*Ann. Agric. Res. New Series Vol. 43 (2) : 127-133 (2022)*

# Integrated application of inorganic and bio-fertilizers affects nitrogen losses and yield of wheat (*Triticum aestivum* L.)

**Sibananda Darjee[1], Pooja LR[1], Ashish Khandelwal[1], Shiva Dhar[2], Manoj Shrivastava[1] and Renu Singh[1*]**

*Division of Environment Science, ICAR-Indian Agricultural Research Institute, New Delhi 110012, India*

Received: February 2022; Revised Accepted: May 2022

## Abstract

Nitrogen (N) is one of the most indispensable nutrients needed for wheat growth and production. Indiscriminate use of inorganic fertilizers leads to N losses from the agro-ecosystem which lower soil fertility, crop yield and impair the environment. N losses in agro-ecosystem majorly occur through ammonia volatilization and denitrification. Integrated application of inorganic and bio-fertilizer could reduce the N losses by synchronizing nutrient supply and demand of crop. Therefore, a field experiment was conducted at ICAR-Indian Agricultural Research Institute, New Delhi during rabi season of 2018–19 for determining the effect of inorganic and bio-fertilizer on N losses and yield of wheat. The experiment was laid out in randomized block design (RBD) replicated thrice. The experiment comprising of eight treatments involving, control (unfertilized, Tc), Azotobacter (Ta), Mycorrhiza (Tm), Azotobacter + Mycorrhiza (Tam), NPK recommended (Tr), Tr + Azotobacter (Tra), Tr + Mycorrhiza (Trm), Tr + Azotobacter + Mycorrhiza (Tram). Results have revealed that Tram showed the highest soil available P, and K. Application of Tram recorded the higher yield (6.4 t $ha^{-1}$) compared to Tr where it was obtained up to 5.8 t $ha^{-1}$. The ammonia volatilization and denitrification losses were reduced by 33.7% and 34.2% respectively, with application of Tram as compared to Tr. Hence, integrated application of inorganic and bio-fertilizers could be recommended in farmers field for reducing N losses as well as increasing wheat productivity.

**Keywords**: Ammonia volatilization, Bio-fertilizer, Denitrification, Root traits

## Introduction

Wheat (*Triticum aestivum* L.) is the most important crop across the world in terms of area and production. It contributes to be the essential component of human diet as primary source of calories for the world population (Braun *et al.* 2010). However, in India, the yield of wheat has been declining or stagnant due to crop lodging, imbalance fertilization, and mining of nutrients etc. (Jinger *et al.,* 2018; Jinger *et al.,* 2020). Indiscriminate use of inorganic nitrogenous fertilizers is the major reason for declining crop yield. N is one of the vital nutrients which mainly involve in plant growth and development (Kant 2018). However, it has been reported that after application, N losses occur through various ways such as runoff (Jinger *et al.,* 2022), ammonia volatilization (Yang *et al.,* 2020), denitrification (Wang *et al.,* 2017) and leaching (Jadon *et al.,* 2018) causes groundwater pollution, water eutrophication, and the greenhouse effect, and the release of nitrous oxides which in turn causes $O_3$ degradation in the stratosphere (Shi *et al.,* 2013). Nitrous oxide is naturally produced through the denitrification and nitrification in the nitrogen (N) cycle, there is a clear link between increased N application rates and increased $N_2O$ emissions (Snyder *et al.*, 2009). Due to these harmful environmental impacts, and the fact that emis-

*Correspondence address: renu_icar@yahoo.com
[2]Principal Scientist Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi 110012

sions are largely anthropogenic in nature, it is critical to identify options for reducing N losses from agriculture.

Although, there is hardly any scope for expansion of area under wheat in the country (Jinger *et al.*, 2022a) and therefore, increasing the productivity of wheat is sine qua non to meet out the food requirement of burgeoning population (Jinger *et al.*, 2020a). Proper nutrient management technique leads to better crop production. Therefore, integrated use of inorganic and bio-fertilizers could play an instrumental role in enhancing wheat productivity (Gupta *et al.*, 2020). Bio-fertilizer are nothing but mass of living microorganisms applied to soil, plant or incorporated with seeds before sowing, which promotes plant growth by increasing supply of nutrient to the plant (Malusa *et al.*, 2014). Gupta et al (2018) has reported that bio-inoculated nutrient management has resulted into enhanced productivity and profitability in pigeonpea under Indo-Gangetic plains of India. Similarly, a two-year experiment in hybrid rice systems using integrated nutrient management (INM) reported higher yield, NUE, and soil organic carbon compared to both organic and inorganic amendments alone (Mondal *et al.*, 2016). Although much research has been dedicated to the effects of INM on crop productivity, NUE, and aspects of soil quality, it remains unclear how INM impacts N losses. Considering all these adverse effect of chemical fertilizer, integrated application of biofertilizer along with recommended doses of fertilizer practices emerges out to be potential substitute for enhancing productivity, sustainability and mitigating environmental pollution through reduced losses of N.

## MATERIAL AND METHODS

The field experiment was carried out at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi during *rabi* season of 2018–19. The wheat cv. "HD 3086" was sown in third week of November on sandy loam soil which was low in organic carbon (0.45%), and K (68.4 kg/ha), medium in N (347 kg/ha), and P (21 kg/ha) with soil pH of 8.2, and electrical conductivity of 0.42 dS/m. The mean minimum and maximum temperature during the experimental period from November to April were 9.18 °C and 25.57 °C respectively. The climate of New Delhi is continental, sub tropical, and semi arid type and the annual average precipitation of this site was 650 mm, from which approximately 80% is due to south-west monsoon. Field experiment was laid out in RBD having 8 treatments and replicated thrice. All the 8 treatment were control (unfertilized, Tc), Azotobacter (Ta), Mycorrhiza (Tm), Azotobacter + Mycorrhiza (Tam), NPK recommended (Tr), Tr + Azotobacter (Tra), Tr + Mycorrhiza (Trm), Tr + Azotobacter + Mycorrhiza (Tram). The N, P, K were applied through urea, di-ammonium phosphate (DAP), and muriate of potash (MOP) respectively. The recommended fertilizer dosage were- 150 kg N, 60 kg $P_2O_5$, 60 kg $K_2O$/ha, and in case of Mycorrhiza treatment- 10 kg/ha and Azotobacter- 20 kg/ha. Fresh soil samples taken from 0–30 cm layer of soil at three different locations from each treatment were collected by using a tube auger. Three soil samples from each treatment were collected during tillering, flowering, grain-filling and physiological maturity of the crop. Analysis of the different soil properties were done by using standard procedures mentioned below. Total N content in soil and plant was determined by Kjeldahl method (Kjeldahl, 1883). Ammonical and nitrate form N in soil was determined by using continuous flow analyzer (Keeney and Nelson 1982). Available soil P and K soil was determined using Olsen's method and ammonium acetate method respectively (Olsen *et al.*, 1954; Hanway and Heidel, 1952). Soil organic carbon (SOC) was determined by using Walkley and Black Method (Walkley and Black 1934). Root traits were analyzed using Win-RHIZO, Reagent instruments Inc. Three representative plant roots were taken for each replication and scanning was done in triplicates for each treatment. Root scanning data were retrieved to calculate total root length, total root volume, total root surface area, average diameter, length of main roots, length of lateral roots, volume of main root, volume of lateral roots, surface area of main root and surface area of lateral roots. Ammonia volatilization estimated using force air graft method (Stumpe *et al.*, 1984). Denitrification potential of soil was determined using the acetylene inhibition method (Ryden *et al.*, 1979). The harvesting was done in fourth week of April, 2019. The yield and yield contributing characteristics *viz.* number of effective tillers and number of grains/spike, grain and straw yield were recorded. The data collected on various parameters under study were statistically analyzed and means were compared at 5% level of significance (Gomez and Gomez, 1984).

## Results and Discussion

### Soil nutrient status

The result showed that total N content varied significantly among the treatment ranging from 0.02% to 0.05% (Table 1). Tram showed the highest total N content in soil i.e. 0.05% which may be attributed due to integrated application of inorganic and bio-fertilizer which result in the slight enhancement of total N content of soil. The finding reported here are in good agreement with (Karad *et al.,* 2016). The available P significantly varied from 20.4 to 32.9 kg/ha with most available P content in the Tram. The available K content was 48.9 to 75 kg/ha. Tram recorded the highest K content in soil. Therefore, it is evident from the results that bio-fertilizer (Azotobacter + Mycorrhiza) in combination with application of inorganic fertilizer improved the soil fertility status which help to obtain sustainable crop yield of wheat. Joshi *et al.* (2018) also reported similar result while working on soil nutrient studies under INM in baby corn (*Zea mays* L.). A significant improvement in SOC under various treatments was also observed. The SOC content varied from 0.47 to 0.58%. The greatest SOC content was recorded under treatment Tram i.e. 0.58 %. This increase in SOC content in Tram could be due to enhanced root development of wheat crop resulting in higher residues as a result of INM. Kaur *et al.* (2008) also found similar result while working on soil organic matter dynamics as affected by long-term use of organic and inorganic fertilizers under maize–wheat cropping system.

### Root traits

Effect of INM on wheat root traits has been represented in Table 2. It showed significant difference in total root length, total root volume, average root diameter, total root surface area, root length density and root dry weight under different treatment. Tram showed significantly higher values of total root length (125.1 cm), total root volume (0.33 $cm^3$), average root diameter (0.63 mm), total root surface area (13.4 $cm^2$), root length density (107 cm $m^{-3}$) and root dry weight (0.78 g) compared to Tc and Tr. Availability of essential nutrients in adequate amount and proportions are important for proper root development, a fact sufficiently illustrated by the data on root parameter of wheat plants as recorded in present investigation. The reason may be due to integrated effect of NPK and bio-fertilizers which help in root growth and development. Alike results were reported by (Meena *et al.,* 2013) while working on effect of nutrient management and planting systems on root phenology and grain yield of wheat.

### Nitrogen use efficiency

Effect of INM on NUE of wheat crop has been shown in Figure 1. The higher NUE (37%) was recorded with Tram i.e. Tram showed an increment of 74% of NUE compared to Tr. However, it

**Table 1. Effect of integrated application of inorganic and bio-fertilizer on soil nutrient status**

| Treatments | Total Nitrogen (%) | Phosphorus (kg/ha) | Potassium (kg/ha) | Organic carbon (%) |
|---|---|---|---|---|
| Tc | 0.028 | 20.42 | 48.96 | 0.47 |
| Ta | 0.031 | 24.52 | 60.48 | 0.49 |
| Tm | 0.032 | 25.13 | 61.60 | 0.49 |
| Tam | 0.036 | 26.98 | 66.56 | 0.50 |
| Tr | 0.041 | 31.25 | 71.68 | 0.51 |
| Tra | 0.048 | 30.65 | 73.92 | 0.54 |
| Trm | 0.047 | 32.15 | 74.20 | 0.55 |
| Tram | 0.05 | 32.98 | 75.04 | 0.58 |
| SEm± | 0.008 | 0.70 | 1.61 | 0.008 |
| CD | 0.02 | 1.38 | 4.89 | 0.02 |

remained statically at par with Tra and Trm. An increment of 24.2% of NUE was observed under Tra compare Tr. Ta and Tm were found statistically at par with each other. Organic source of nutrients enhanced the use efficiency of fertilizers and aid as alternative source of nutrients. Integrated use of bio-fertilizer and N fertilizer maintains a continuous N supply, checked N losses and thus helped in more efficient utilization of the applied N. Our results are in conformity with the findings of (Dwivedi *et al.*, 2016) while working on integrated nutrient management for enhancing NUE.

**Nitrogen losses**

This study revealed that there is significant decrease in ammonium volatilization losses in plot receiving both inorganic and organic sources of nutrient compared to plot receiving recommended dose of fertilizers from inorganic sources (Figure 2). Tr had the highest ammonium volatisation losses i.e. 16.1 kg N/ha and least was observed in Tc i.e. 3.8 kg N/ha. Tram showed 33.7% and 76% decrease in ammonium volatilization losses compared to Tr and Tc, respectively. Ta and Tm also showed threefold decrease in ammonium volatisation loss compare to Tr. However, Tram, Tra, and Trm remained statistically at par with each other. Yaduvanshi (2001) observed that combined application of nutrients from organic and inorganic resulted in 50% decrease in ammonia volatilization in rice fields in Karnal region of Haryana. Similarly, data depict that highest (3.8 kg N/ha) and lowest (1.05 kg N/ha) denitrification loss observed in Tr and Tc, respectively. Tram showed decrease of 34.2% and 72.3% in denitrification losses compare to Tr and Tc, respectively. Ta and Tm showed twofold decrease in denitrification losses compared to Tr. Tam showed a decrease in 48.6 % in denitrification losses compare to Tr. It might be due increased soil available N, vigorous root growth, increased NUE, more uptake of N made it less susceptible for N losses. Aulakh (2010) has also reported that application

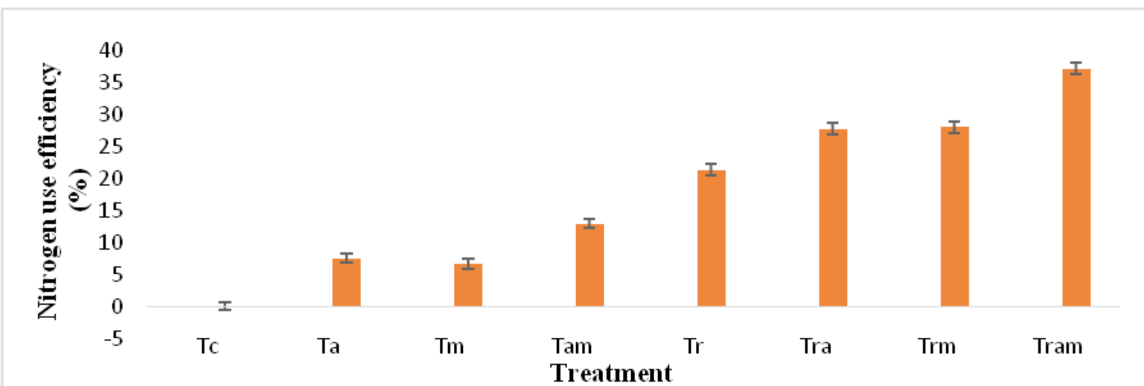


**Fig. 1.** Effect of integrated nutrient management on NUE

**Table 2. Effect of integrated application of inorganic and bio-fertilizer on root traits of wheat**

| Treatments | Total root length (cm) | Root dry weight (g) | Average root diameter (mm) | Total root surface area ($cm^2$) | Root volume ($cm^3$) | Total root length density ($cm/m^3$) |
|---|---|---|---|---|---|---|
| Tc | 63.6 | 0.30 | 0.29 | 8.9 | 0.12 | 72.2 |
| Ta | 65.6 | 0.45 | 0.36 | 9.0 | 0.14 | 81.4 |
| Tm | 87.4 | 0.46 | 0.31 | 9.3 | 0.17 | 83.0 |
| Tam | 115.4 | 0.33 | 0.50 | 10.9 | 0.16 | 81.5 |
| Tr | 119.7 | 0.45 | 0.49 | 11.7 | 0.16 | 93.3 |
| Tra | 121.9 | 0.70 | 0.55 | 11.7 | 0.29 | 104.9 |
| Trm | 124.8 | 0.74 | 0.56 | 12.5 | 0.32 | 104.6 |
| Tram | 125.1 | 0.78 | 0.63 | 13.4 | 0.33 | 107 |
| SEm± | 2.49 | 0.014 | 0.013 | 0.28 | 0.005 | 2.57 |
| CD | 7.55 | 0.042 | 0.04 | 0.86 | 0.016 | 7.81 |

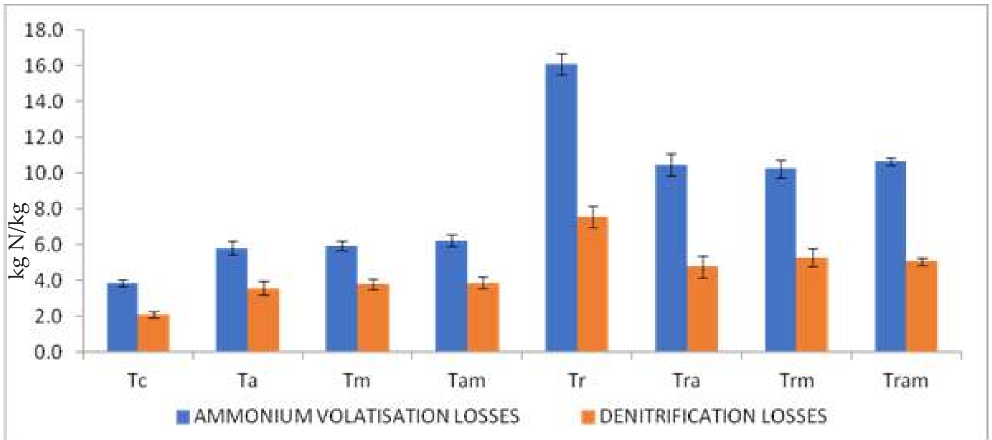


**Fig. 2.** Effect of integrated application of inorganic and bio-fertilizer on nitrogen losses

of nutrients through INM approach significantly reduced the denitrification losses compared to inorganic or organic sources applied alone.

**Yield and yield attributes**

Integrated source of nutrient significantly influenced grain yield, straw yield, test weight, no. of grains/ear, and no. of spikelet/ear are presented in Table 3. The significantly higher grain yield (6.4 t/ha) was observed in Tram compared to Tr and Tc. Tram showed a percentage increase of 10.7% in grain yield compare to Tr. Tram showed significantly higher test weight (41.2 g), number of grains/ear (48.6), spikelet's/ear (19.3) harvest index (42.2%) compare to Tr and Tc. Similar result were reported by (Soleimanzadeh and Gooshchi, 2013) while working on effects of Azotobacter and N chemical fertilizer on yield and yield components of wheat. The increase in grain and straw yield might be due to sufficient quantities and balanced fraction of plant nutrient delivered to the crop as per need during the growth period resulting in increase in yield attributing character. Integrated use of fertilizers with bio-fertilizers increased the dry matter accumulation, number of effective tillers, grains spike and the test weight. The enhanced early vegetative growth in terms of vigorous root system resulted in more spikes which consequently increased the number of spikes bearing tillers significantly (Devi *et al.*, 2011).

## CONCLUSION

The present study showed that the combined

**Table 3. Effect of integrated application of inorganic and bio-fertilizer on wheat yield and yield attributes**

| Treatment | Wheat Yield (t ha$^{-1}$) | Straw yield (t ha$^{-1}$) | Biological yield (t ha$^{-1}$) | Test weight (g) | Grains/ear (No.) | Spikelet/ ear (No.) | Harvest index (%) |
|---|---|---|---|---|---|---|---|
| $T_C$ | 2.7 | 5.2 | 8 | 36.8 | 38.1 | 11.9 | 34 |
| Ta | 3.7 | 6.4 | 10.1 | 37.6 | 39.8 | 12.6 | 36.4 |
| Tc | 3.4 | 6.1 | 9.6 | 36.9 | 38.6 | 12.7 | 36.1 |
| Tam | 4.3 | 7.2 | 11.5 | 37.9 | 40.2 | 13.8 | 37.1 |
| Tr | 5.8 | 9.1 | 15 | 38.9 | 47.7 | 15.2 | 39 |
| Tra | 6.1 | 8.8 | 14.9 | 39.5 | 48.2 | 18.6 | 41.2 |
| Trm | 6.2 | 8.7 | 14.9 | 39.3 | 47.9 | 18.9 | 41.6 |
| Tram | 6.4 | 8.8 | 15.3 | 41.2 | 48.6 | 19.3 | 42.2 |
| Sem± | 0.11 | 0.19 | 0.34 | 0.6 | 0.7 | 0.26 | 0.98 |
| CD | 0.35 | 0.57 | 1.04 | 1.85 | 2.12 | 0.79 | 2.98 |

application of inorganic with bio-fertilizer improved the soil available nutrient pool as well as the root growth of the wheat crop. The vigorous roots increased the nutrient uptake, yield and NUE. The enhanced NUE made the soil less susceptible for N losses either in the form of ammonia volatilization or denitrification. Therefore, it is recommended that integrated application of inorganic and bio-fertilizers could be an agronomically feasible, economically viable and environmentally sound technology for wheat crop for sustainable crop production.

## References

Aulakh, M.S. 2010. Integrated nutrient management for sustainable crop production, improving crop quality and soil health, and minimizing environmental pollution. In 19th world congress of soil science, soil solutions for a changing world, Brisbane, Australia, pp. 1–6.

Braun, H.J., Atlin, G. and Payne, T. 2010. Multi-location testing as a tool to identify plant response to global climate change. *Climate €Change and Crop Production*, 1: 115–138. https://doi.org/10.1079/9781845936334.0115

Devi, K.N., Singh, M.S., Singh, N.G. and Athokpam, H.S. 2011. Effect of integrated nutrient management on growth and yield of wheat. *Journal of Crop and Weed*, *7*(2) : 23–27.

Dwivedi, B.S., Singh, V.K., Meena, M.C., Dey, A. and Datta, S.P. 2016. Integrated nutrient management for enhancing nitrogen use efficiency. *Indian Journal of Fertilizers*, 12 : 62–71.

Gomez, K.A. and Gomez, A.A. 1984. Statistical Procedures for Agricultural Research. John Willey and Sons, New York.

Gupta, G., Dhar, S., Dass, A., Sharma, V.K., Singh, R.K., Kumar, A., Jinger, D. and Kumar, A. 2018. Influence of bio-inoculant mediated organic nutrient management on productivity and profitability of pigeonpea (*Cajanus cajan*) in a semi-arid agro-ecology. *Indian Journal of Agricultural Sciences* 88(10) : 1593–6.

Gupta, G., Dhar, S., Dass, A., Sharma, V.K., Singh, Shukla, L., Singh, R., Kumar, A., Kumar, A., Jinger, D., Sannagoudar, M.S., Kamboj, N.K. and Verma, G. 2020. Assessment of bio-inoculant mediated nutrient management in terms of productivity, profitability and nutrient harvest index of pigeonpea-wheat cropping system in India. *Journal of Plant Nutrition* **43**(19): 2911–2928. https://doi.org/10.1080/01904167.2020.1806302

Hanway, J.J. and Heidel, H. 1952. Soil analysis methods as used in Iowa state college soil testing laboratory. *Iowa agriculture*, 57 : 1–31.

Jadon, P., Selladurai, R., Yadav, S.S., Coumar, M.V., Dotaniya, M.L., Singh, A.K., Bhadouriya, J. and Kundu, S. 2018. Volatilization and leaching losses of nitrogen from different coated urea fertilizers. *Journal of Soil Science and Plant Nutrition,* 18(4). http://dx.doi.org/10.4067/S0718-95162018005002903

Jinger, D., Dhar, S. and Kaur R. 2018. Crop lodging: its causes and management for sustainable crop production. *Indian Farming* 68(02) : 24–27.

Jinger, D., Dhar, S., Dass, A. Sharma, V.K., Shukla, L., Paramesh, V., Parihar, M., Joshi, N., Joshi, E., Gupta, G. and Singh, S. 2022a. Residual silicon and phosphorus improved the growth, yield, nutrient uptake and soil enzyme activities of wheat. Silicon. https://doi.org/10.1007/s12633-022-01676-w

Jinger, D., Dhar, S., Dass, A., Sharma, V.K., Vijayakumar, S. and Gupta, G. 2020a. Influence of residual silicon and phosphorus on growth, productivity, lodging and grain quality of succeeding wheat under rice-wheat cropping system. *Journal of Environmental Biology* 41(6): 1676–84.

Jinger, D., Dhar, S., Vijayakumar, S., Pande, V.C., Kakade, V., Jat, R.A. and Dinesh, D. 2020. Silicon nutrition of graminaceous crops. *Indian Farming* 70(10): 18–2.

Jinger, D., Kumar, R., Kakade, V., Dinesh, D., Singh, G., Pande, V.C., Bhatnagar, P.R., Rao, B.K., Vishwakarma, A.K., Kumar, D. and Singhal, V. 2022. Agroforestry system for controlling soil erosion and enhancing system productivity in ravine lands of Western India under climate change scenarios. *Environmental Monitoring and Assessment*. https://doi.org/10.1007/s10661-022-09910-z

Joshi, G., Chilwal, A. and Bhatt, P. 2018. Soil nutrient studies under integrated nutrient management in baby corn (*Zea mays* L.). *The Pharma Innovation Journal,* 7(9): 41–43.

Karad, G.U., Babariya, N.B., Viradiya, M.B., Parmar, J.K., Deshmukh, S.D. and Polara, K.B. 2016. Effect of integrated nutrient management on yield and active pools of soil organic carbon under groundnut-wheat system of typic Haplustept in long term fertilizer experiment. *Journal of Pure and Applied Microbiology*, 10(1) : 787–794.

Kaur, T., Brar, B.S. and Dhillon, N. S. 2008. Soil organic matter dynamics as affected by long-term use of organic and inorganic fertilizers under maize–wheat cropping system. *Nutrient Cycling in Agroecosystems*, 81(1): 59–69.

Keeney, D.R., Nelson, D.W. and Page, A.L. 1982. Methods of soil analysis. Part 2. Chemical and microbiological properties. *Eds. CA Black et al*, 711–733.

Kjeldahl, C. 1883. A new method for the determination of nitrogen in organic matter. Z *Analytical Chemistry*, 22: 366.

Malusa, E. and Vassilev, N. 2014. A contribution to set a legal framework for bio-fertilizers. *Applied Microbiology and Biotechnology,* 98(15): 6599–6607.

Meena, B.L., Singh, A.K., Phogat, B.S. and Sharma, H.B. 2013. Effects of nutrient management and planting systems on root phenology and grain yield of wheat (Triticum aestivum). *Indian Journal of Agricultural Sciences*, 83(6): 627–632.

Mondal, S., Mallikarjun, M., Ghosh, M., Ghosh, D.C. and Timsina, J. 2016. Influence of integrated nutrient management (INM) on nutrient use efficiency, soil fertility and productivity of hybrid rice. *Archives Agronomy and Soil Sciences*, 62: 1521–1529.

Olsen, S.R. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate (No. 939). US Department of Agriculture.

Shi, Z., Jing, Q., Cai, J., Jiang, D. and Cao, W. 2013. The fates of $15^N$ fertilizer in relation to root distributions of winter wheat under different N splits. *European Journal of Agronomy*, 40: 86–93. https://doi.org/10.1016/j.eja.2012.01.006

Snyder, C.S., Bruulsema, T.W., Jensen, T.L. and Fixen, P.E. Review of greenhouse gas emissions from crop production systems and fertilizer management effects. *Agriculture, Ecosystems & Environment,* 133 : 247–266.

Soleimanzadeh, H. and Gooshchi, F. 2013. Effects of Azotobacter and nitrogen chemical fertilizer on yield and yield components of wheat (*Triticum aestivum* L.). *World Applied Sciences Journal*, 21(8): 1176–1180. https://doi.org/10.5829/idosi.wasj.2013.21.8.2702

Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science,* 37(1): 29–38.

Wang, S., Shan, J., Xia, Y., Tang, Q. and Xia, L. 2017. Different effects of biochar and a nitrification inhibitor application on paddy soil denitrification: a field experiment over two consecutive rice-growing seasons. *Science of The Total Environment,* 593, 347–356. https://doi.org/10.1016/j.scitotenv.2017.03.159

Yaduvanshi, N.P.S. 2001. Ammonia Volatalization Losses from Integrated Nutrient Management in Rice Fields of Alkali Soils. *Journal of the Indian Society of Soil Science* 49(2): 276–280.

Yang, G., Ji, H., Sheng, J., Zhang, Y., Feng, Y., Guo, Z. and Chen, L. 2020. Combining Azolla and urease inhibitor to reduce ammonia volatilization and increase nitrogen use efficiency and grain yield of rice. *Science of The Total Environment*, 743: 140799. https://doi.org/10.1016/j.scitotenv.2020.140799