) mentioned the advantages of the AWD method for expanding the number of tillers.

Table 5. Effects of PU and USG on grain yield, straw yield, biological yield and harvest index (%) of BRRI dhan29 under both CF and AWD conditions.

Treatments	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})		Biological yield (t ha^{-1})		Harvest index (%)	
	AWD	CF	AWD	CF	AWD	CF	AWD	CF
T1	2.93c	2.90d	3.40d	3.43d	6.34f	6.34f	44.21	45.74
T2	5.36b	5.27b	5.62bc	5.58c	10.98e	10.85e	48.82	48.57
T3	5.64b	5.58b	6.07abc	6.00abc	11.71bcde	11.58cde	48.16	48.19
T4	5.50b	5.34b	6.03abc	5.94abc	11.53cde	11.28de	47.70	47.34
T5	6.11a	6.16a	6.53abc	6.59abc	12.64abcd	12.75abc	48.34	48.31
T6	6.53a	6.45a	6.77a	6.81a	13.30a	13.26a	49.10	48.64
T7	6.34a	6.52a	6.73ab	6.67abc	13.07ab	13.19a	48.51	49.43
SE (±)	0.46	0.47	0.44	0.95	0.90	0.90	0.63	0.45
CV (%)	22.04	22.69	19.90	12.53	20.88	21.15	3.47	2.47

Panicle length

The interaction effect of N and irrigation systems was not significant on panicle length under both AWD and CF conditions. In CF, all of the treatments resulted in longer panicles than that in AWD. The highest panicle length (22.16 cm) was recorded in AWD + T_6 (USG, 7 DAT). The lowest panicle length of (17.57 cm) was observed in AWD + T_1 (Control) (Table 4). From previous studies (Hossain *et al.*, 2014; BRRI, 2014), the highest panicle length (23.80 cm) was recorded in the combination of CF + BRRI recommended fertilizers compared to AWD + BRRI recommended fertilizers which is not agreed with the result. Furthermore, Islam *et al.* (2018) and Singh *et al.* (2006) found that when USG (130 kg ha^{-1}) was used instead of PU (130 kg ha^{-1}), rice panicle length increased and with rising nitrogen levels (150 kg ha^{-1}), panicle length ranged from 19.7 to 23.9 cm.

Grains $panicle^{-1}$

In both AWD and CF conditions, the influence of nitrogen and irrigation methods on the number of grains $panicle^{-1}$ was significant. The number of grains $panicle^{-1}$ varied from 110.00 to 143.00. The highest grains $panicle^{-1}$ (143.00) was measured in AWD + T_6 (USG, 7 DAT) and the lowest value (110.00) was found in CF + T_1 (Control). In addition, treatment AWD + T_2, AWD + T_4, CF + T_5, CF + T_6 and CF + T_7 had statistically similar value which ranged from 137.00 to 138.67 respectively (Table 4). Similarly, the maximum number of grains $panicle^{-1}$ (124 and 121) was obtained from the application of USG 103 kg ha^{-1} and USG 130 kg ha^{-1} for BRRI dhan46 and BRRI dhan49 (Shaha *et al.*, 2018 and Rea *et al.*, 2019). Among three irrigation management treatments [Direct seeded aerobic rice (AR), direct seeded rice with AWD, and direct seeded flooded rice (CF)], AWD had more number of grains $panicle^{-1}$ compared to CF and AR but a non-significant difference was found between AWD and CF treatments (Hussain *et al.*, 2021) which support the studied results.

1000-grain weight

In both AWD and CF conditions, the variation of 1000-grain weight of BRRI dhan29 in various treatments was not significant. The 1000-grain weight ranged from 19.50-22.40 g. All the treatments produced a higher 1000-grain weight over control of both irrigation methods. The highest 1000 grain weight (22.40 g) was observed in AWD + T_7 (USG, 10 DAT) whereas the lowest (19.50 g) was recorded in CF + T_1 (Control) (Table 4). This is consistent with the investigations of Yakubu *et al.* (2019) who found that N fertilizer and irrigation methods had no significant effect on 1000-grain weight under both AWD and CF conditions. In another experiment (Ishfaq *et al.,* 2020), AWD and nitrogen have been shown to minimize spikelet sterility and improve grain weight by increasing the activity of enzymes involved in grain filling.

Grain yield

Both irrigation methods and N fertilizer had a significant impact on rice grain yield in this experiment. The grain yield ranged from 2.92 to 6.53 t ha^{-1}. The highest grain yield (6.53 t ha^{-1}) was recorded in AWD + T_6 followed by CF + T_7 (6.52 t ha^{-1}), CF + T_6 (6.45 t ha^{-1}) and AWD + T_7 (6.34 t ha^{-1}) whereas the lowest was observed in CF + T_1 (2.90 t ha^{-1}) (Table 5). In comparison to PU, USG at a rate of 216 kg ha^{-1} increased rice grain production more effectively. Our findings corroborate with the findings of Carrijo *et al.* (2018) who found that AWD had the potential to boost production by maintaining adequate soil moisture for the healthy growth of crops. Zheng *et al.*, (2020) found that AWD techniques increased grain yields by more than 13% when compared to flooded irrigation. However, Hou *et al.*, (2019) and Sun *et al.*, (2020) reported that the use of too much nitrogen had no effect on rice grain yield. Sah *et al.,* (2019) discovered a considerable increase in yield at 120 kg N ha^{-1}, as well as a drop in yield at 180 kg N ha^{-1} due to increased N rate.

Straw yield

The combination of irrigation methods and N levels had a considerable effect on straw yield. The highest straw yield (6.81t ha^{-1}) was found in AWD + T_6 (USG, 7 DAT) whereas the lowest (3.40 t ha^{-1}) was recorded in AWD + T_1 (Control) (Table 5). When compared to CF, Zheng *et al.* (2020) found that AWD could increase straw yield by up to 5.3%. According to Chaturvedi (2005), N fertilizer increases leaf area, which results in increased photoassimilates and thus more dry matter formation.

Biological yield

The forms of urea (PU and USG) significantly influenced biological yield (Table 5) under both AWD and CF conditions. The treatment combination AWD + T_6 (USG, 7 DAT) showed the significantly highest (13.30 t ha^{-1}) whereas both AWD + T_1 (Control) and CF + T_1 (Control) produced the lowest (6.34 t ha^{-1}) biological yield. Miah *et al.* (2012) observed vegetative growth was influenced due to the higher dose of urea and found the highest significant (17.58 t ha^{-1}) biological yield for the use of USG rather than the application of PU (17.11 t ha^{-1}). Similarly, Mohammad *et al.* (2014) recorded the highest biological yield 12.05 t ha^{-1} for BR11 with the hand application of USG. This could be related to the development of higher plants with more effective tillers, as well as the longest panicle and grain yield (Faroque *et al.,* 2021). Previously, Rahman and Bulbul, (2014) stated that BRRI hybrid dhan2 gave a maximum of 13.33 t ha^{-1} (irrigation when water was 15 cm below the soil surface) and 12.39 t ha^{-1} (irrigation when water was 20 cm below the soil surface) biological yield under AWD compared to CF condition.

Harvest index (%)

In this investigation, the percent harvest index varied with different treatments applied in AWD and CF irrigation systems. The harvest index of BRRI dhan29 ranged from 45.75 to 49.43 (%). The highest harvest index (49.43%) obtained in CF + T_6 (USG, 7 DAT) whereas the lowest value (45.74%) recorded in CF + T_1 (Control) (Table 5). When the application of USG was compared with PU, a non-significant interaction effect on the harvest index of BRRI dhan28 and BRRI dhan29 was found by Bhuiyan *et al.* (2016) and the grain harvest index ranged from 0.40 to 0.52 in BRRI dhan28 and 0.42 to 0.54 in BRRI dhan29. Similarly, Mboyerwa *et al.* (2021) revealed that the harvest index was significantly affected by N levels, which ranged from 0.45 to 0.53, but irrigation methods had little influence ($p > 0.05$).

Conclusion

Based on the findings, it can be concluded that rice yield was affected by both irrigation methods and N. As compared to split application of PU, N supplied by USG demonstrated better results on yield contributing traits, grain yield, straw yield, and harvest index under both AWD and CF conditions (PU). Although the combination AWD + USG (7 at DAT) produced the maximum yield, it was statistically identical to the combination CF + USG (10 at DAT) with an equal dose of 216 kg ha^{-1} N. Thus, it is suggested that farmers could apply an AWD + USG (7 at DAT) treatment combination with 216 kg ha^{-1} N to save water and N as well as boost rice yield while lowering production costs.

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