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Research paper

Different nitrogen rates and methods of application for dry season rice cultivation with alternate wetting and drying irrigation: Fate of nitrogen and grain yield

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ABSTRACT

Improvement of nitrogen use efficiency (NUE) is a challenging task because of its several losses through ammonia volatilization, surface runoff, leaching and nitrification-denitrification. Fertilizer deep placement (FDP) has been proven effective in increasing grain yields and NUE under continuous standing water (CSW) condition. However, the impacts of FDP have not been investigated under alternate wetting and drying (AWD) irrigation. Field experiments were conducted in the dry seasons during 2014–2016 to determine the interaction effect of fertilizer x water regime on N losses as floodwater ammonium and ammonia volatilization, grain yields and NUE. Broadcast prilled urea (PU), deep placement of urea briquettes (UB) and nitrogen-phosphorus-potassium fertilizer briquettes (hereafter NPK) at varied N rates and zero N were tested under AWD and CSW conditions.

The deep placement of UB and NPK, irrespective of N rates and water regimes, reduced floodwater ammonium and ammonia volatilization significantly compared to broadcast PU. Deep placement of either UB-N78 or NPK-N104 increased grain yields under both AWD (21–26%) and CSW (13–20%) conditions compared to broadcast PUN104. The magnitude of increase was larger under AWD, because AWD significantly reduced grain yields (8%) compared to CSW at PU-N104. However, yields of deep-placed UB were similar between AWD and CSW. Deep placement of UB and NPK increased N recovery up to 57–66% from 36% of PUN104. These results suggest that UBN78 and NPK-N104 can be utilized under AWD not only for increased grain yield and NUE but also to reduce additional pumping cost for irrigation water. Moreover, combined approach of AWD and FDP might be a good option for improving water and fertilizer use efficiencies in rice cultivation.

1. Introduction

Rice occupies about 11.4 million ha of land with the production of 51.64 million tons (BBS, 2015). Boro or dry season rice (grown from January/February to April/May) makes up the majority of total production in Bangladesh, covering about 4.8 million ha, while Aus (from May/June to August/September) and Aman (from July/August to November/December) are wet seasons in which rice coverage is 1.05 and 5.6 million ha, respectively (BBS, 2015). With the increasing population growth rate, it is estimated that the demand for rice will be 56% higher by 2050 than in 2001 (36.1million tons) (Mukherjee et al., 2011; Kabir et al., 2015). Therefore, rice productivity should be increased to meet the food demand of a growing population, taking into account the dwindling amount of land area available for farming. This requires judicious use of agricultural inputs, including quality seeds and fertilizers, and irrigation water management, among other good agricultural practices.

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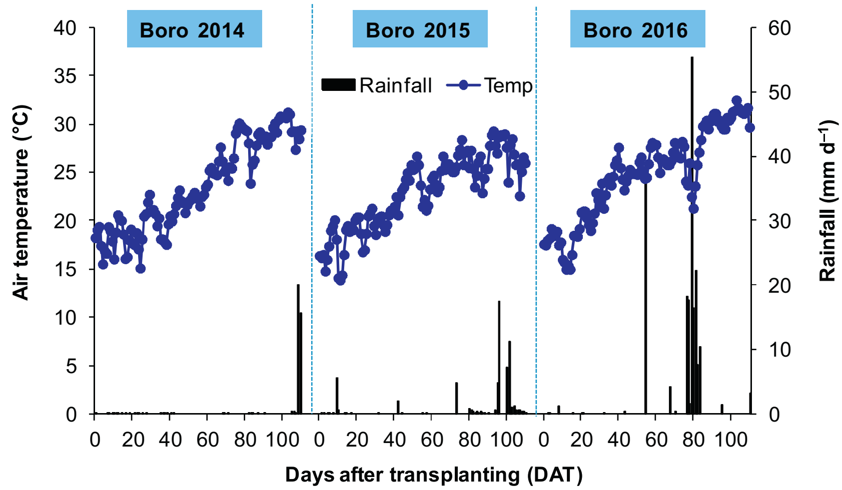

Fig. 1. Daily average of rainfall and air temperature for rice-growing seasons during 2014–2016.
(Data Source: Weather station, Bangladesh Rice Research Institute, Gazipur.)

Table 1
Physicochemical properties of soils before the experiment and after harvest of Boro 2016.

Soil properties	Initial soil (2013)		After harvest of Boro 2016	
	AWD	CSW	AWD	CSW
pH-H_2O	5.8	6.0	6.2	6.2
Organic carbon (%)	1.27	1.25	1.26	1.25
Total N (%)	0.14	0.13	0.12	0.11
Available P (mg kg^{-1})	11.47	11.33	11.37	11.53
Available K ($cmol_c kg^{-1}$)	0.12	0.11	0.10	0.11
Texture	Clay loam			

AWD and CSW represent alternate wetting and drying, and continuous standing water, respectively.

Fertilizer application and water management are the most important practices in rice production. Though nitrogen (N) fertilizer plays a major role in rice production, all fertilizers should be applied in a balanced way for increasing crop productivity and improving soil fertility. However, most farmers in developing countries, such as Bangladesh, are not familiar with balanced fertilization practices. They often use excessive N and insufficient phosphorus (P) and potassium (K) fertilizers (Quamruzzaman, 2006), with little or no secondary and micronutrient fertilizers. Moreover, farmers apply fertilizers using the conventional broadcast method, which leads to lower nutrient use efficiency. The nitrogen use efficiency (NUE) in lowland rice is only 30–40%, particularly when prilled urea (PU) is applied via broadcast method, resulting in financial losses and harm to the environment (Ladha et al., 2005; Savant and Stangel, 1990; Raun et al., 2002). The low NUE is caused by N losses through ammonia (NH_3) volatilization, surface runoff, nitrification and denitrification, and leaching (Savant and Stangel, 1990; Peng et al., 2006; Hayashi et al., 2008; Watanabe et al., 2009; Dong et al., 2012). These losses increase when urea is applied via broadcast method. One of the major loss mechanisms is NH_3 volatilization, which reaches up to 50% of applied N (Sommer et al., 2004).

In lowland rice fields, placement of N in the root zone, i.e., urea deep placement (UDP), reduces N losses and increases NUE and crop productivity (Savant and Stangel, 1990; Rochette et al., 2013; Huda et al., 2016). When urea is deep-placed in continuously flooded rice soils, losses of N as floodwater ammonium (NH_4^+-N), NH_3 volatilization and nitrous oxide emissions are negligible (Kapoor et al., 2008; Rochette et al., 2013; Gaihre et al., 2015; Huda et al., 2016). With the reduction of these losses, UDP increases NUE up to 80% compared to 30–45% with broadcast application. Thus, UDP in rice cultivation reduces N fertilizer required by 30–35% and increases grain yields by up to 15–20% compared to broadcast PU. In addition to increased farm profitability, UDP reduces government subsidy payments in countries where N fertilizer subsidies exist. Moreover, deep placement of compound fertilizer (NPK) briquettes was recently introduced in Bangladesh, supplying all three major nutrients in a compound briquette (Miah et al., 2016). Since many farmers do not practice balanced fertilization (Quamruzzaman, 2006), deep placement of compound fertilizer briquettes offers the potential for higher yields and improves fertilizer use efficiency because of balanced use of nutrients and reduced nutrient losses.

In most studies related to fertilizer deep placement, including deep placement of both urea briquettes (UB) and NPK briquettes, fertilizers were tested under continuous standing water (CSW) irrigation regime. Under CSW irrigation regime, deep-placed N remains in the root zone as NH_4^+-N, ensuring continuous supply to plants throughout the growing season, depending on soil type. In contrast, when the irrigation regime is changed from CSW to alternate wetting and drying (AWD), the fate of N in the soil, particularly dynamics of soil C and N, may be changed, affecting soil fertility. Generally, AWD makes soil C and N unstable, increasing their mineralization rates (Ponnamperuma, 1972), and these, in turn, have important consequences on C and N losses. Several studies were conducted in different rice-growing countries on AWD regime and its effects on grain yields and farm profitability. However, the effects of AWD irrigation on rice yields are not consistent and are still inconclusive (Bouman et al., 2005; Chapagain and Yamaji, 2010; Liu et al., 2013; Chu et al., 2015; Wang et al., 2016). On the other hand, there are still few studies on the effect of AWD irrigation regime on NUE, particularly under different rates and placement methods of N fertilizers. Therefore, the main objective of this study was to determine the interaction effect of N fertilizer (rates and placement methods) x water management on rice yields and NUE in lowland rice during the dry season. The specific objectives of this study were:

- To compare N losses, in terms of floodwater $NH_4^+$and NH_3 volatilization, between broadcast PU and deep-placed UB and NPK at different N rates.
- To determine yields, N uptake and NUE of Boro rice for broadcast PU, UB and NPK under CSW and AWD.