Journal of Agriculture and Environmental Sciences
December 2018, Vol. 7, No. 2, pp. 64-70
ISSN: 2334-2404 (Print), 2334-2412 (Online)

Published by American Research Institute for Policy Development
DOI: 10.15640/jaes.v7n2a7
URL: https://doi.org/10.15640/jaes.v7n2a7

Ammonia Assessment in Irrigated Rice System after Nitrogen Fertilizers Application

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Abstract

Nitrogen fertilization is widely used in irrigated rice fields in Burkina Faso, but its efficiency is very low due to the N- based greenhouse gas emitting traditional management practices. Urea deep placement (UDP) in lowland rice fields is one of the best currently applicable management techniques to mitigate N emissions while increasing N use efficiency. Floodwater ammonia concentration was quantify under irrigated rice field fertilized with N fertilizers prilled urea (PU) and briquettes—urea super granules (USG). Field experiments were carried out in Sourou valley in Burkina Faso in the wet season of 2012 and dry season of 2013. PU was broadcast and USG were point-placed deeply into the soil at 5–7 cm. Full rate (52 kg N ha^{-1}) of USG was applied and half rate of PU (29 kg N ha^{-1}) was applied. The concentrations of ammonium in the floodwater and the pH values were collected ten days after urea application was shown to be high with PU than USG. The use of USG reduced ammonium accumulation in the floodwater by 18 to 37% relative to the application of PU. Highest pH values were observed with the use of PU compared to USG. USG technology can reduce N accumulation in floodwater and thereby limit N losses in floodwater and N emissions into the atmosphere.

Keywords: urea deep placement; ammonia concentration; floodwater; rice

- Introduction

Management of nitrogen (N) fertilizer is an important factor in productivity and profitability. However, the current system of fertilization causes losses of about 60 to 70% of the applied N (Morales *et al*., 2000, Huda *et al.,* 2016). These losses are due to several factors including N fertilizer form, application mode, varietal differences, soil characteristics, cropping systems and weather conditions (Wang *et al*., 2010, Rahman and Zhang, 2018, Dobermann and Fairhust, 2000). Only 30 - 40% of N fertilizer applied by conventional broadcasting method is available for plant growth; the rest of the N is subject to losses through ammonia volatilization, denitritification, leaching, runoff, and biological or chemical immobilization (Craswell *et al*., 1981; Ladha *et al.,* 2005). Several distinct layers are observed in paddy rice soils following flooding. Flooded zone varies in depth (1 – 15 cm) and this layer is colonized by bacteria and algae which contribute to biological N fixation. The surface of this zone also increases with the submersion duration (Chowdary *et al*., 2004). Beneath this zone, a thin layer of oxidized soil (usually < 10 mm) remains oxidized after flooding because of the diffusion of O_2 (Dobermann and Fairhurst, 2000). This oxidized layer promotes the development of microorganisms and their numbers increase during submersion. When ammonium-N fertilizer (e.g. urea, ammonium sulphate) is broadcasted into the floodwater, N hydrolysis and nitrification take place in the oxidized zone (Mosier *et al*., 1990). NH_4^+ ions diffuse into the oxidized soil following hydrolysis and are absorbed by the rice plant either directly or following nitrification, or become temporally immobilized in soil organic- N pool. After nitrification of NH_4^+-N in the oxidized layer, NO_3^--N is either taken up by rice root or leached into the reduced soil layer, where it is denitrified and is lost as ammonia by volatilization and N_2 gas by denitrification (Dobermann and Fairhurst, 2000).

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Flooded soils are anaerobic area where ammonification process is more pronounced than nitrification. The inefficient recoveries of N by plants are caused by nitrate leaching and emissions of N_2O and NO_x gas forms from agricultural soil with health and environmental implications (Whitehead, 2000, Rahman and Zhang, 2018). The main source of nitrogen supply is ammonia (Gaudin, 1991). Irrigated rice cultivation and urea deep placement technologies are expanding in Burkina Faso and information on ammonia fate in floodwater is hardly available. This study was carried out to investigate N metabolism when applied as PU broadcast or point deep placed as USG, and understand the associated environmental implications towards increasing N use efficiency in irrigated rice systems.

- **Materials and methods**

- **Experimental site**

The study was carried out in Sourou Valley during 2012 and 2013 in the wet seasons. The valley is an intensively cultivated area with a potential irrigated land of about 615,000 ha. The irrigation water is supplied by Sourou River with a capacity of 600,000,000 m^3. The geographic coordinates are 13°00' latitude North 03°20' longitude west. The region of Sourou is characterized by a north Soudanian climate with an average rainfall below 900 mm. Temperature are stable and between a minimum of 17°C in coolest season and maximum of 41°C in hottest season. The soils in Sourou Valley are mainly brown, poorly developed, hydromorphic soils and Vertisols with fine texture, high water retention capacity, low permeability, poor ventilation of subsurface horizons and strong compaction (Faggi and Mozzi 2000).

- **Floodwater sampling and pH measurement**

Field experiment on the effect of fertilizer deep placement with urea supergranule on nitrogen use efficiency in irrigated rice system was used to evaluate floodwater pH and ammonium. A recommended rate of phosphorus (69 kg of P_2O_5 ha^{-1}) and potassium (24 kg of K_2O ha^{-1}) were applied uniformly to all pots at transplanting, as basal in the form of triple superphosphate and muriate of potash respectively. One granule of 1.8 g corresponding to 52 kg N ha^{-1} was placed seven days after transplanting between four plants in the pot receiving USG. The prilled urea was split into two at the same rate. The first half was applied 14 days after transplanting. Half rate of PU (57 kg N ha^{-1}) was applied and full rate of USG (113 kg N ha^{-1}) was applied for the experiment. Floodwater pH was taken during 10 days after prilled and supergranules urea application. A pH - meter was used to read directly the value of pH in each plot. Floodwater samples were taken before and after urea application during ten (10) days. Plastic bottles of 150 ml were used to sample floodwater. The samples were kept in the refrigerator until analysis of ammonium ($NH4^+$) was carried out.

- **Floodwater analysis**

Floodwater $NH4^+$ concentrations were determined in the laboratory by the colorimetric method. The colorimetric method for $NH4^+$ quantification was the phenol-hypochloride method. Ammonium ion reacts with hypochlorous acid and salicylate ions in the presence of nitroferricyanide to form the salicylic acid analog of indophenol blue.

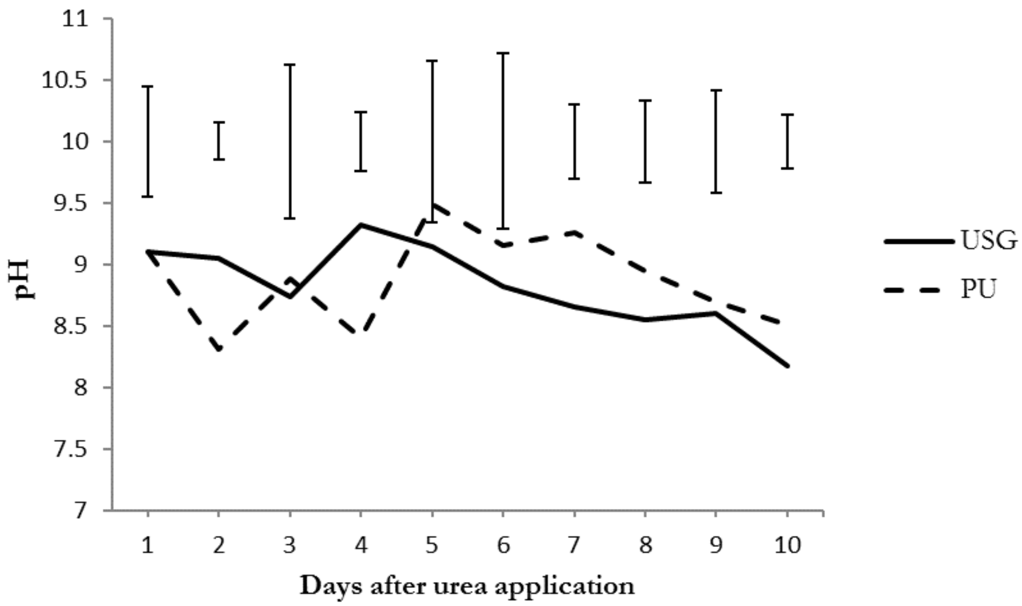
- **Data analysis**

Repeated measurement was conducted with Genstat package edition 9th to determine the significance of the effects of N fertilization. Analysis of variance was conducted to determine significance among yields. Treatment means were compared with the least significant different (Lsd) at the probability of 0.05.

- **Results**

- **Changes in floodwater pH after urea application**

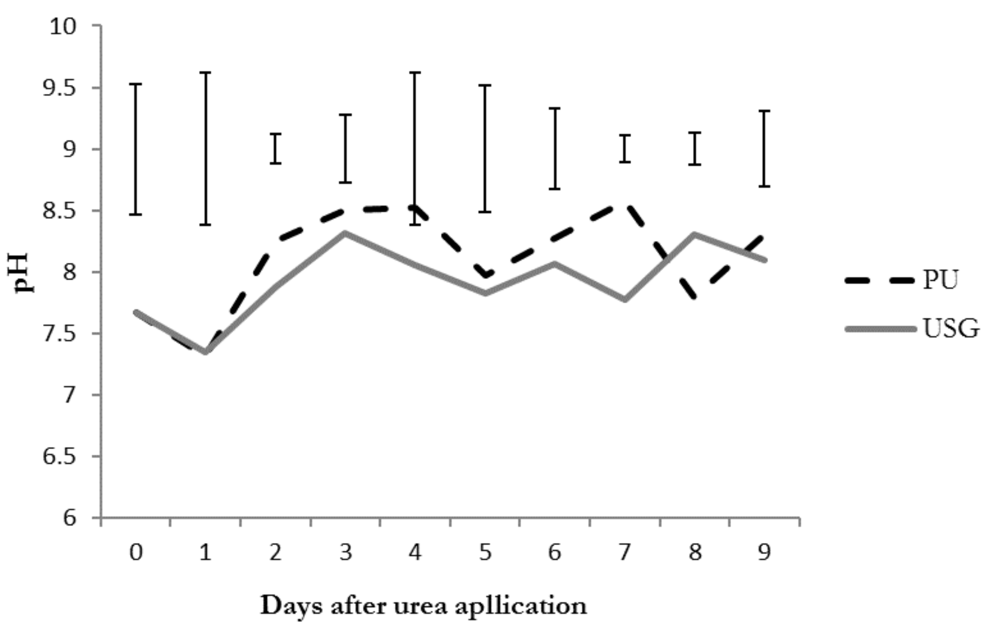
Significant difference ($P<0.05$) was observed in the pH values between the treatments and time during the wet season of 2012. In general, pH value of floodwater fluctuated during 3 days after urea application in general. When PU was used a peak (pH = 9.49) was observed 5 days after urea application and then declined (Figure 1).



Bars indicate Lsd (5%)

Figure 1: Changes in floodwater pH in irrigated rice field in the wet season of 2012.

Similar trend was observed with USG which peaked 4 days after urea application (pH = 9.32). Floodwater pH (Figure 2) during the wet season of 2013 followed a similar pattern with the two treatments after urea application. No significant difference was observed between USG and PU (half rate) after urea application. The highest (8.12) and the lowest (7.96) floodwater pH values were observed with PU applied at half rate and USG full rate, respectively.

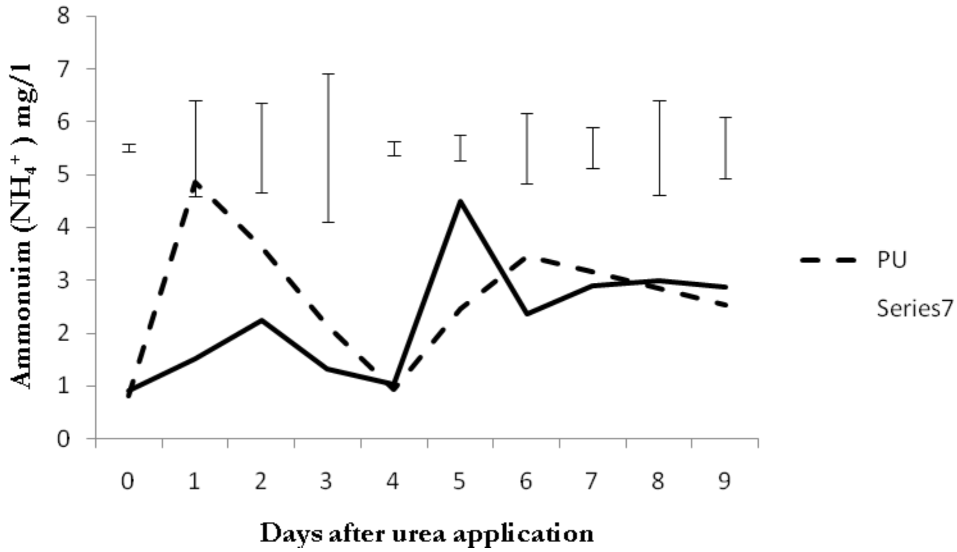


Bars indicate Lsd (5%)

Figure 2: Changes in floodwater pH in irrigated rice field in the wet season of 2013.

- Ammonium concentration in floodwater after urea application

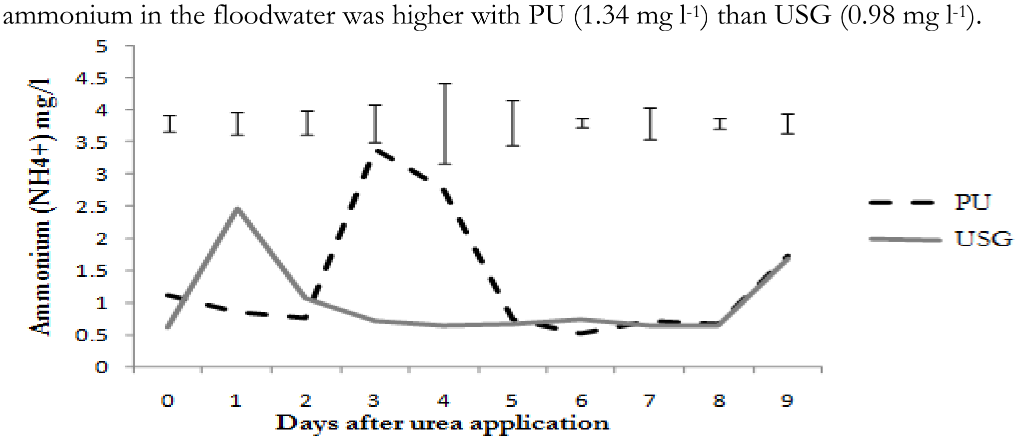
After urea application, there was an increase in NH_4^+-N concentrations in the floodwater in all plots in 2012 wet season. The NH_4^+-N concentration in floodwater increased and reached a peak value of 4.85 mg l^{-1} in one day after prilled urea application. In contrast, a peak of NH_4^+-N (4.49 mg l^{-1}) was observed 5 days after USG application (Figure 3). There was a significant ($P<0.05$) interaction between the treatment and the time of urea application even though half of PU rate (57 kg ha^{-1}) was applied 14 days after transplanting and the full USG rate (113 kg ha^{-1}) was deep placed 7 days after transplanting. Significant difference ($P<0.05$) was observed between the two treatments (PU and USG). The highest and lowest NH_4^+ concentration was recorded with PU (2.68 mg l^{-1}) and USG (2.26 mg l^{-1}), respectively.



Bars indicate Lsd (5%)

Figure 3: Evolution of ammonium in floodwater after urea application in irrigated rice field in the wet season of 2012.

A significant difference ($P <0.05$) was observed between the two treatments during 2013 wet season. After urea application NH4+ concentration in floodwater treated with USG quickly increased and a peak value (2.46 mg l^{-1}) was observed after one day. A decrease of NH_4^+-N concentration was observed with floodwater with PU one day after urea application. A peak value (3.40 mg l^{-1}) was observed 3 days after urea application. The concentration of floodwater (NH_4^+-N) increased after 8 days of urea application for the two treatments (Figure 4). The overall concentration of ammonium in the floodwater was higher with PU (1.34 mg l^{-1}) than USG (0.98 mg l^{-1}).



Bars indicate Lsd (5%)

Figure 4: Evolution of ammonium in floodwater after urea application in irrigated rice field in the wet season of 2013.

- **Discussion**
- **Effect of urea application on pH of floodwater**

The increase in floodwater pH after urea application observed especially during the wet season of 2012 can be explained by the fact that urea N stimulates the growth of photosynthetic microorganisms. These, in turn increase the pH of the floodwater through CO_2 uptake (Stangel *et al.,* 1984). The importance of floodwater algae in the transformation of applied N fertilizer is well recognized; mainly because they cause an increase in floodwater pH during the day (Thind *et al*., 2000; Mikkelsen *et al*., 1978; Simpson *et al*., 1988). The increase of floodwater pH can also be due to the inherent alkalinity associated with urea hydrolysis. Vlek and Craswell (l981) suggested that the reduction in pH often noted after the application of N fertilizer to non - buffered floodwater is the result of H^+ ion accumulation during NH_3 volatilization due to the presence of ammonia in floodwater. The increase in floodwater pH can also be attributed to the fact that floodwater induces anaerobic conditions that inhibit nitrification and favours nitrate reduction which, tends to increase floodwater pH (Dobermann and Fairhurst, 2000).

Floodwater pH values decrease 3 days after USG application and 4 days after PU application in 2012. These results are in agreement with the findings of Vlek and Craswell (1981) who found that the hydrolysis of urea ends 3 to 4 days after urea application, which decreased the concentrations of $(NH_4)_2CO_3$ and also decreased the pH of floodwater. In 2013 cropping season, variation of pH values in floodwater was significantly influenced by the mode of urea application. The flooded rice field is usually a temporary aquatic environment subject to large variations of pH. This fluctuation can be attributed to microbial activities as reported by Roger (1996) that largest daily variations in pH occur at the beginning of the crop cycle when explosive blooms of microalgae develop after N fertilizer is broadcast in the floodwater. In fact, broadcasting method of N fertilizer encourages algal growth.

According to their findings, the N loss resulted from a chemical process caused mostly by a marked increase in floodwater pH in relation to algal activity. Futhermore, practices that decrease algal growth such as urea deep placement decrease diurnal variations in pH.

- **Ammonium concentration in floodwater after urea application**

The peak of NH_4^+ concentration was observed during the two seasons between one to 5 days after urea application. These results are in conformity with the findings of Fillery *et al.* (1984) who reported that urea hydrolysis takes place before one week after urea application. The peak of NH_4^+-N concentration from USG was reached 5 days after application in 2012 cropping season and only one day after urea application in 2013 cropping season. This difference can be attributed to the weather conditions during the cropping season (hot temperature 28°C in average and wind). The temperature variation during the cropping season can affect urea hydrolysis (Dobermann and Fairhust, 2000). The amount of NH_4^+ in floodwater was significantly ($P<0.05$) higher in the floodwater with PU than USG during the two seasons. Rapid hydrolysis of urea leads to high concentrations of NH_4^+ in the floodwater especially when urea is broadcast directly in floodwater. Similar trends were reported by Snitwongse *et al.* (1988) and Craswell *et al.* (1981). This result is likely due to the fact that urea supergranules when deep placed in the soil (5 to 7 cm), hinders the escape of urea and ammoniacal_N formation in floodwater. The latter reduces the contact of urea with floodwater, avoiding rapid hydrolysis of urea and causing elevation of NH_4^+ in floodwater. The increased ammoniacal - N concentrations in floodwater after the application of urea highlight the potential for NH_3 volatilization from this N source as floodwater ammoniacal-N is proportional to the partial pressure of ammonia, which is directly proportional to ammonia volatilization (Freney *et al*., 1983; Fillery and Vlek, 1986). Thus, the amount of ammoniacal-N present in floodwater provides an estimate for potential volatilization. According to De Datta and Crasswell (1980) and Gaihre *et al*., 2016, broadcast application of urea on the surface of soil causes losses up to 50%, but point placement of USG in 10 cm depth may result in negligible loss. The possible reasons for the decline in NH_4^+-N concentrations in the treatments is the assimilation of N by algae, NH_3 volatilization, nitrification and/or diffusion into the underlying soil layers (Thind and Rowel, 2000).

- **Conclusion**

This study was focused on comparative environmental advantages of two mode of N application including urea deep placement (UDP) using urea supergranule (USG) and prilled urea (PU) broadcast. The results provided insight in the N metabolism, N emissions and pH-variation when using USG in Burkina Faso. The use of USG reduced ammonium accumulation in the floodwater by 18 to 37% relative to the application of PU, hence, potentially reduces volatilization of harmful N greenhouse gases, as well as groundwater and waterway contamination.

UDP-technology is an economically viable and environmentally sound N management practice to reduce N fertilizer losses while increasing rice productivity in irrigated rice systems.

Acknowledgments

The authors are very grateful to Alliance for Green Revolution in Africa (AGRA) for financing this study through their scholarship support to lead author. We also like to thank International Fertilizer Development Center (IFDC) and the National Institute of Environmental and Agricultural Research (INERA) for their technical and material support.

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