# WATER MANAGEMENT PRACTICES AND NITROGEN SOURCES EFFECTS ON N-MINERALIZATION AND USE EFFICIENCY IN RABI PADDY (*Oryza sativa* L.) IN SOUTHERN TELANGANA

## ABSTRACT

A field study was conducted on clay loam soil at college farm, College of Agriculture, Rajendranagar, Hyderabad, Telangana, India During Rabi 2015-16 and *Rabi* 2016-17, to investigate the effect of water management strategies and nitrogen sources on rice N-mineralization patterns. The experiment was laid out in a split plot design under two types of water management practices i.e., Continuous flooding (CF) and alternate wetting and drying (AWD) as main treatments with five treatments *viz*., $T_1$- $N_0$:$P_2O_5$ @ 60 kg $ha^{-1}$: $K_2O$ @ 60 kg $ha^{-1}$ (Control); $T_2$- Nitrogen @ 120 kg $ha^{-1}$ (Prilled Urea): $P_2O_5$ @ 60 kg $ha^{-1}$: $K_2O$ @ 60 kg $ha^{-1}$ $T_3$- Soil test based Nitrogen fertiliser application (STCR); $T_4$- Nitrogen @ 60 kg $ha^{-1}$ + 60 kg $ha^{-1}$ through green manure and $T_5$- Nitrification inhibitor Coated Urea as sub plot treatments. The MTU-1010 variety was grown with the recommended management practices. Continuous flooding plots were kept at a 5cm water level at all times, while alternate wetting and drying plots were irrigated when a hairline fissure emerged on the soil surface.

Significantly $NH_4^+$-N content increases with time and peaked at 15 DAT under continuous flooding as well as alternate wetting and drying (27.12 mg $kg^{-1}$ and 28.28 mg $kg^{-1}$). Green manure treatment resulted in faster $NH_4^+$ -N release and accumulation, in the order of Green manure > PU > STCR > coated urea > control treatments. In comparison to STCR and green manure, $NO_3^-$-N release was low in coated urea, followed by prilled urea. Alternate wetting and drying resulted in 29 per cent greater AE than continuously flooded rice. The treatment which receives nitrogen through STCR (21.30 kg grain yield per kg N applied and 23.94 kg grain yield per kg N applied) followed by nitrification inhibitor coated urea treatment had the highest AE.

**Key words:** Mineralization, Coated urea, Green manure, continuous flooding, Alternate drying and Rice

## 1. Introduction:

Rice (*Oryza sativa*) is the most important staple food for a large part of the world's human population (about 3 billion) and supplies as much as half of the daily calories of the world population (Abbasi *et al*., 2011). It is the grain with the second-highest worldwide production, after maize (corn) covering around 161 M ha with an annual production of 701 million tons (FAOSTAT, 2017). In India, 43.79 M ha of area was under rice cultivation in 2017-18 (Indiastat, 2018). An increase in rice production is essential to ensure global food security (Hu *et al.,* 2014). This crop can be grown in different environments, depending upon water availability. The traditional method for cultivating rice is flooding the fields, puddling the soil and then transplanting the young seedling (IPCC, 2007).

Today, only 30-40% of applied N fertilizer is used by crops (Ladha *et al*., 2005) and more than 60% of applied N is lost because of the lack of synchrony of plant demand with N supply (Singh and Singh, 2003) from agricultural fields, results in polluting the environment. A primary goal of improved fertilizer management practice is to increase the recovery efficiency of N *i.e.*, N uptake per unit of N application (kg $kg^{-1}$) in crop production and reduce loss to environment (Pathak, 2010). In many field situations, Site-specific nutrient management approach for rice has been evaluated at numerous locations in Asia and has been found to be more efficient than the conventional methods (Bhatia *et al.*, 2011). The aim of the present study was to improve the use efficiency of applied nitrogen fertilizer in synchrony with the crop requirements under different water management practices.

## 2. Material and methods

The present investigation was carried out during *rabi* (October to March), 2015 and 2016 at the College Farm, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad at an altitude of 542.6 m above mean sea level falls under the Southern Telangana agro-climatic zone of Telangana.

Soil samples were collected and stored in the refrigerator for nitrogen analysis. N fractions were determined by using extraction-distillation method as suggested by Bremner and Keeney (1966) as detailed below:

### 2.1 Ammonical nitrogen

The incubated soil samples (10 g) as per the treatments were shaken for 1 hour on mechanical shaker after adding 100 ml of 2M KCl-1000ppm $Ag_2SO_4$ solution. The extract was then filtered and 20 ml of aliquot was pipette out from the filtrate into distillation flask and 0.2 g MgO was added and attached to distillation unit. A 250 ml conical flask was taken and 25 ml of 2% boric acid containing mixed indicator was added and was kept at the receiving end of the distillation unit. Distillation of the sample was done for 5 min. Then, the boric acid mixed indicator was titrated with 0.005N $H_2SO_4$ till the colour changes from green to a permanent, faint pink. The titre values were recorded and $NH_4^+$-N was calculated and expressed in mg $kg^{-1}$.

### 2.2 Nitrate nitrogen

Then to the same distillate which was used for the determination of $NH_4^+$-N. 0.2 g Devarda’s alloy was added and immediately attached to the distillation apparatus. Distillation was continued for 5 min with the fresh boric acid mixed indicator solution. Then $NO_3^-$-N was determined by titrating the boric acid mixed indicator solution with 0.005N $H_2SO_4$ till the colour changes from green to a permanent, faint pink.

## 3. Results and discussion

### 3.1 Effect of water management practices and nitrogen sources on N-mineralization

$NH_4^+$-N grew significantly with time and peaked at 15 DAT under continuous flooding as well as alternate wetting and drying (27.12 mg $kg^{-1}$ and 28.28 mg $kg^{-1}$). The $NH_4^+$-N concentration in both years decreased considerably after 15 DAT under continuous and alternate drying (Table. 1 and 2). The rapid hydrolysis of prilled urea, which exhausts the urea as well as nitrification, ammonia volatilization and nitrous oxide emission from the soil, could be responsible. The results were similar to those of Mohapatra and Khan (1987), Singh et al. (2001), and Naidu et al. (2013).

In comparison to the other nitrogen treatments, green manure applied plots had significantly higher $NH_4^+$-N content. It is due to the green manure crop incorporation in the field resulted in a slower release of nutrients and less losses than prilled urea. After application of urea there was increase in $NH_4^+$-N content in both years. Interaction between water management practices and nitrogen sources on release pattern of $NH_4^+$-N. The ammonical-N content in continuous flooding was higher as compared to alternate wetting and drying whereas $NO_3^-$ -N was lower during both the years of study. The $NH_4^+$ -N under continuous flooding was 21.7, 21.9, 62.38, 22.57, 16.28 and 31.91% in 2015-16 and 21.0, 21.77, 21.19, 19.29, 19.24, 24.50% in 2016-17 was higher at 15, 30, 45, 60, 75 and 90 DAT, respectively than alternate wetting and drying. Whereas the $NO_3^-$ -N in alternate wetting and drying at 15, 30, 45, 60, 75 and 90 DAT was 14.34, 16.92, 17.61, 15.04, 24.58 and 13.75% in 2015-16 and 14.20, 20.06, 23.19, 22.33, 27.87 and 32.17% in 2016-17 higher, respectively over continuous flooding. Continuous flooding resulted in reduced $NH_4^+$-N and greater $NO_3^-$-N content due to urea hydrolysis and higher nitrification of $NH_4^+$ due to favourable soil moisture conditions for the nitrification process (Sannigrahi and Mandal, 1987; Kumar et al., 2000; Singh et al., 2001 and Gupta et al., 2003). The greater $NO_3^-$-N content in alternate wetting and drying is due to nitrification, an oxidation process that involves nitrifying bacterium that develops more quickly in well-aerated soils. As a result of the continuous flooding, $NO_3^-$-N levels dropped. (Kumar et al., 2000; Singh et al., 2001; Naidu, 2013; Prosser and Cox, 1983). Further it was observed that, the decrease in $NO_3^-$N after 60 days could be due to the production of nitric acid during nitrification under alternate wetting and drying conditions. Because nitric acid causes the soil to become acidic, which makes nitrification difficult. As a result, the rate of nitrification in the soil is retarded (Bhuiya et al., 1974).

Control (no nitrogen application) treatment released low quantities of $NH_4^+$-N throughout the crop period, ranging from 2.85 to 9.70 mg kg$^{-1}$ in 2015-16 and 2.30 to 11.20 mg kg$^{-1}$ in 2016-17. The amount of $NH_4^+$-N in the green manure applied treatment increased at 15 DAT (31.20 mg kg$^{-1}$ in 2015-16 and 32.15 mg kg$^{-1}$ in 2016-17) and then decreased until the end of the crop growth period, i.e. 90 DAT (21.10 mg kg$^{-1}$ in 2015-16 and 24.65 mg kg$^{-1}$ in 2016-17). Green manure treatment resulted in faster $NH_4^+$-N release and accumulation, in the order of Green manure > PU > STCR > coated urea > control treatments. These nitrification inhibitors also influence urea hydrolysis and acts as urease inhibitors, as observed by the reduced $NH_4^+$-N. The rate of urea hydrolysis, nitrification and $NH_4^+$ -N buildup varied depending on the treatment. Green manure has a higher concentration of $NH_4^+$ -N, indicating rapid urea breakdown, which limits the action of the urease enzyme. Purakayastha et al., 1997, and Parama and Munawery, 2012, both demonstrated that urease and nitrification inhibitory abilities of green manure inhibited urea hydrolysis. Whereas, 15 DAT higher $NH_4^+$ -N accumulation was observed in Green manure (31.20, 32.15 mg kg$^{-1}$), STCR (29.75, 30.90 mg $kg^{-1}$), prilled urea (27.60, 28.65 mg $kg^{-1}$), coated urea (22.60, 23.65 mg $kg^{-1}$) over control (9.20, 11.20 mg $kg^{-1}$) respectively during both the years. Whereas, the release of $NO_3^-$ -N was higher from STCR treated soil, which ranged from 11.50 to 17.00 mg $kg^{-1}$ in 2015-16 and 12.50 to 17.65 $NO_3^-$ -N at 15 to 60 DAT (Table. 3 and 4). The decrease in $NO_3^-$ -N was in the order of STCR > Green manure > PU > CU > Control. $NO_3^-$ -N release was low in coated urea followed by prilled urea as compared to application of STCR and green manure. The release of $NO_3^-$-N followed the order of $T_1 < T_5 < T_2 < T_4 < T_3$.

The values pertaining to percent decrease in release of $NO_3^-$ -N over STCR and Green manure clearly indicate highly significant inhibition of nitrification process with application of nitrification inhibitors till the end of crop period. These results indicate that nitrification inhibitors were highly effective in retaining $NH_4^+$ -N in mineral pool at higher concentration for longer period by reducing the nitrification and denitrification and this is evident by lower $NO_3^-$ -N content in natural nitrification inhibitors (Dharani *et al.,* 2009; Abbasi *et al.,* 2011; Abbasi and Manzoor, 2013 and Saha *et al.,* 2013).

### 3.2 **Effect of water management practices and nitrogen management practices on N use efficiency.**

Continuously flooded rice had significantly greater agronomic efficiency (AE) in 2016 than rice grown under alternate wetting and drying approach (Table 5). However, in 2017, the efficiency of water management systems was insignificant. Rice that was continually flooded had a 29 percent higher AE than rice that was wet and dried alternately. Dong et al., 2012, reported similar findings. With contrast to the above results, significantly higher agronomic N use efficiency (AEN, kg grain $kg^{-1}$ N applied) and N recovery efficiency (REN, %) was noticed in alternate wetting and drying over conventional flooding (Ye *et al.,* 2013). Significantly highest AE (21.30 kg grain yield per kg N applied and 23.94 kg grain yield per kg N applied) was observed with treatment received nitrogen through STCR followed by nitrification inhibitor coated urea treatment (19.89 kg grain yield per kg N applied and 17.67 kg grain yield per kg N applied). However which was comparable with green manure applied treatment (18.43 kg grain yield per kg N applied and 17.46 kg grain yield per kg N applied) in both the years respectively. With application of nitrogen based on STCR significantly improved AE of 26.5 % and 41.6 % over prilled urea applied plot respectively in both the years.

STCR treatment showed significantly highest apparent recovery efficiency (45.27 % and 49.93 %) and superior over other treatments. Results were in accordance with the findings of Wang *et al.,* 2000; Dong *et al.* (2012) also noted higher loss of fertilizer N through nitrification-denitrification under AWD irrigation than in continuous flooding (0.04 vs 0.22 g N $m^{-2}$), but it removed only 2.5 per cent of the total applied N fertilizer which was quantitatively insignificant and negligible.

## Conclusion:

From the present study it can be concluded that coated nitrogen fertilizers with nitrification inhibitors highly effective in reducing the losses of N as ammonical and nitrate form and helps in retaining $NH_4^+$ -N in mineral pool at higher concentration for longer period by reducing the nitrification and denitrification process. Whereas highest agronomic efficiency and recovery efficiency was observed in nitrogen applied with soil testing treatment.

## References:

Abbasi MK, Manzoor M. Effect of soil-applied calcium carbide and plant derivatives on nitrification inhibition and plant growth promotion. *International Journal of Environmental Science and Technology*. 2013. 10: 961–972.

Abbasi MK, Hina M, Tahir MM. Effect of *Azadirachta indica* (neem), sodium thiosulphate and calcium chloride on changes in nitrogen transformations and inhibition of nitrification in soil incubated under laboratory conditions. *Chemosphere*. 2011. 82: 1629-1635.

Bhatia A, Pathak H, Jain N, Singh PK, Tomer R. Greenhouse gas mitigation in rice–wheat system with leaf color chart-based urea application. *Environment Monitoring and Assessment*. 2011. 1-13.

Bhuiya ZH, Sattar MA Islam MS. Yield and nitrogen uptake by rice in relation to nitrogen release from modified urea materials. *Journal of the Indian Society of Soil Science.* 1974. 22 (1): 31-35.

Bremner JM, Keeney DR. Determination and isotope-ratio analysis of different forms of nitrogen in soils. 3. Exchangeable ammonium, nitrate, and nitrite by extraction-distillation methods. *Soil Science Society of America Proceedings.* 1966. 30: 577-582.

Dharani D, Patra, Usha K, Sukhmal C, Mohd A. Use of urea coated with natural products to inhibit urea hydrolysis and nitrification in soil. *Biology and fertility of soils*. 2009. 45: 617–621.

Dong NM, Brandit KK, Sorensen J, Hung NN, Hach CV, Tan PS and Dalsgaard T. Effects of alternating wetting and drying versus continuous flooding on fertilizer nitrogen fate in rice fields in the Mekong Delta, Vietnam. *Soil Biology and Biochemistry*. 2012. 47: 166-174.

Gupta RK, Arora BR, Sharma KN. Effect of urea and manures addition on mineral nitrogen content of the texturally divergent soils. *Journal of the Indian Society of Soil Science*. 2003. 51 (2): 63-67.

http://www.fao.org/3/i3107e/i3107e00.htm

https://www.indiastat.com

Hu MY, jian GD, Jun LL, Qin WZ, Hao Z, Chang YJ. Changes in grain yield of rice and emission of greenhouse gases from paddy fields after application of organic fertilizers made from maize straw. *Rice Science*. 2014. 21(4): 224-232.

IPCC. Summary for Policymakers. Climate Change: Synthesis Report of Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom. 2007. 22.

Kumar U, Jain MC, Pathak H, Kumar S, Majumdar D. Effects of moisture levels and nitrification inhibitors on $N_2O$ emission from a fertilized alluvial clay loam soil. Current Science. 2000. 79 (2): 224–228.

Ladha JK, Pathak H, Krupnik TJJ, Six J, van Kessel C.. Efficiency of fertilizer nitrogen in cereal production: ret-rospects and prospects. *Advances in Agronomy.* 2005. 87:85–156.

Mohapatra SP, Khan SK. Dynamics of soil nitrogen fractions under different soil moisture regimes. *Oryza*. 1987. 24: 191-198.

Naidu A. Effect of moisture levels and coated urea fertilizers on release pattern of nitrogen in an alfisol and vertisol. *M.sc (Ag) Thesis*, Acharya N.G. Ranga Agricultural University, Hyderabad. 2013.

Parama VRR, Munawery A. Sustainable Soil Nutrient Management. *Journal of the Indian Institute of Science*. 2012. 92: 1-16.

Pathak H. Mitigating greenhouse gas and nitrogen loss with improved fertilizer management in rice: quantification and economic assessment. *Nutrient Cycling in Agroecosystems*. 2010. 87: 443-454.

Prosser JI, Cox DJ. *In Experimental Microbial Ecology* (Burns, R.G and Salater, J.H. eds). Blackwell Scientific Publication, Oxford. 1983.178.

Purakayastha TJ, Katyal JC Goswami NN. Evaluation of ammonia volatilization from some modified urea fertilizers. *Journal of the Indian Society of Soil Science*. 1997. 45 (1): 9-14.

Saha S, Saha B, Antil RS, Dahiya DS. Urea hydrolysis and N transformation in soil amended with different proportions of neem cake. *Crop Research.* 2013. 45: 280-283.

Sannigrahi AK, Mandal LN. Mineralization of slow release nitrogenous fertilizers in soils. *Journal of the Indian Society of Soil Science*. 1987. 35: 10-18.

Singh B, Singh Y. Efficient nitrogen management in rice wheat system in the Indo-Gangetic plains. In Yadvinder Singh, Bijay-Singh, V. K. Nayyar, & J. Singh (Eds.), *Nutrient management for sustainable rice–wheat cropping system*. National Agricultural Technology Project. 2003. 99-114.

Singh Y, Grewal JPS, Singh B Khind CS. Effect of soil moisture on nitrification in a sandy loam soil. *Journal of the Indian Society of Soil Science*. 2001. 49 (2): 342-344.

Wang G, Dobermann A, Witt C, Sun Q, Fu R. Performance of site- specific nutrient management for irrigated rice in Southeast China. *Agronomy Journal*. 2000. 93: 869-878.

**Table 1. Effect of water management and nitrogen sources on release of ammonical nitrogen (mg kg$^{-1}$) in rice, during 2015-16**

| **Treatments** | **$NH_4$ - N (2016)** | | | | | |
|---|---|---|---|---|---|---|
| | **15 DAT** | **30 DAT** | **45 DAT** | **60 DAT** | **75 DAT** | **90 DAT** |
| $M_1$ | 27.12 | 23.60 | 24.62 | 20.20 | 21.62 | 17.38 |
| $M_2$ | 21.22 | 18.42 | 19.98 | 15.64 | 18.10 | 13.10 |
| SEm ± | 0.188 | 0.202 | 0.054 | 0.084 | 0.238 | 0.144 |
| CD (p=0.05) | 1.161 | 1.247 | 0.335 | 0.523 | 1.471 | 0.891 |
| $T_1$ | 9.70 | 6.10 | 6.60 | 4.50 | 5.00 | 2.85 |
| $T_2$ | 29.75 | 27.40 | 28.85 | 23.70 | 26.00 | 20.60 |
| $T_3$ | 27.60 | 24.55 | 25.85 | 21.30 | 23.15 | 18.65 |
| $T_4$ | 31.20 | 27.65 | 29.45 | 25.05 | 26.55 | 21.10 |
| $T_5$ | 22.60 | 19.35 | 20.76 | 15.05 | 18.60 | 13.00 |
| **SEm ±** | 0.234 | 0.175 | 0.356 | 0.385 | 0.225 | 0.289 |
| **CD (p=0.05)** | 0.702 | 0.526 | 1.068 | 1.154 | 0.676 | 0.866 |
| **MxT, SEm ±** | 0.421 | 0.452 | 0.121 | 0.189 | 0.533 | 0.322 |
| **CD (p=0.05)** | 1.295 | 1.100 | 1.534 | 1.684 | 1.372 | 1.400 |

$M_1$- Continuous flooding (CF); $M_2$-alternate wetting and drying (AWD); $T_1$- $N_0$:$P_2O_5$ @ 60 kg ha$^{-1}$: $K_2O$ @ 60 kg ha$^{-1}$ (Control); $T_2$- Nitrogen @ 120 kg ha$^{-1}$ (Prilled Urea): $P_2O_5$ @ 60 kg ha$^{-1}$: $K_2O$ @ 60 kg ha$^{-1}$; $T_3$- Soil test based Nitrogen fertiliser application (STCR); $T_4$- Nitrogen @ 60 kg ha$^{-1}$ + 60 kg ha$^{-1}$ through green manure and $T_5$- Nitrification inhibitor Coated Urea

**Table 2. Effect of water management and nitrogen sources on release of ammonical nitrogen (mg kg$^{-1}$) in rice, during 2016-17**

| Treatments | $NH_4$ - N (2017) | | | | | |
|---|---|---|---|---|---|---|
| | 15 DAT | 30 DAT | 45 DAT | 60 DAT | 75 DAT | 90 DAT |
| $M_1$ | 28.28 | 25.04 | 25.76 | 22.18 | 23.42 | 19.02 |
| $M_2$ | 22.34 | 19.59 | 20.30 | 17.90 | 18.82 | 14.36 |
| SEm ± | 0.198 | 0.197 | 0.249 | 0.106 | 0.092 | 0.089 |
| CD (p=0.05) | 1.221 | 1.218 | 1.541 | 0.658 | 0.572 | 0.553 |
| $T_1$ | 11.20 | 6.85 | 5.45 | 3.95 | 3.10 | 2.30 |
| $T_2$ | 30.90 | 28.30 | 29.55 | 26.65 | 27.80 | 22.65 |
| $T_3$ | 28.65 | 26.23 | 27.70 | 24.30 | 25.50 | 19.90 |
| $T_4$ | 32.15 | 29.35 | 30.50 | 27.15 | 29.05 | 24.65 |
| $T_5$ | 23.65 | 20.85 | 21.95 | 18.15 | 20.15 | 13.95 |
| SEm ± | 0.265 | 0.353 | 0.271 | 0.241 | 0.178 | 0.119 |
| CD (p=0.05) | 0.796 | 1.060 | 0.814 | 0.725 | 0.535 | 0.359 |
| MxS, SEm ± | 0.442 | 0.441 | 0.558 | 0.238 | 0.207 | 0.200 |
| CD (p=0.05) | 1.433 | 1.758 | 1.573 | 1.143 | 0.873 | 0.648 |

**Table 3. Effect of water management and nitrogen sources on release of nitrate nitrogen (mg kg$^{-1}$) in rice, during 2015-16**

| **Treatments** | **$NO_3$ - N (2016)** | | | | | |
|---|---|---|---|---|---|---|
| | **15 DAT** | **30 DAT** | **45 DAT** | **60 DAT** | **75 DAT** | **90 DAT** |
| $M_1$ | 8.24 | 10.80 | 8.98 | 11.52 | 7.24 | 5.96 |
| $M_2$ | 9.62 | 13.00 | 10.90 | 13.56 | 9.60 | 8.16 |
| SEm ± | 0.157 | 0.120 | 0.078 | 0.008 | 0.106 | 0.162 |
| CD (p=0.05) | 0.971 | 0.741 | 0.485 | 0.050 | 0.658 | 1.003 |
| $T_1$ | 5.75 | 4.95 | 3.90 | 3.15 | 2.00 | 1.40 |
| $T_2$ | 9.95 | 13.85 | 11.50 | 15.30 | 9.80 | 8.00 |
| $T_3$ | 11.50 | 16.00 | 13.95 | 17.00 | 12.35 | 10.70 |
| $T_4$ | 10.35 | 14.80 | 12.20 | 15.90 | 11.00 | 9.35 |
| $T_5$ | 7.10 | 9.90 | 8.15 | 11.35 | 6.95 | 5.85 |
| SEm ± | 0.274 | 0.209 | 0.231 | 0.263 | 0.226 | 0.268 |
| CD (p=0.05) | 0.822 | 0.628 | 0.693 | 0.790 | 0.679 | 0.805 |
| MxS, SEm ± | 0.352 | 0.268 | 0.176 | 0.018 | 0.238 | 0.363 |
| CD (p=0.05) | N.S. | 1.049 | 1.050 | 1.118 | 1.085 | 1.364 |

**Table 4. Effect of water management and nitrogen sources on release of nitrate nitrogen (mg kg$^{-1}$) in rice during 2016-17**

| **Treatments** | **$NO_3$ - N (2017)** | | | | | |
|---|---|---|---|---|---|---|
| | **15 DAT** | **30 DAT** | **45 DAT** | **60 DAT** | **75 DAT** | **90 DAT** |
| $M_1$ | 8.70 | 11.16 | 9.34 | 11.34 | 7.40 | 5.82 |
| $M_2$ | 10.14 | 13.96 | 12.16 | 14.60 | 10.26 | 8.58 |
| SEm ± | 0.315 | 0.198 | 0.104 | 0.244 | 0.106 | 0.188 |
| CD (p=0.05) | N.S. | 1.222 | 0.643 | 1.511 | 0.654 | 1.161 |
| $T_1$ | 5.65 | 5.10 | 4.60 | 3.60 | 2.40 | 1.70 |
| $T_2$ | 10.45 | 14.75 | 12.55 | 15.05 | 10.35 | 8.00 |
| $T_3$ | 12.50 | 16.65 | 14.45 | 17.65 | 12.65 | 11.20 |
| $T_4$ | 10.85 | 15.70 | 13.40 | 16.45 | 11.45 | 9.35 |
| $T_5$ | 7.65 | 10.60 | 8.75 | 12.10 | 7.30 | 5.75 |
| SEm ± | 0.235 | 0.215 | 0.211 | 0.225 | 0.252 | 0.208 |
| CD (p=0.05) | 0.705 | 0.647 | 0.634 | 0.674 | 0.758 | 0.626 |
| MxS, SEm ± | 0.706 | 0.443 | 0.233 | 0.547 | 0.237 | 0.421 |
| CD (p=0.05) | 1.556 | 1.249 | 1.022 | 1.383 | 1.184 | 1.201 |

**Table 5. Effect of water management and nitrogen sources on agronomic efficiency (kg grain kg$^{-1}$ N applied) and apparent efficiency (%) of N in rice**

| Treatments | 2016 | | 2017 | |
|---|---|---|---|---|
| | Agronomic efficiency | Apparent efficiency | Agronomic efficiency | Apparent efficiency |
| $M_1$ | 16.23 | 36.66 | 17.11 | 38.38 |
| $M_2$ | 13.88 | 24.74 | 12.09 | 23.30 |
| SEm ± | 0.75 | 1.69 | 0.39 | 0.36 |
| CD (p=0.05) | NS | 11.07 | 2.58 | 2.34 |
| $T_2$ | 15.65 | 28.39 | 13.96 | 24.55 |
| $T_3$ | 21.30 | 45.27 | 23.94 | 49.93 |
| $T_4$ | 18.43 | 38.69 | 17.46 | 39.61 |
| $T_5$ | 19.89 | 41.14 | 17.67 | 40.15 |
| SEm ± | 1.29 | 2.06 | 0.53 | 0.81 |
| CD (p=0.05) | 3.92 | 6.24 | 1.61 | 2.46 |