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Fertilizer deep placement increases nitrogen use efficiency and rice productivity

Yam Kanta Gaihre [1], Upendra Singh[1], Azmul Huda[2], S.M. Mofijul Islam[3], M. Rafiqul Islam[2], JatishChandra Biswas[3], Josh DeWald[1]

[1] *International Fertilizer Development Center (IFDC), Muscle Shoals, 35622 USA, ygaihre@ifdc.org*
[2] *Bangladesh Agricultural University (BAU), Mymensingh, Bangladesh*
[3] *Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh*

Abstract: Increasing nitrogen fertilizer application has increased crop productivity and met the food demands of growing populations, but its use efficiency is very low. Morethan 50% of applied nitrogen is not utilized by crops,posing huge economical costs and environmental concerns. Therefore, fertilizer management should consider optimum time, rates, source 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. Experiments were conducted at different locations of Bangladesh to determine the effects of urea deep placement (UDP) and multi-nutrient fertilizer briquette (NPK) deep placement vs 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 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 labour is sufficientfor cultivation, but requires modifications to work in larger scale farming systems where labour availability is an issue.Due to the increasing trend of labour outmigration, availability of labour has become one of the major issues of FDP adoption. Another issue relates to the non-availability of fertilizer briquettes throughout the country. Therefore, for large scale dissemination in other countries such as 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.

Key words: Fertilizer deep placement, nitrogen management, environment, rice, greenhouse gas emissions

1. Introduction

Fertilizer use has played a crucial role in meeting the food demand of a growing world population. The use of nitrogen (N) fertilizer for cereal crop production has increased consistently since the 1960s. N fertilizers are being used excessively in most countries in Asia, leading to imbalanced use of nutrients. Nfertilizer is the most consumed fertilizer in the world, with use projected to rise by 1.4% each year through 2018 (FAO 2015). However, more than 50% of applied N is not utilized by plants and lost to the environment (Savant and Stangel 1990). The excessive use of fertilizers poses a huge environmental cost in addition to reduced farm profitability, particularly in light of more recent discussions of planetary boundaries associated with anthropogenic N removed from the atmosphere. Therefore, concerns on fertilizer use efficiency along with the imbalanceduse of nutrients are growing, with immediately applicable N use efficiency enhancing measures being of paramount importance.

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. 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 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%. Moreover, deep placement of compound fertilizer (NPK) briquettes was recently introduced in Bangladesh, supplying all three major nutrientsin 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.

In this paper, we present a case of Bangladesh, where FDP technology is widely disseminated, discussing both the benefits of FDP and the challenges to broader adoption. We present these findings not just 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. The majority of the farmers in Bangladesh are small land holders (<2 ha). Therefore, FDP technology is being disseminated by the Government of Bangladesh in partnership with IFDC by developingmicro-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 retailors' 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). Some of the challenges for wider dissemination are availability of the fertilizer briquettes and labour 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. China alone consumes 29% of the world total fertilizer followed by South Asia (20%) (IFA 2013).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). Given that China and India have recently committed to increasing fertilizer use efficiency – with China's laudable goal of zero growth in N fertilizer us by 2020 being a prime example – FDP could be a key technology to contribute to these goals.

2. Methods

2.1 Study site and fertilizer treatments

Field experiments were conducted in Bangladesh in 2012-2015 to compare the effects of fertilizer deep placement on grain yields, NUE and nitrogen losses. Treatments included broadcast prilled urea (PU), urea deep placement (UDP) and compound fertilizer deep placement (NPK).Grain yields and total aboveground nitrogen uptake were recorded at harvest.

2.2 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).

3. Results

3.1 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^{-1}) 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 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)

3.2 Floodwater ammonium, ammonia volatilization and nitrous oxide emissions

Fig. 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 N0 plot. Deep placement of fertilizer briquettes in 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 (Fig. 2a).

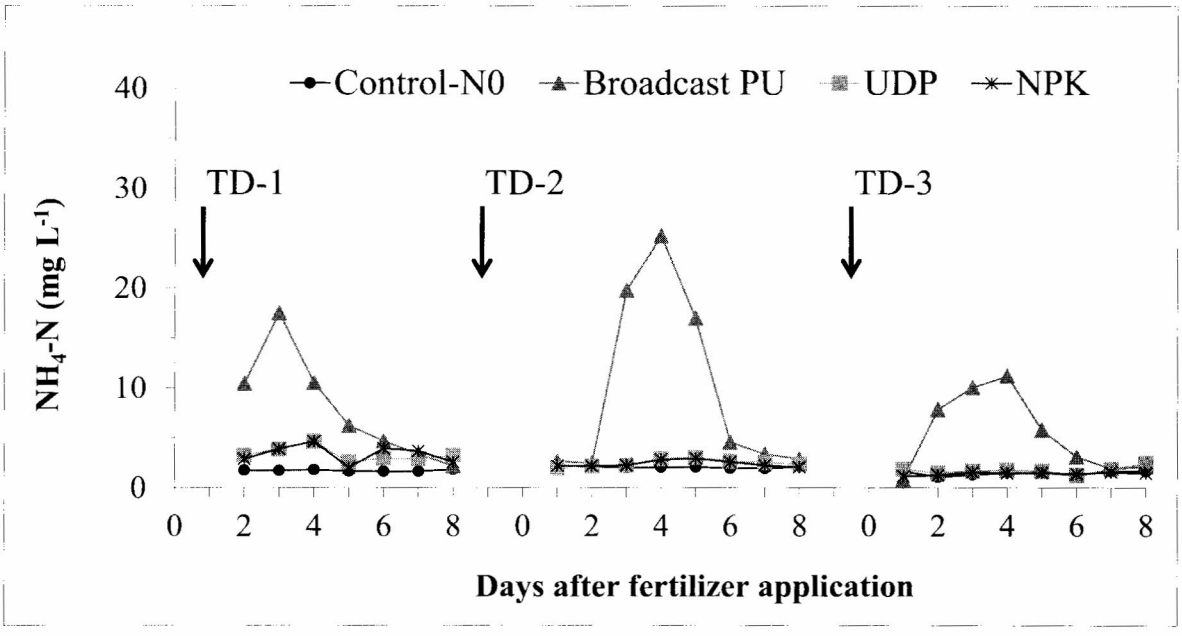

Fig. 1 Dynamics of floodwater ammonium (NH_4-N) under control (N0), broadcast PU, urea deep placement (UDP) and NPK deep placement (NPK) treatments (104 kg N ha^{-1}) at Bangladesh Rice Research Institute (BRRI) during dry season (Boro) 2012. TD-1, TD-2, TD-3 represent first, second and third topdressing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

Fertilizer deep placement not only has potential to reduce nitrogen losses as surface runoff and ammonia volatilization but also to reduce greenhouse gas nitrous oxide emissions. Fig 2b shows the cumulative nitrous oxide emissions measured continuously throughout the dry (*Boro*) season 2014 at 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.

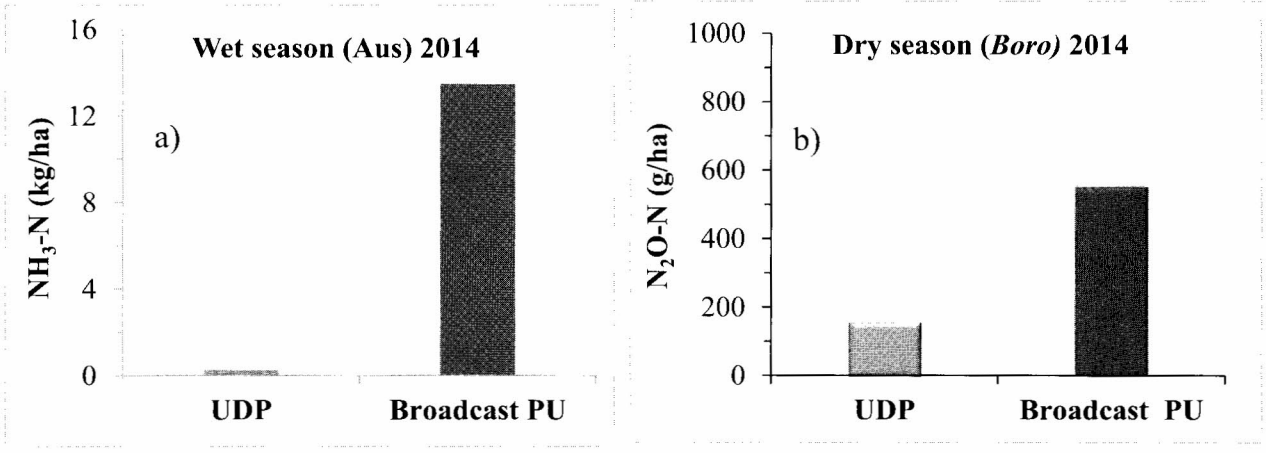

Fig. 2 Nitrogen loss as a) nitrous oxide (N_2O-N) emissions and b) ammonia (NH_3) volatilization from urea deep placement (UDP) and broadcast prilled urea (PU) at Bangladesh Agricultural University (BAU).

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.However, availability of fertilizer briquettes and mechanization of deep placement is needed for larger scale dissemination.

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