Efficient Fertilizer and Water Management in Rice Cultivation for Food Security and Mitigating Greenhouse Gas Emissions

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Abstract

Increasing nitrogen fertilizer application has increased crop productivity and met the food demands of growing populations, but its use efficiency is very low. More than 50% of applied nitrogen is not utilized by crops, posing huge economic costs and environmental concerns. Therefore, fertilizer management should consider optimum source, rates, time, and methods of application (the “4Rs” of nutrient stewardship) to increase use efficiency, crop yield, soil health, and farm profits and to reduce negative environmental effects. Fertilizer deep placement (FDP) is one of the best currently applicable management techniques to achieve these multiple benefits. Multi-location experiments were conducted in Bangladesh to determine the effects of urea deep placement (UDP) and multi-nutrient fertilizer briquette (NPK) deep placement versus broadcast prilled urea (PU) on rice yields, nitrogen use efficiency, and nitrogen losses, including floodwater ammonium, ammonia volatilization, and nitrous oxide emissions. Deep placement of both urea and NPK briquettes in the dry (*Boro*) season increased grain yields. Across the years, the average observed yield increase was 30% compared to broadcast PU. Deep placement significantly reduced nitrogen losses compared to broadcast PU. Broadcast PU resulted in higher amounts of ammonium in floodwater and ammonia volatilization, both of which were negligible in deep-placed treatments. Moreover, UDP reduced nitrous oxide emissions by 70% as compared to broadcast PU. In Bangladesh, fertilizer briquettes are produced by micro-enterprises and applied manually in fields. This approach is effective in small-scale farming where household labor is sufficient for cultivation but requires modifications to work in larger scale farming systems where labor availability is an issue. Another issue relates to the non-availability of fertilizer briquettes throughout the country. Therefore, for large-scale dissemination in other rice-growing countries in Asia, including China and India where greater N use efficiency gains can be realized, government and/or private sector actors must work together to promote wide-scale adoption by farmers through industrial-level briquette production and mechanized on-farm application.

Introduction

Rice is the staple food of more than half of the world's population. More than 90% of the world's rice is grown in Asia, where one-half of the world's population and 80% of the world's poor are concentrated. In Bangladesh, one of the most climate-vulnerable nations (Climate Home, 2013), farmers intensively cultivate rice on 80% of agricultural lands. With the increasing population growth rate, it is estimated that the demand for rice will be 56% higher by 2050 than in 2001. 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 water management, among other good agricultural practices.

Fertilizer use has played a crucial role in meeting the food demand of a growing world population. Among the fertilizers, nitrogen (N) fertilizer is the main driving force to produce large rice yields under irrigated and favorable rainfed conditions. However, N fertilizers are being used excessively in most countries in Asia, leading to imbalanced use of nutrients. Farmers usually apply urea as a broadcast method. Much research conducted across countries reported that more than 50% of applied nitrogen is not utilized by crops and lost to the environment as reactive forms (ammonia, nitrate, nitrogen oxides) through volatilization or surface water runoff, contributing to greenhouse gas emissions and other environmental problems, such as eutrophication and groundwater pollution (Savant and Stangel, 1990). The excessive use of fertilizers poses a huge environmental cost in addition to reduced farm profitability. Because of the rising costs of production, along with increasing input costs (including fertilizers), the quest for food security, and the need to mitigate environmental impacts, there is a need for more efficient and balanced use of plant nutrients. Thus, immediately applicable N use efficiency-enhancing measures are of paramount importance.

Over the past years, many research and development groups, including the International Fertilizer Development Center (IFDC), have worked on improving N use efficiency (NUE) through urea deep placement (UDP), urease inhibitors, and slow and controlled N fertilizers, such as polymer- and sulfur-coated fertilizers. Research conducted across different countries showed that fertilizer deep placement (FDP) could be one the best management techniques to achieve the multiple benefits of increasing grain yield, farm profits, and NUE while reducing negative environmental effects – in short, more yield with less fertilizer (IFDC, 2013). UDP in lowland rice fields, particularly under continuous flooding irrigation condition, has been widely recognized as an effective management practice that reduces fertilizer (urea) use by 25-40% and increases yield by an average of 15-20% (Savant and Stangel, 1990; Huda et al., 2016). Research conducted in Bangladesh has shown that UDP is equally effective under alternative wetting and drying (AWD) irrigation. 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, 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.

The majority of the farmers in Bangladesh are small landholders (<2 ha). Therefore, FDP technology is being disseminated by the Government of Bangladesh, in partnership with IFDC, by developing micro-enterprise briquette producers. Each local entrepreneur who owns a briquetting machine – many of whom are fertilizer dealers – produces fertilizer briquettes amounting to approximately 1 mt per day. Farmers access fertilizer briquettes through retailer networks. Results across different districts in Bangladesh demonstrated the multiple benefits of FDP. FDP was found to reduce fertilizer use and increase crop productivity, leading to increased farm profits, while reducing the government fertilizer subsidy burden. FDP was also found to protect the environment by reducing nitrogen losses, including runoff, ammonia volatilization, and greenhouse gas nitrous oxide (Gaihre et al., 2015; IFDC, 2013; Rochette et al., 2013).

In this paper, we present a case in Bangladesh, where FDP technology is widely disseminated, discussing both the benefits of FDP and the challenges to broader adoption. We present these findings not only to illustrate the findings in Bangladesh, but to suggest that FDP – if spurred to greater scale by innovative actors in larger markets – can be an important part of the solution in terms of NUE gains in the near term.

Methods

Study Sites and Fertilizer Treatments

Field experiments were conducted in Bangladesh during 2012-2015 to compare the effects of FDP on grain yields, NUE, and nitrogen losses under two water regimes – continuous standing water (CSW) and AWD. Treatments included broadcast PU, UDP, and compound fertilizer deep placement (NPK). Grain yields and total aboveground nitrogen uptake were recorded at harvest.

Quantification of Nitrogen Losses

Nitrogen losses including floodwater ammonium (NH_4), ammonia (NH_3) volatilization, and nitrous oxide (N_2O) emission were measured from on-station trials conducted at Bangladesh Agricultural University (BAU) and Bangladesh Rice Research Institute (BRRI). NH_3 volatilization was measured using dynamic closed-chamber and acid-trap methods. Similarly, N_2O emissions were measured with the static automated closed-chamber technique (Gaihre et al., 2014).

Results

Grain Yields and Nitrogen Use Efficiency

Deep placement of urea briquettes and NPK briquettes increased grain yield by up to 30% compared to broadcast PU in the dry (*Boro*) season (Table 1). Moreover, deep placement doubled the agronomic efficiency and nitrogen recovery over broadcast PU – giving higher yields with less N. These results are consistent with previous studies conducted across different districts in Bangladesh (Huda et al., 2016; Miah et al., 2016).

Table 1. Grain yield and nitrogen use efficiency (NUE) in different fertilizer treatments during dry (Boro) seasons at Bangladesh Agricultural University.

N Source	N Rate	Grain Yield (t/ha) ǂ	Agronomic Efficiency (AE_N)	Recovery Efficiency (RE_N)
Boro 2013				
PU	78	4.57b	19.7c	32b
UB	78	6.66a	46.5a	67a
NPK	78	6.41a	43.3a	65a
Boro 2014				
PU	104	4.87b	28.06c	39c
UB	78	6.31a	55.93a	82a
NPK	78	4.95b	37.09b	59b
Boro 2015				
PU	104	4.73b	23.1b	29b
UB	78	6.41a	52.4a	78a
NPK	78	6.40a	50.4a	65a

Within a column and season, means followed by the same letters are not significantly different at 5% probability level by Tukeys's honest significant difference (HSD) test.

ǂGrain yield is at 14% moisture content.

AE_N= agronomic efficiency (kg grain/kg N); RE_N= recovery efficiency (increased N uptake/applied N, expressed in percentage).

Floodwater Ammonium, Ammonia Volatilization, and Nitrous Oxide Emissions

Figure 1 shows that broadcast PU produced significant amounts of ammonium in floodwater, which is prone to runoff and volatilization losses. On the other hand, floodwater ammonium in deep placed treatments was similar with control (N0) plot. Deep placement of fertilizer briquettes at 7-10 cm depth ensures retention of ammonium nitrogen in the soil, thereby reducing floodwater ammonium and surface runoff loss. In addition to surface runoff, the negligible amount of floodwater ammonium in deep placement ensures a reduction in volatilization loss (Figure 2a).

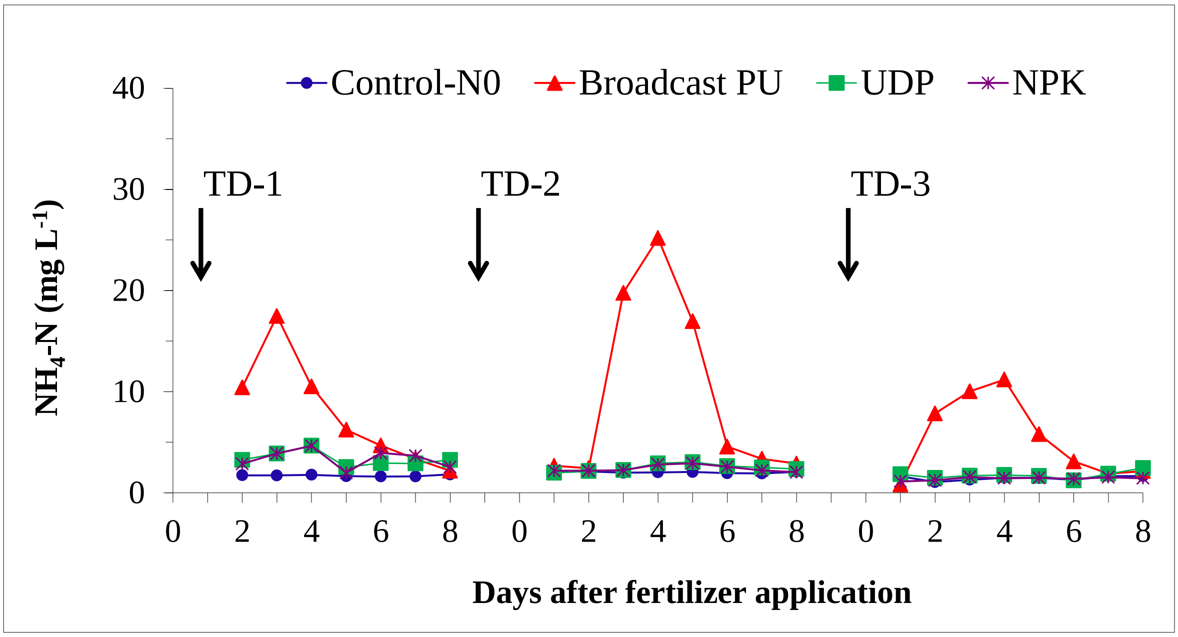

Figure 1. Dynamics of floodwater ammonium (NH_4-N) under control (N0), broadcast PU, urea deep placement (UDP), and NPK deep placement (NPK) treatments (104 kg N/ha) at Bangladesh Rice Research Institute (BRRI) during dry season (Boro) 2012. TD-1, TD-2, and TD-3 represent first, second, and third topdressing of urea fertilizer, respectively. Deep placement was done at a time during the first topdressing of urea.

FDP not only has potential to reduce nitrogen losses as surface runoff and ammonia volatilization but also to reduce greenhouse gas nitrous oxide emissions. Figure 2b shows the cumulative nitrous oxide emissions measured continuously throughout the 2014 dry (*Boro*) season at the BAU site. UDP reduced emissions by 70% as compared to broadcast PU. Gaihre et al. (2015) reported the effects of UDP on nitrous oxide and nitric oxide across different rice-growing seasons in Bangladesh.

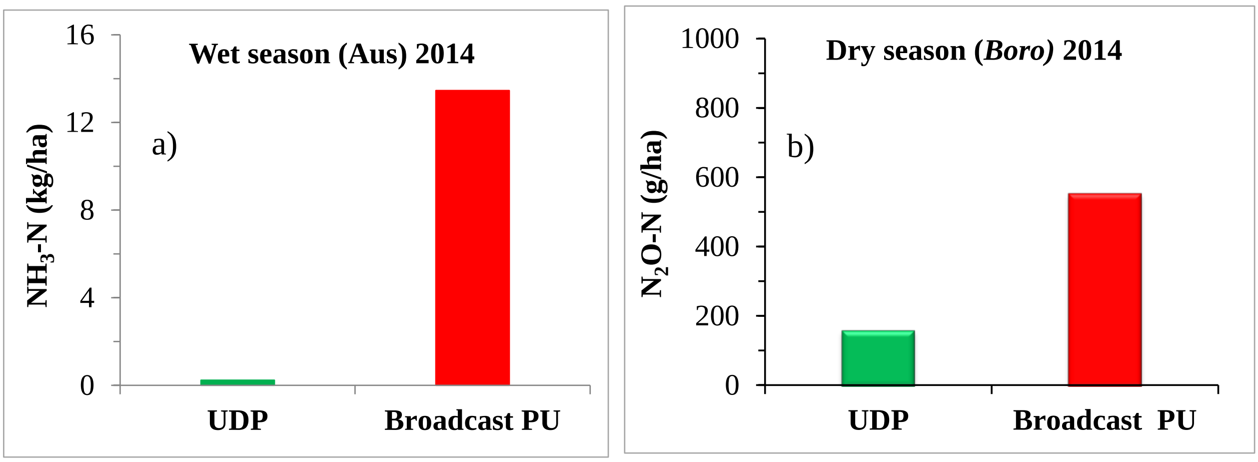

Figure 2. Nitrogen loss as (a) nitrous oxide (N_2O-N) emissions and (b) ammonia (NH_3) volatilization from urea deep placement (UDP) and broadcast prilled urea (PU) at Bangladesh Agricultural University (BAU).

Conclusion

Deep placement of urea and NPK briquettes with ~30% less fertilizer compared to broadcast prilled urea significantly increased grain yields and nitrogen use efficiency compared to broadcast prilled urea. Moreover, deep placement significantly reduced floodwater ammonium nitrogen, ammonia volatilization, and nitrous oxide emissions. FDP increases yields and farm profitability (Miah et al., 2016) while reducing fertilizer use and environmental hazards, generating agronomic, economic, and environmental benefits.

Some of the challenges for wider dissemination of FDP are availability of the fertilizer briquettes and labor for deep placement. Overcoming these challenges will require government and private sector initiatives to make fertilizer briquettes more widely available while developing efficient mechanized on-farm deep-placement solutions. This will have immediate impacts, particularly for large producers and consumers of N fertilizer, such as China and India. Some research conducted in China has shown higher economic returns and use efficiency from FDP trials but emphasized the need for mechanization for broader dissemination (Liu et al., 2015).

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