

Review Article

<https://doi.org/10.20546/ijcmas.2020.901.063>

Influence of Balanced Fertilization on Productivity, Nutrient Use Efficiency and Profitability of Rice in Inceptisol: A Review

Rahul Kumar*, Mohan Lal, R. K. Naresh, Mukesh Kumar,
Shipra Yadav and Rajendra Kumar, M. Sharath Chandra and Pradeep Rajput

Department of Agronomy, Sardar Vallabhbhai Patel University of Agriculture & Technology,
Meerut, U.P., India

*Corresponding author

ABSTRACT

The decline in the rice crop responses to applied fertilizer nutrients, inter alia, could be ascribed to emerging nutrient deficiencies on account of modern era of agriculture and inadequate or imbalanced application of fertilizers. It has become increasingly recognized around the world that N, P and K fertilizers alone are not always sufficient to provide balanced nutrition for optimal rice yields and quality, therefore, application of secondary and micronutrient elements has to be made. Balanced application of NPK with Zn, Fe and Mn resulted in highest number of panicles, maximum panicle length and highest grain and straw yield. Das *et al.*, (2015) recorded highest grain and straw yield with the application of S, B and Zn along with NPK. Application of fertilizers through SSNM i.e. application of N:P:K:Zn:S:B (100:60:60:25:30:5) produced at par grain and straw yield with yield obtained with the application of 150% NPK (150:90:90). Application of 75 % of nitrogen through polymer coated urea (POCU) along with 100% P and K resulted in highest grain yield and harvest index. It is found that balanced application of NPK and Zn (100:60:60:5) resulted in higher Recovery efficiency of N, P & K. The highest Agronomic and recovery efficiency of NPK was recorded with the application of 50% RDF along with Nanomaterials of gypsum and rock phosphate. The highest N uptake and recovery efficiency in rice with the application of urea super granules @ 90 kg/ha. It can be concluded that the nutrient management through chemical fertilizers along with customised slow release fertilizer were the viable tools of improving FUE and synchronized crop demand. Therefore, balanced fertilization using chemical fertilizers of macro and micro nutrients not only has the potential to improve crop yields and farmer profits but also has positive implications on possible environmental footprint of fertilizer

Keywords

Customised fertilizers, Productivity, Profitability

Article Info

Accepted:
15 December 2019
Available Online:
20 January 2020

Introduction

Area, production and productivity of rice is 43.79 mha, 112.91 mt and 2.57 t/ha,

respectively (Anonymous, 2018). To feed the ever increasing population we need to produce more, nutrient supply is the most limiting factor for crop production, next to the water.

Successful nutrient management can optimize crop yields, increase profitability and minimize nutrient losses. The decline in the rice crop responses to applied fertilizer nutrients, inter alia, could be ascribed to emerging nutrient deficiencies on account of modern era of agriculture and inadequate or imbalanced application of fertilizers. It has become increasingly recognized around the world that N, P and K fertilizers alone are not always sufficient to provide balanced nutrition for optimal rice yields and quality, therefore, application of secondary and micronutrient elements has to be made. Comparing western U.P. and Punjab in the north and Tamil Nadu in the south, the N:P₂O₅:K₂O consumption ratio is much wider in western U.P. and Punjab (42.6:11.9:1.0) as compared to Tamil Nadu (2.6:1.0:1.0). This indicates that the highest fertilizer consuming states have the greatest imbalanced use of nutrients. The main reason of the variation in fertilizer consumption ratios in north and south is due to the nature of soils and cropping pattern. About 35% of total fertilizer is consumed by rice in India (Datta *et al.*, 2010).

Rice production demand by 2025 will be 130 mt. About 38-40% of total fertilizers consumption accounts for rice only, heavy and imbalanced use of chemical fertilizers is causing multiple nutrient deficiency and reduced organic matter content in the soil. About 8 mha rice soils are deficient in Zn and 15 mha of rice soils are acidic associated with Fe or Al toxicity, depletion of bases (Ca, K, Mg), P fixation and likely deficiency of B and Si on other hand the organic sources are insufficient for nutritional need of HYVs. Imbalanced fertilization is causing reduction in the productivity and fertilizer use efficiency of rice. Balancing the micronutrients for rice cultivation enhanced both the quality and yield of rice (Ma, 2007). Nevertheless, the availability of micronutrients such as Fe and Zn was much affected by pH, CaCO₃ content

and soil texture. Each element of these micronutrients has its own function in plant growth (Fouly, 1983). Foliar application of micronutrients particularly Zn and Fe in small amounts had significant positive effect on 1000 grain weight, plant height, biological yield, grain yield, harvest index and oil content of sunflower (Babaeian, 2011), and growth of rice (Wissuma, 2008). The highest grain number per panicle was recorded when Fe+Si and mixture of the three elements were applied. Meanwhile, maximum 1000 grain weight was obtained in Zn+ Si foliar application treatment. The simultaneously application of these elements had the highest biomass weight and grain yield. Also, grain yield in Zn + Fe foliar application treatment was 9 and 13 percent greater than those in Fe and Zn treatments, respectively (Esfahani *et al.*, 2014). Zinc deficiency has received great attention in India, because nearly half of the Indian soils are poor in availability of Zn. The essentiality of Zn was first shown by Maze (1915) in maize, where it is known as 'white bud'. Its deficiency in rice was first reported by Nene (1966) at the Govind Ballabh Pant University of Agriculture & Technology, Pantnagar. Rice is the bulk of food security of the global population. Rice is most susceptible to zinc deficiency. In rice cultivation, the application of micronutrient such different zinc management practices. The great sources of Zn such as zinc sulphate and zinc oxide (ZnSO₄ or ZnO). Boron is second emerging deficient nutrient in rice tract which is affecting crop impressively. Studies on boron fertilization revealed that rice yield consistently increased with boron application. Boron may stimulate the enzymatic activity, availability of sugar and respiration which leads towards improved pollen growth. In case of severe boron deficiency, root growth of plants ceases which leads toward the death of root tips. Boron deficiency has been realized as the second most important micronutrient constraint in crops after that of zinc (Zn) on

global scale. Boron deficiency has been reported to result considerable yield reduction in cereal mainly in rice. Zinc is a secondary plant nutrient which plays a significant role in increasing production and providing resistance against disease in rice crops. Zinc deficiency of lowland rice occurs widely in near-neutral to alkaline soils, particularly calcareous soils. In a severe case of zinc deficiency, transplanted rice seedlings may die or direct-sown seeds may fail to emerge. Sulphur is also secondary plant nutrient which plays a vital role in rice crop production as it increases root growth, seed formation and synthesis of chlorophyll. Sulphur deficiency is a common nutritional disorder in upland crops but it rarely occurs in lowland rice. A recent trend in the fertilizer industry to shift from ammonium sulphate to urea and from superphosphate to non sulphur phosphatic fertilizer may induce more widespread sulphur deficiency in lowland rice. Micronutrients are as important as macronutrients in plant nutrition and the deficiency of micronutrients is considered one of the major causes of declining the productivity trends in rice growing countries including Micronutrients are needed in trace amounts but their adequate supply improves nutrient availability and positively affects the cell physiology that is reflected in yield as well. Farmers apply N, P, K and S fertilizers widely and application of micronutrients such as Zn, Cu, Mn and B is not a usual practice. Soils deficient in their supply of micronutrients are alarmingly widespread across the globe due to intensive cropping, loss of fertile topsoil and losses of nutrients through leaching. When micronutrients are in short supply, the growth and yield of crops are severely depressed. The presence of micronutrient deficiency renders it impossible for the plants to gain maximum benefit from NPK fertilizers application. Micronutrient deficiency in 50% of the world's soils and many crops greatly reduces the amount and quality of food which adversely affects human

health, the economic status of farmers and the environment around the world. Despite the fact that these nutrients are actively involved in various plant growth mechanisms, their specific role for yield improvement in crops is still need to be investigated. The exact effects of applying micronutrients in combination with NPK to rice crop in micronutrient deficient soils and specific climate conditions need to be better established. In order to improve crop productivity, the limiting micronutrient (s) must be identified and the soils should be enriched with the addition of those nutrients in properly balanced fertilizer programme. Keeping this in view, the present research was undertaken to investigate the effect of micronutrients viz. Zn, Cu, Mn and B along with NPK on growth and yield of rice. Chemical fertilizer has played a major role in the global food production over the past 60 years. It supplies about 50 % of total N required by crops. However, its use efficiency in crop production is low (10-50 %) mainly due to loss of N through nitrate (NO_3) leaching, volatilization of ammonia (NH_3) and nitrous oxide (N_2O) emission resulting in pollution of groundwater and atmosphere (Zhaohui *et al.*, 2012; Galloway *et al.*, 2003). Moreover, the production cost of nitrogen fertilizer is very high. These scenarios lead to the use technologies such as nitrogen inhibitors and slow nitrogen releasing fertilizers given as fertilizer additives to increase nutrient uptake, fertilizer use efficiencies and yields of crops (Frame and Reiter, 2013).

Slow released fertilizers, nitrification and urease inhibitors are the three possible types of products that control nitrogen losses and consequently improve nitrogen use efficiency (Schwab and Murdock, 2010). Therefore, the main aim of this paper is to review the effects of nitrogen inhibitors and slow nitrogen releasing fertilizers on crop yield, nitrogen use efficiency and mitigation of N_2O emission.

Nitrification and urease inhibitors are called nitrogen inhibitors. Nitrification inhibitors are substances that inhibit biological oxidation of ammonium to nitrate (Schwab and Murdock, 2010). Some of nitrification inhibiting products includes dicyandiamide (DCD), 3,4-dimethyl-1H-pyrazoliumdihydrogen (DMPP), thiosulphate, neem, karanjin, and nitrapyrine (N-serve) (Khan *et al.*, 2013). Exudates of some plant species have also the capacity to inhibit nitrification process in the soil (Al-Ansari and Abdulkareem, 2014). Urease inhibitors are substances that inhibit conversion/hydrolysis of urea to ammonia and carbon dioxide and hence minimize ammonia volatilization losses (Schwab and Murdock, 2010). The common urease inhibitor products are phenyl phosphorodiamidate (PPD), hydroquinone (HQ), N-(n-butyl) thiophosphorictriamide (NBPT), phenyl mercuric acetate (PMA), and catechol. Controlled-released fertilizers are fertilizers such as urea that are coated with a polymer or sulfur (Khan *et al.*, 2013). Polymer coated urea is newest and technically advanced fertilizer that gradually release nitrogen for longer time, synchronize nitrogen application to crop requirement and induce complete utilization of fertilizer for crop growth. Adequate supply of nitrogen at later growth stage improve development of yield attributes like more and longer panicle with healthy grain. Therefore the study was initiated to evaluate response of growth and yield of rice to polymer coated urea under lowland cultivation. However, monetary or economic considerations have hindered the adoption of POCU for the local farmers. The cost is more expensive to purchase POCU than NCU while POCU is primarily used on high value ornamental and nursery plants. In contrast, limited research has paid attention to economic efficiency or net economic return of N fertilization under an optimal N fertilization rate, which is major concern from rice growers (Cassman *et al.*, 1998; Ohnishia *et al.*, 1999;

Zhu and Chen, 2002; Ju *et al.*, 2009; Haefele *et al.*, 2010; Chen *et al.*, 2011). Partial factor productivity of N (PFPN) and nitrogen agronomic efficiency (NAE) are useful measurements because they provide integrative indices that quantify total economic output relative to the utilization of N fertilizer (Cassman *et al.*, 1996; 1998). By definition, PFPN is the grain yield obtained by per unit applied N under N fertilization without the subtraction of grain yield obtained under no-N fertilization. In contrast, a positive NAE represents a net grain yield gain under per unit applied N after the subtraction of grain yield under no-N fertilization. The goal of N fertilization is therefore to obtain maximal grain yield with optimal investment in N input (Haefele *et al.*, 2010). Obviously, a higher net economic return in crop production relies on a lower cost of per unit N input through a higher yield. For instance, economic efficiency was greater when using three slow-release N fertilizers, compared to the chemical ammonium nitrate in irrigated turfs (Arrobas *et al.*, 2011). However, limited information is available how POCU applications could increase net economic return from rice production (Guo *et al.*, 2010). The application of macro and micronutrients as well as use of slow release fertilizers are seems to be necessary to reduce the use of fertilizers and to improve yield and fertilizer use efficiency in rice production.

Balance fertilization

The requirement of nutrients such as Nitrogen, Phosphorus and Potash is soil and crop specific. The use of right amount and ratio of nutrients as per soil or crop requirement is known as "balanced fertilization" (**J.V. Liebig**). Balanced fertilization is the deliberate application of essential plant nutrients to soils that are enable to supply these nutrients in order to meet crop demand at a specific location. Balanced fertilization (BF) aims at

nutrient supplementation in order to assist crop performance while minimizing nutrient losses. Balanced fertilization is one of the keys to improve fertilizer use efficiency, in principle, the concept of balanced fertilization aims at a dynamic balance between nutrient requirement and nutrient uptake by crops.

Panwar *et al.*, (2019) reported that the highest productivity of RWCS with fertilizer treatments was recorded at Amritsar, except with NPK and NPK+Zn fertilization, where Katni supersedes Amritsar. Application of N exerted a significant effect on RGEY and on an average a 106% productivity enhancement was recorded over the control across the locations. The yield improvement due to N application varied from 31% at Samba to 122% at Pakur over control. An approximately 3-fold productivity gain in RWCS was recorded with combined application of N and P over control across the locations; although, the increase in system productivity ranged from 83 to 265% over the control [Fig. 1].

Balanced fertilization effects on crop productivity of rice

Abid *et al.*, (2000) reported that maximum paddy yield was exhibited by the application of NPK+Mn+Zn. Zn showed better performance in combination with Mn than that Fe. It was probably due to the mutual antagonism that existed between Fe and Zn as indicated by several workers (Tiwari *et al.*, 1976; Halder and Mandal, 1981). The higher Zn (10 mg kg⁻¹soil) level showed more paddy yield over all other treatments when it was added in NPK and Mn. This might be due to the fact that pronounced effect of micronutrients would be expected only when the micronutrients were in the required ratio and quantity (Chaudhry and Ali, 1986).

Moe *et al.*, (2019) also found that rice plants accumulated a large amount of DM during the

tillering stage in the CF₁₀₀ treatment in 2017 (Fig. 2). After that stage, DM production was similar among the CF₁₀₀, CF₅₀ PM₅₀, CF₅₀ CM₅₀, and CF₅₀ CP₅₀ treatments. At harvest, the maximum DM produced was 15.01 t ha⁻¹, from the CF₅₀ PM₅₀ treatment, followed by 14.29 t ha⁻¹ in the CF₁₀₀ treatment. The amounts of DM produced in the CF₅₀ CM₅₀ and CF₅₀ CP₅₀ treatments were 12.30 and 11.26 t ha⁻¹, respectively. The most DM was produced in CF₅₀ PM₅₀ plots in 2018 even during the early stage. Throughout the crop period, plots treated with organic fertilizers produced DM amounts similar to those from plots treated with CF₁₀₀. At harvest time, CF₅₀ PM₅₀ plots produced the most DM, 15.49 t ha⁻¹. CF₅₀ CM₅₀ and CF₅₀ CP₅₀ also produced significantly more DM in 2017 than in 2018.

Zayed *et al.*, (2011) revealed that the three micronutrients Zn, Fe and Mn and their combinations significantly affected grain yield, straw yield and harvest index, foliar application of the comparative treatment with the three studied micronutrients twice significantly improved and increased grain and straw yields of rice. Meanwhile, the differences among Zn, Fe and Mn application as single and Zn +Mn as combination were insignificant regarding rice grain yield and harvest index. The triple combination of Zn+ Fe+ Mn+ as soil application gave the highest values of grain yield followed by the comparative foliar application treatment of the three nutrients twice. The lowest values of rice grain yield was recorded when rice plant did not receive any of the applied micronutrients. Gomaa *et al.*, (2015) reported that the application of micronutrients fertilization resulted in higher grain yield and led to a significant increase in Zn and Fe concentrations in rice grains. The highest mean values of Zn and Fe concentrations were produced by application of mixture (Zn + Fe) when compared with the untreated.

Suresh and Salakinkop (2016) reported that the soil application of ZnSO_4 and FeSO_4 each @ 25 kg ha^{-1} recorded significantly higher grain and straw yield (3575 kg ha^{-1} and 5299 kg ha^{-1} , respectively) compared to lower levels of ZnSO_4 and FeSO_4 each @ 10, 15 and 20 kg ha^{-1} and control (2878 and 3718 kg ha^{-1} , respectively). Increased yield due to Zn and Fe application was attributed to better performance of growth and yield parameters through adequate availability of major and micro nutrients in soil, which in turn, favourably influenced physiological processes and build-up of photosynthates (Tabassum *et al.*, 2013). There was increased grain yield of 16.5 per cent upon application of $2.5 \text{ kg Zn ha}^{-1}$; while 15 per cent upon application of $5.0 \text{ kg Zn ha}^{-1}$ in rice (Rahman *et al.*, 2006).

Siddika *et al.*, (2016) stated that the grain yield of rice was significantly influenced due to different treatments and was recorded highest with the application of NPKS+Zn+Cu, application of micronutrients in association with NPKS showed better performance in respect of grain yield and yield contributing characters viz. plant height, number of effective tillers hill^{-1} , number of grains panicle $^{-1}$ and dry matter yield of rice as compared to the application of NPKS only. The performance of Zn+Cu with NPKS was the best for improving the growth and yield of rice. Therefore, application of Zn at 1 kg ha^{-1} and Cu at 2 kg ha^{-1} in association with NPKS fertilizers could be the promising combination for maximizing rice yield. Cuong *et al.*, (2017) stated that most of the yield components (such as number of grains per panicle, seed-setting rate and 1000-grain weight), grain yield and straw yield were significantly affected by Si application. Number of grains per panicle was increased by almost 6% under RDF + $400 \text{ kg/hm}^2 \text{ SiO}_2$ treatment compared with the control. Seed-setting rate was 89.8% under the highest dose of Si and RDF, whereas it was 80.2% for the control. Similarly, 33% increase

in 1000-grain weight was recorded for RDF + $400 \text{ kg/hm}^2 \text{ SiO}_2$ compared with only RDF treatment. There was about 23% increase in grain yield and nearly 20% increase in straw yield for RDF + $400 \text{ kg/hm}^2 \text{ SiO}_2$ compared with the control.

Kumar *et al.*, (2017) reported progressive increase the grain and straw yield of transplanted rice which increased significantly with different sources of zinc over control. However, maximum grain yield (7.11 t ha^{-1}) and straw yield (8.45 t ha^{-1}) were recorded with @ soil application of $50 \text{ kg ZnSO}_4 \text{ ha}^{-1}$, this treatment was statistically at par with soil application of ZnO equivalent to $50 \text{ kg ZnSO}_4 \text{ ha}^{-1}$ and Seedling dip in ZnO Slurry equivalent to $10 \text{ kg ZnSO}_4 \text{ ha}^{-1}$ [Table 1]. This might be due to increased transplantation of photosynthate from source to sink due to zinc application as reported by Varsheny (1988). Superiority of soil application of $50 \text{ kg ZnSO}_4 \text{ ha}^{-1}$ over other treatments might be attributed due to higher zinc concentration alone with availability of sulphur which resulted more number of productive tillers, filled grains panicle $^{-1}$ and higher test weight which ultimately increased grain and straw yield in soil application of $50 \text{ kg ZnSO}_4 \text{ ha}^{-1}$ followed by soil application of ZnO equivalent to $50 \text{ kg ZnSO}_4 \text{ ha}^{-1}$, seedling dip in ZnO Slurry equivalent to $10 \text{ kg ZnSO}_4 \text{ ha}^{-1}$. The results corroborate with the findings of Singh and Sharma (1994).

Mohan *et al.*, (2017) reported that the maximum growth and yield of rice with the application of 100% RDF + 2 foliar spray of $10 \text{ kg ZnSO}_4 \text{ ha}^{-1} + 5 \text{ kg FeSO}_4 \text{ ha}^{-1} + 10 \text{ kg Borax ha}^{-1} + 10 \text{ kg Sulphur ha}^{-1}$ was significantly superior over rest of the treatments at all the stages of crop growth. It is due to fact that balanced dose of nutrients is responsible for the better growth of crop. Similar results have also been reported by Lin and Lin (1985) and Desmukh *et al.*, (1988).

Pasha *et al.*, (2018) also found that the application of recommended dose of NPK+ZnSO₄ recorded significantly higher grain yield over years and lowest with control. However, the treatments recommended NPK and farmers practice were registered at par on average grain yield to that of NPK+ ZnSO₄ [Table 2]. Rice grain equivalent yield was also with recommended dose of NPK+ZnSO₄ (5.80tha⁻¹). However, sustainable yield index (SYI) was higher with recommended dose of NPK followed by farmer's practice and recommended dose of NPK+ZnSO₄. Control treatment registered lowest SYI.

Customised fertilizers effects on nutrient use and productivity of rice

Bulbule *et al.*, (2006) also found that briquettes at rates of 28, 56,84 and 112 kg N/ha in a single dose after transplanting in modified spacing of 15-25 x15-25 cm. The results revealed distinct superiority of briquettes over the conventional fertilizer (prilled urea) under the prevailing conditions. The yields of rice consistently increased when the crop was fertilized through briquettes (56 kg N/ha) compared to the application of N through conventional fertilizer(100 kg N/ha). Placement of briquettes in modified spacing of 15-25 x 15-25 cm at lower rates at an extra cost is certainly affordable to farmers since it offsets the additional cost through substantial increase in grain yields (25-30%) at lower levels of fertilizer. Mendhe *et al.*, (2006) revealed that increase in plant height, number of tillers/plant, dry matter accumulation/plant, effective tillers/plant, number of grains/panicle, grain yield (34.02q/ha) and straw yield (45.90 q/ha) due to the application of UB-DAP (@ 56 :14 kg) at trans planting+25% N at panicle initiation, over the only organic manure FYM @ 5 t/ha at the time of transplanting (26.90 and 36.31 q/ha). Bhagat *et al.*, (2005) revealed that application of recommended fertilizer dose of NPK

(100:50:50 kg/ha) through briquettes, significantly influenced the height of plant, test weight of grain, grain and straw yield (44.28 and 59.78q/ha, respectively). This was found effective in improving all growth and yield attributes along with yield of grains and straw. Bowen *et al.*, (2005) reported that the yield increase under urea deep placement was achieved using much less urea fertilizer. Urea deep placement resulted in higher grain yield and N fertilizer use efficiency than FP. The average urea deep placement grain yield benefit over FP was 1120 kg/ha during the boro season and 890 kg/ha during the aman season.

Jagtap *et al.*, (2011) reported that, the grain yield of rice was significantly influenced due to various fertilizer sources. Among all these sources, treatment receiving urea-DAP briquettes gave higher grain yield (49.29, 53.04and 51.17 q/ha during the year 2009-10 and pooled mean, respectively) followed by urea-suphala briquettes which were at par with each other but found significantly superior to RDF. The treatments receiving urea-suphala briquettes and RDF were at par with each other during both the years and in the pooled mean. The mean increase in grain yield recorded under the application of urea-DAP briquettes over urea-suphala briquettes and application of RDF was to the tune of 3.89 and 8.06%,respectively. The increase in grain yield of rice due to application of urea- DAP briquettes maybe accounted for significant improvement in yield attributes viz., number of panicles/hill, length of panicle, number of filled grains/panicle, weight of filled grains/panicle and test weight which finally resulted in increased grain yield.

Rajani and Sen (2017) concluded that the low solubility and synchronized release of nitrogen are the important characteristics of polymer coated urea that ensures single (co-situs) application of entire recommended dose of

nutrient at a time. At same amount of nitrogen polymer coated urea improved plant height, tiller numbers, grains per panicle and grain yield by 8.51%, 24.33%, 16.07% and 23.37% respectively, over uncoated urea at harvesting. Highest grain and straw yield (24.17 and 31.08 q ha⁻¹ respectively) was observed under polymer coated urea (double layer). It is confirmed from the findings of experiment that polymer coated urea is one of the best fertilizer for rice grower for producing higher and sustainable yield with minimum cultivation cost.

Balanced fertilization and fertilizer use efficiency

Patil *et al.*, (2010) reported that highest grain yield and partial factor productivity was recorded with application of fertilizer mixture of FM-N56:C28 (FM-25:13:13, NPK). Kumar *et al.*, (2014) studied the effect of nano-fertilizers on nutrient use efficiency in rice and reported that the highest recovery efficiency, agronomic efficiency and grain yield was recorded with the application of 50% + Nanomaterials of gypsum and rock phosphate @ 3 kg/ha as soil application. Dhane *et al.*, (2002) indicated that use of UB-DAP with improved management practice increased the rice grain yield by 37% over control with 44% saving in recommended dose of fertilizer. Powar and Deshpande (2001) observed that the grain yield obtained with deep placement of UB-DAP was at par with that of broadcast application of PU+SSP. Mishra *et al.*, (1998) observed that NUE with urea briquette (UB) +PU @ 30 kg/ha each (46.4q/ha and 35.50%) were significantly superior over broadcast and split application 60kg N through PU. Dafterdar and Savant (1995) reported that simply deep placement of either urea briquette (UB) or UB-DAP at 7-10 cm soil depth (1briquette per 4 hills) immediately after transplanting with modified 20 x 20 cm spacing substantially increased the grain yield

(4.55 t/ha) and straw yield (6.67 t/ha) of rice compared to conventional practice of split application of PU, basal application of SSP by broad cast method (2.29 and 4.54 t/ha) at the same level of N and P application.

Battacharya *et al.*, (2014) conducted an experiment to study of effect of nutrient rate on nutrient use efficiency in rice and revealed that balanced application of NPK and Zn (100:60:60:5) resulted in higher Recovery efficiency of N, P & K. However, the highest grain yield was obtained with the application of NPK and Zn (100:75:75:5). The lowest grain yield was recorded in control treatment. Li *et al.*, (2015) reported that the grain yield of rice was influenced by N fertilizer type and N input level. Averaged over years and N levels, greater annual grain yields were significantly ranked as under POCU > under NCU > under control (11.4, 10.6 and 7.2 Mg ha⁻¹, respectively) [Table 3].

Liu *et al.*, (2016) reported that the highest yield (91.6 g hill⁻¹) was observed when 210 mg N kg⁻¹ soil was applied as basal fertilizer, which was a 14.6% improvement on FFP (79.9 g hill⁻¹) [Fig. 4]. However, treatment yields when N was applied as a jointing or panicle fertilizer were all lower than FFP regardless of N rate.

Li *et al.*, (2015) stated, Nitrogen use efficiency and NAE are major indicators of N efficiency in the field (Moll *et al.*,1982; Weih *et al.*, 2010). In general, 20–40% of NUE and 10–20 kg grain kg⁻¹ N of NAE could be improved by the decrease of N supplement to rice in the Chinese paddy soils (Cassman *et al.*, 2002; Zhu and Chen, 2002; Wang *et al.*, 2007; Huang *et al.*, 2008; Zhang *et al.*, 2008; Peng *et al.*, 2010). Results of this study indicated that POCU application had significantly higher aboveground biomass (yield plus straw), NUE, NAE and PFP N compared to NCU, both in the early and late rice (Table 3). These

advantages of POCU over NCU might be that the N release from POCU could synchronize to plant N requirement (Shoji and Kanno, 1994; Xu *et al.*, 2005). Some reports showed that the use of POCUs can be related to an improvement of N₂ fixation in flooded rice (Carreres *et al.*, 2003) and the reduction in nutrient concentration in runoff water (Emilsson *et al.*, 2007). In addition, the applications of POCU increased the residual N in the soil compared to NCU, particularly in the late growth period of rice (Soon *et al.*, 2011), resulting in higher N uptake in rice. As a consequence, NUE was increased and N losses was decreased under POCU (Xu *et al.*, 2013). One of the best management procedures for NCU was to split its application at different crop growth stages, although it was difficult to operate and labour intensive (Patil *et al.*, 2010). Nevertheless, one time application of POCU was similar to the two or three split applications of NCU in terms of yield and reduction of N loading in the environment (Shaviv and Mikkelsen, 1993; Patil *et al.*, 2010; Soon *et al.*, 2011).

Balanced fertilization and economics

Bulbule *et al.*, (2006) reported that placement of briquettes (in modified spacing 15-25 x 15-25 cm) at lower rates at an extra cost was certainly affordable to farmers since it offset the additional cost through substantial increase in grain yields (25-30%) at lower levels of fertilizer. Ghodke *et al.*, (2008) reported that maximum gross returns (Rs. 47251.19/ha), net returns (Rs. 11181.58/ha) and B : C ratio (1.31) were observed with urea-DAP briquettes treatment as compared to different levels of recommended dose of fertilizers. Darade (2007) revealed that the placement of urea-DAP briquettes+50 kgK₂O/ha realized the maximum net returns of Rs. 25268.92/ha with highest B: C ratio of 2.23. Kumar *et al.*, (2017) revealed that soil application of 50 kg ZnSO₄ ha⁻¹ recorded to highest net return of

Rs. 82607 followed by foliar application twice with 0.2% ZnSO₄ (Rs. 72627) and seedling dip in ZnO slurry equivalent to 10 kg ZnSO₄ ha⁻¹ (Rs.71577) [Table 4]. Highest benefit cost ratio (BCR) of 2.34 were recorded treatment, soil application of the 50 kg ZnSO₄ ha⁻¹ followed by foliar application twice with 0.2% ZnSO₄ and seedling dip in 10 kg ZnSO₄ slurry ha⁻¹ recording to 2.23 and 2.10 (BCR) respectively. These result could corroborated with findings of Varsheney *et al.*, (2008).

Chen *et al.*, (2011) reported that improper input of excessive N fertilizer to rice field could result a low return due to the high loss. This can be verified from the dry matter production (Fig.5). Total 84.87 t dry matters were produced per hectare in FN in three years with total N input of 1530 kg. The dry matter production per kg N fertilizer was 0.055 t for FN treatment, 0.067–0.068 t kg⁻¹ for OCN, RCN and CRU treatments, and further increased to 0.074 t kg⁻¹ for SSNM treatment when the N application decreased by about 35%.

Singh and Singh (2017) reported that to produce optimum rice yields, amount and time of application of fertilizer N be governed by the amount and pattern of organic N mineralized after "flooding. The rice production systems that lack controlled water management and undergo several alternate aerobic and anaerobic shifts during a crop season show inefficient N use because substantial amounts of applied as well as native soil N are preferentially lost via denitrification. The most fundamental N recommendation for lowland rice is to use ammonical or NH₄⁺ forming fertilizers such as urea. Ammonium N may be lost through volatilization, fixed by clay minerals, or immobilized by soil organic matter (Fig.6). The NO₃⁻ containing fertilizer sources should not be applied prior to soil submergence as NO₃⁻-N may get denitrified or lost via

leaching, particularly on permeable sandy soils or may possibly be transported in the general direction of water movement across a field (Buresh *et al.*, 2008). As NH_4^+ , a cation, attaches to the soils cation exchange complex and is held by the soil very close to its point of placement, NH_4^+ fixation capacity of a soil should be taken into account when strategies for N fertilization are developed to maximize N-use efficiency.

Pasha *et al.*, (2018), among the different treatments tested, cost of cultivation was highest (Rs 75290 ha^{-1}) with farmer's practice and was lowest in control (Table 5). Recommended dose of NPK+ ZnSO_4 resulted in higher gross (Rs 164740 ha^{-1}) and net return (Rs 902600 ha^{-1}) with a cost of cultivation of Rs. 74480 ha^{-1} and was followed by recommended dose of NPK with Rs 156620 ha^{-1} of gross returns and Rs 86600 ha^{-1} of net returns. However, Benefit Cost ratio was higher in recommended dose of NPK (2.24) due to less cost of cultivation (Rs 70020 ha^{-1}) when compared with recommended dose of NPK+ ZnSO_4 (2.21). In farmers practice the cost of cultivation was high when compared to other NPK combinations but the productivity was lesser than recommended NPK with or without ZnSO_4 , hence resulted lower net returns and B:C ratio.

Likewise in control, though cost of cultivation was less due to no fertilizer application, this treatment recorded lesser grain yield and net benefit was also the lowest. These results are in agreement with findings of Sharma *et al.*, (2011). Hiremath and Hosamani (2015) in their study on maize-chickpea system stated that recommended dose of NPK along with ZnSO_4 recorded significantly higher net returns and benefit cost ratio than other treatments. Singh *et al.*, (2017) also confirmed that application of recommended quantity of nitrogen, phosphorus and potassium together with supplementation of location specific

deficient micronutrient enhanced marginal returns in cereal based cropping systems.

Yu *et al.*, (2019) revealed that long-term balanced fertilization increases the soil microbial functional diversity in a phosphorus-limited paddy soil, chemical fertilization significantly increased the diversity and abundance of most genes involved in C, N, P and S cycling, especially for the treatments NK and NPK.

Significant correlations were found among functional gene structure and abundance, related soil enzymatic activities and rice yield, suggesting that a fertilizer-induced shift in the microbial community may accelerate the nutrient turnover in soil, which in turn influenced rice growth. The effect of N fertilization on soil microbial functional genes was mitigated by the addition of P fertilizer in this P-limited paddy soil, suggesting that balanced chemical fertilization is beneficial to the soil microbial community and its functions.

Jahan *et al.*, (2019) showed their findings and concluded that in both AEZs, 'STB' fertilizer management with CRI resulted in the highest gross return (26823 & 49530 Rs ha^{-1}), followed by 'STB' (52085 & 49246 Rs ha^{-1}), 'IPNS+CRI' (51375 & 48466 Rs ha^{-1}), and 'IPNS' (51091 & 48182 Rs ha^{-1}), due to higher yields in those treatments (Table 6).

With some exceptions, similar trends were also found for gross margin and net returns. In both AEZs, due to higher yields, BCR was also higher in STB management (251 & 238), followed by 'STB+CRI' (237 & 226) and 'IPNS' (231 & 219).

Similarly, MBCR was also highest for 'STB' (743 & 723) followed by 'STB+CRI' (598 & 573), due to comparatively lower variable costs. Control plots, on the other hand,

resulted in the lowest gross returns, gross margin, net returns and BCR due to low yield (Table 6).

These results indicate that the overall economic performance of the aforesaid T. aman rice is sustainable with 'STB', 'STB+CRI' and 'IPNS' management. Other researchers (Jahan et al., 2016 and Hossain et al., 2016) also reported similar results for different cropping patterns and without CRI.

Prices: rice grain, 9.22 Rs kg⁻¹; rice straw, 0.22 Rs kg⁻¹. Labour: Rainfed monsoon rice, 110-120 people (labourwage 71-106 Rs person-1 day⁻¹). Fertilizers and manure: urea (N), 5.67-6.39 Rs kg⁻¹; triple super phosphate (P), 16.32-17.74 Rs kg⁻¹; murate of potash (K), 13.48-14.19 Rs kg⁻¹; gypsum (S), 4.25-56.76 Rs kg⁻¹; zinc sulphate (Zn), 57.47-60.31 Rs kg⁻¹; cowdung, 0.28-0.35 Rs kg⁻¹ BCR = Benefit-cost ratio; MBCR = Marginal benefit-cost ratio HYG'; High Yield Goal, 'MYG'; Moderate Yield Goal, 'IPNS'; Integrated Plant Nutrient System, 'STB'; Soil Test Based, 'FP'; Farmer's Practice, 'CON'; without fertilizers, 'CRI': crop residue incorporation.

This review paper emphasized the role and importance of balanced fertilization *i.e.* major and micro inorganic nutrient sources as a management strategy that can bring sustainability to the rice crop of the Indian subcontinent. Micro nutrients improve chemical properties of a soil but the nutrients may not be as readily available to the plants. Inorganic fertilizer is usually immediately and fast containing all necessary nutrients that are ready for plants. The excess use of inorganic fertilizers in agriculture can lead to soil deterioration, soil acidification and

environment pollution. The balanced plant nutrient management system is an alternative approach for the sustainable and cost-effective management of soil fertility and is characterized by reduced input of inorganic fertilizers and combined use of inorganic macro nutrient fertilizers with micro nutrient materials. Balanced applications of macro and micro nutrients improve soil fertility, productivity and reduce the impact of heavy use of inorganic fertilizers on environment.

So, it is an alternative way for sustainable soil fertility and productivity. On the basis of foregoing discussion it can be concluded that balanced use of fertilizers along with slow release fertilizers and nutrient release inhibitors enhanced the productivity of rice.

Combined application of micronutrients, nutrient inhibitors with 100% RDF resulted in good growth parameters, yield attributes, significantly higher yield, grain quality of rice.

Integrated use of macro and micro nutrient provide the scientific basis for balanced fertilization not only between the fertilizer nutrients themselves but also that with the soil available nutrients. Moreover, the nutrient management through chemical fertilizers alongwith customised slow release fertilizer were the viable tools of improving fertilizer use efficiency and synchronized crop demand.

Therefore, balanced fertilization using chemical fertilizers of macro and micro nutrients not only has the potential to improve crop yields and farmer profits but also has positive implications on possible environmental footprint of fertilizer use.

Table.1 Effect of different sources of Zinc on protein content, yield and nutrient uptake of rice crop (Kumar *et al.*, 2017)

Treatments	Grain yield (t ha ⁻¹)	Straw yield (t ha ⁻¹)	Total N uptake (kg ha ⁻¹)	Zn Uptake by grain (kg ha ⁻¹)	Protein content (%)
T ₁ : No zinc application	5.70	7.00	107.50	0.79	6.87
T ₂ : Soil application of the 50 kg ZnSO ₄ ha ⁻¹	7.11	8.45	146.34	1.06	7.43
T ₃ : Soil application of Zn equivalent 50 kg ZnSO ₄ ha ⁻¹	6.74	7.82	120.35	0.89	7.31
T ₄ : Seedling dip in 10 kg ZnSO ₄ slurry ha ⁻¹	6.17	7.20	115.81	0.9	7.12
T ₅ : Seedling dip in ZnO Slurry equivalent to 10 kg ZnSO ₄ ha ⁻¹	6.47	7.40	123.39	0.93	7.25
T ₆ : Foliar application twice with 0.2% ZnSO ₄	6.39	7.33	122.68	0.92	7.12
T ₇ : Foliar application twice with ZnO equivalent to 0.2% ZnSO ₄	6.02	7.17	116.89	0.85	7.00
T ₈ : Foliar application twice with Zn-EDTA equivalent to 0.2% ZnSO ₄	6.19	7.25	134.60	0.99	7.13
SEm±	0.22	0.21	4.38	0.04	0.81
C.D. (P=0.05)	0.69	0.66	12.72	0.12	0.25

Table.2 Grain and straw yield of rice during Rabi season as influenced by different NPK combinations [Source: Pasha *et al.*, 2018]

Treatment	Grain yield (t ha ⁻¹)					Straw yield (t ha ⁻¹)					System rice grain equivalent yield (t ha ⁻¹)	Sustainable yield index (SYI)
	2013-14	2014-15	2015-16	2016-17	Pool ed Mean	2013-14	2014-15	2015-16	2016-17	Pool ed Mean		
Control	2.57	3.01	3.34	2.34	2.82	3.5	3.91	4.66	5.49	4.39	3.1	0.39
N	3.13	4.00	4.61	2.61	3.59	4.05	4.85	5.29	6.04	5.06	3.97	0.45
NP	3.78	4.39	4.92	3.92	4.25	4.41	5.23	5.99	6.89	5.63	4.58	0.57
NK	4.28	4.86	5.23	4.23	4.65	5.07	6.01	6.78	7.99	6.46	5.12	0.6
NPK	5.04	5.82	6.4	5.4	5.67	5.88	7	7.96	9.14	7.49	6.02	0.58
NPK + ZnSO ₄	5.38	6.13	6.38	5.48	5.84	6.21	6.81	7.98	8.97	7.49	6.39	0.71
Farmers practice	4.07	5.46	5.91	4.91	5.09	5.02	6.77	7.68	8.6	7.02	5.69	0.54
SEm(□)	0.34	0.10	0.12	0.09	0.17	0.36	0.19	0.11	0.11	0.17		
LSD(0.05)	1.00	0.31	0.37	0.27	0.49	1.06	0.57	0.34	0.32	0.51		

Table.3 Plant N uptake, nitrogen use efficiency (NUE), nitrogen agronomic efficiency (NAE) and partial factor productivity of applied N (PFPN) under different fertilization treatments (Li *et al.*, 2015)

Treatments	N uptake (kg N ha ⁻¹)		NUE (%)		NAE (g grain kg ⁻¹ N)		PFPN (kg grain kg ⁻¹ N)	
	2002	2003	2002	2003	2002	2003	2002	2003
Early rice								
Control	42.8± 2.0d	52.5±3. 4c	–	–	–	–	–	–
NCU-75	75.3± 3.5c	85.5±1. 4b	43.3±3. 4b	44.0±3. 2b	27.8±2 .6b	14.7±2 .1b	66.7±3 .6b	69.2±1.1b
NCU-150	89.1± 2.8b	94.1±2. 4a	30.9±1. 7c	27.7±2. 4c	19.9±1 .1c	8.6±2. 3b	39.3±0 .6d	35.9±2.0c
POCU- 75	96.0± 2.8b	100.5± 0.7a	71.0±4. 1a	64.0±5. 0a	47.4±0 .9a	22.3±3 .4a	86.4±2 .5a	76.8±2.2a
POCU- 150	113.0 ±2.1a	93.4±3. 2a	46.8±2. 0b	27.3±4. 3c	27.6±2 .3b	7.3±1. 4b	47.0±1 .8c	34.6±0.2c
Late rice								
Control	38.6± 1.3c	44.6±2. 4c	–	–	–	–	–	–
NCU-75	62.7± 1.2b	78.5±4. 5b	32.2±1. 0b	45.2±4. 2b	10.4±1 .5b	17.4±2 .8b	51.3±1 .0b	74.6±4.3b
NCU-150	80.8± 1.3a	98.3±2. 5a	28.1±1. 2bc	35.8±1. 9b	10.0±0 .8b	17.0±1 .6b	30.4±0 .4c	45.6±1.2c
POCU- 75	80.7± 1.3a	94.6±5. 2a	56.2±1. 7a	66.7±7. 8a	17.9±0 .6a	35.1±6 .0a	58.7±1 .0a	92.3±5.1a
POCU- 150	76.8± 3.5a	108.9± 3.7a	25.5±3. 0c	42.9±3. 1b	2.4±0. 9c	16.5±2 .3b	22.8±1 .3d	45.1±1.5c
Total								
Control	81.4± 2.8d	97.1±1. 6c	–	–	–	–	–	–
NCU-75	138.0 ±4.7c	164.0± 4.7b	37.8±1. 5b	44.6±2. 8b	19.1±0 .9b	16.0±1 .0b	59.0±2 .0b	71.9±1.6b
NCU-150	169.9 ±2.8b	192.4± 4.2a	29.5±0. 9c	31.8±1. 8c	15.0±0 .6c	12.8±1 .8b	34.9±0 .3c	40.7±1.5c
POCU- 75	176.7 ±3.2b	195.1± 5.8a	63.6±1. 3a	65.3±4. 8a	32.7±0 .5a	28.7±4 .0a	72.5±1 .3a	84.5±3.5a
POCU- 150	189.8 ±2.9a	202.3± 5.4a	36.1±1. 4b	35.1±2. 3bc	15.0±0 .9c	11.9±1 .0b	34.9±1 .0c	39.8±0.8c

Data were means ± SE (n = 3) and different letters (a, b, c, d) within a column refer to significant differences (P < 0.05) among treatments in the same rice season. NAE, nitrogen agronomic efficiency; NUE, nitrogen use efficiency; NCU, non-coated urea; POCU, polyolefin-coated urea; PFPN, Partial factor productivity of N

Table.4 Economics of the various treatment combinations [Source: Kumar *et al.*, 2017]

Treatments	Net return (Rs. ha ⁻¹)	B:C ratio
No zinc application	62927	1.95
Soil application of the 50 kg ZnSO ₄ ha ⁻¹	82607	2.34
Soil application of ZnO equivalent to 50 kg ZnSO ₄ ha ⁻¹	64897	1.43
Seedling dip in 10 kg ZnSO ₄ slurry ha ⁻¹	69037	2.10
Seedling dip in ZnO Slurry equivalent to 10 kg ZnSO ₄ ha ⁻¹	71577	2.06
Foliar application twice with 0.2% ZnSO ₄	72627	2.23
Foliar application twice with ZnO equivalent to 0.2% ZnSO ₄	66197	1.97
Foliar application twice with Zn- EDTA equivalent to 0.2% ZnSO ₄	68297	2.01

Table.5 Productivity and profitability of rice-rice cropping sequence as influenced by different NPK combinations [Source: Pasha *et al.*, 2018]

Year/Treatment	Control	N	NP	NK	NPK	NPK+ Zn SO ₄	Farmers practice
Productivity (kg ha⁻¹)							
System Rice Grain Equivalent Yield (t ha ⁻¹)	6.34	8.22	9.18	10.06	11.41	12.19	11.10
System per day productivity (kg ha ⁻¹ day ⁻¹)	17.37	22.52	25.15	27.56	31.26	33.40	30.41
Cost of Cultivation (×10³ ha⁻¹)							
2013-14	59.00	61.39	67.19	63.90	69.55	74.04	75.20
2014-15	59.57	62.21	67.47	64.42	69.98	74.43	75.18
2015-16	60.05	63.02	67.76	64.94	70.51	74.82	75.40
2016-17	59.58	62.69	67.80	64.98	70.03	74.63	75.37
Pooled	59.55	62.33	67.55	64.56	70.02	74.48	75.29
Gross returns (×10³ ha⁻¹)							
2013-14	85.40	112.10	127.04	140.50	154.20	168.29	144.19
2014-15	83.38	105.87	116.52	126.97	148.78	157.51	147.02
2015-16	98.19	134.06	141.12	151.40	178.35	182.20	172.04
2016-17	77.05	91.20	113.53	120.11	145.14	150.95	141.76
Pooled	86.00	110.81	124.55	134.75	156.62	164.74	151.25
Net returns (×10³ ha⁻¹)							
2013-14	26.40	50.71	59.85	76.61	84.65	94.25	68.99
2014-15	23.81	43.67	49.05	62.55	78.80	83.08	71.84
2015-16	38.14	71.04	73.36	86.46	107.84	107.38	96.64
2016-17	17.47	28.51	45.73	55.13	75.11	76.32	66.39
Pooled	26.45	48.48	57.00	70.19	86.60	90.26	75.97
B:C ratio							
2013-14	1.45	1.83	1.89	2.20	2.22	2.27	1.92
2014-15	1.40	1.70	1.73	1.97	2.13	2.12	1.96
2015-16	1.64	2.13	2.08	2.33	2.53	2.44	2.28
2016-17	1.29	1.45	1.67	1.85	2.07	2.02	1.88
Pooled	1.44	1.78	1.84	2.09	2.24	2.21	2.01

Table.6 Economics of different nutrient management strategies in rainfed monsoon rice in two locations (AEZ-25 & AEZ-11) of Bangladesh [Source: Jahan *et al.*, 2019]

Treatments	Fixed cost (Rs. ha ⁻¹) 1		Variable cost (Rs. ha ⁻¹) 2		Total cost (Rs. ha ⁻¹) 3=(1+2)		Gross return (Rs. ha ⁻¹) 4		Gross margin (Rs. ha ⁻¹) 5=(4-2)		Net return (Rs. ha ⁻¹) 6=(4-3)		BCR 7=(4/3)		MBCR (over control) 8	
	AEZ-25	AEZ-11	AEZ-25	AEZ-11	AEZ-25	AEZ-11	AEZ-25	AEZ-11	AEZ-25	AEZ-11	AEZ-25	AEZ-11	AEZ-25	AEZ-11	AEZ-25	AEZ-11
HYG	11141	11141	4044	3974	15185	15185	48750	46195	44705	42221	33635	31010	228	216	605	575
MYG	11141	11141	2909	2909	14050	14050	40873	37680	37893	34770	26752	23630	206	190	641	585
IPNS	11141	11141	4541	4400	15682	15611	51091	48182	46479	43711	35409	32571	231	219	573	550
STB	11141	11141	3618	3477	14760	14689	52085	49246	48466	45698	37325	34558	251	238	743	723
FP	11141	11141	1915	1490	13057	12631	25900	28952	24055	27462	12915	16321	141	162	432	439
CON	11141	11141	0	0	11141	11141	14334	13837	14334	13837	3193	2626	92	88	0	0
HYG+CRI	11141	11141	4967	4896	16108	16037	49175	46550	44208	41654	33067	30513	217	206	499	475
MYG+CRI	11141	11141	3760	3690	14902	14902	41015	38035	37325	34345	26184	23133	196	182	506	464
IPNS+CRI	11141	11141	5463	5322	16605	16534	51375	48466	45840	43144	34770	32003	219	209	478	461
STB+CRI	11141	11141	4541	4400	15611	15611	52368	49530	47827	45060	36686	33919	238	226	598	573
FP'+CRI	11141	11141	2625	2129	13695	13340	26184	29306	23630	27178	12489	15966	136	156	326	511
CON+CRI	11141	11141	425	497	11566	11637	14476	13908	14050	13411	2909	2271	89	85	31	15

ig.1

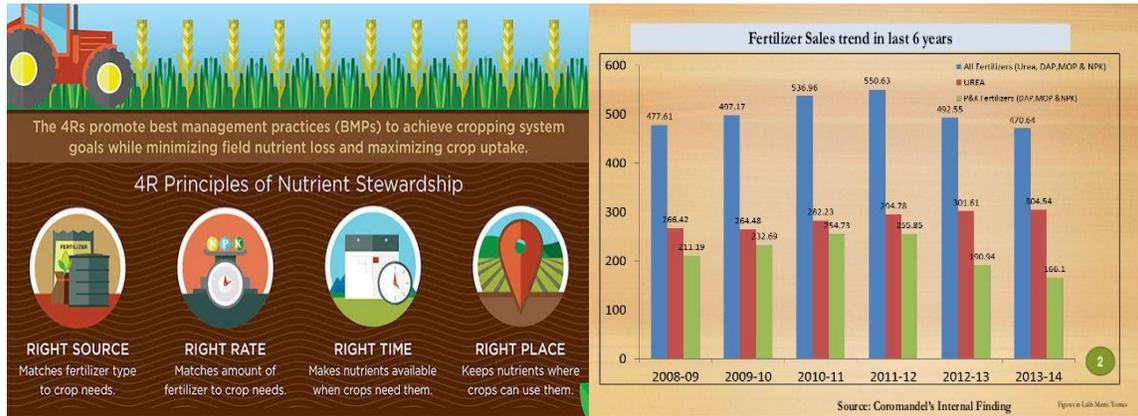


Fig.2 Effect of NPK and Zn on system rice equivalent yield (SREY) Mg ha⁻¹

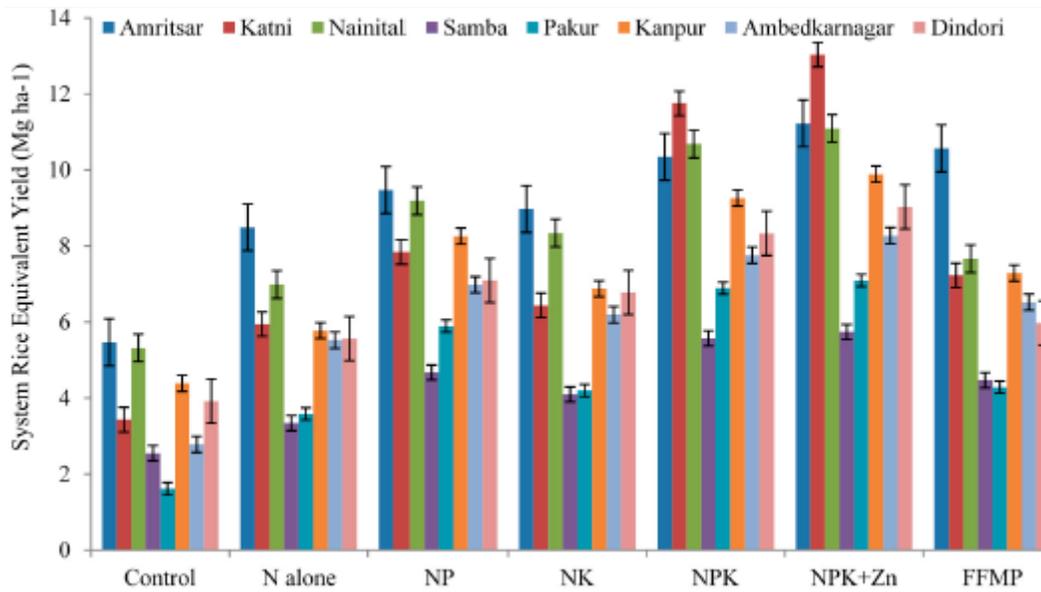


Fig.3 Dry matter (t ha⁻¹) of rice affected by organic fertilizers at the critical growth stages.

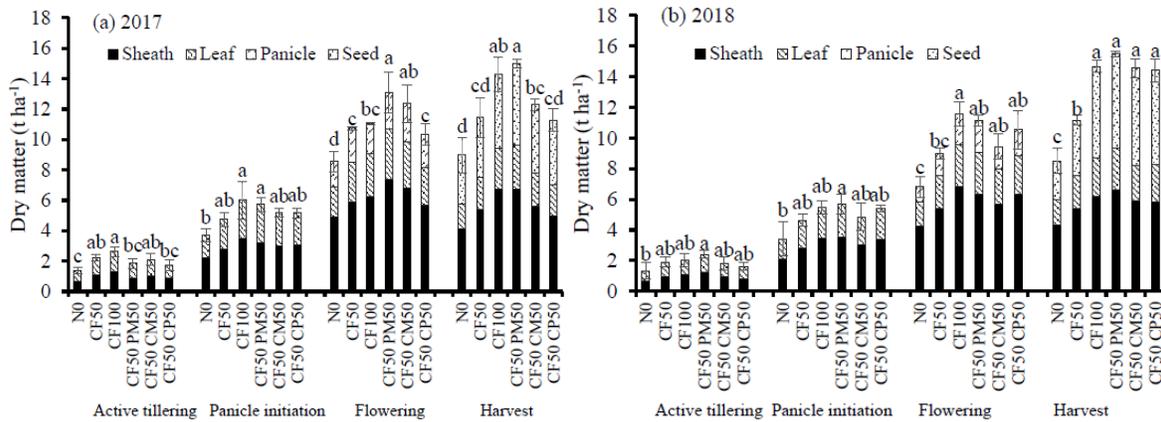


Fig.6

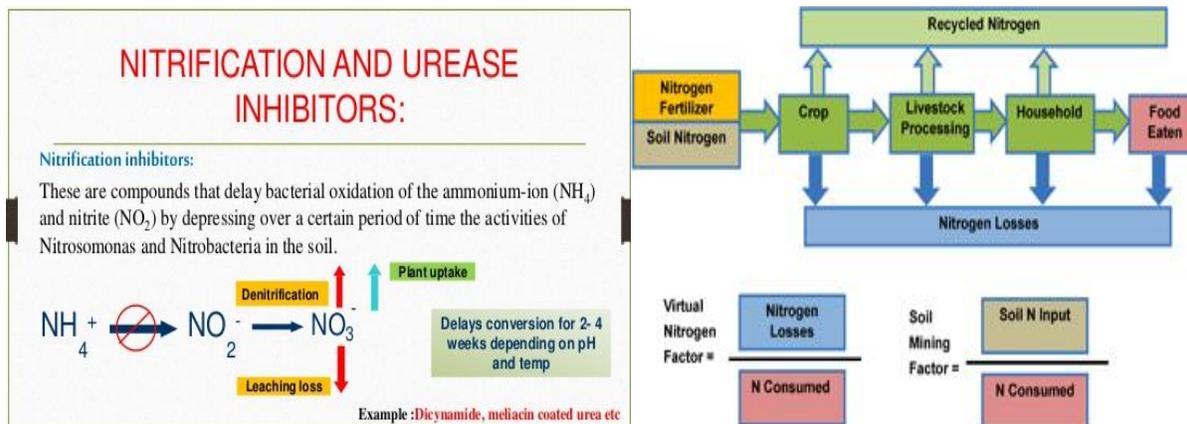


Fig.7 Effect of N application stage and N rate on rice Yield (a), Straw N content (b), Grain N content (c) and Total N accumulation (d)

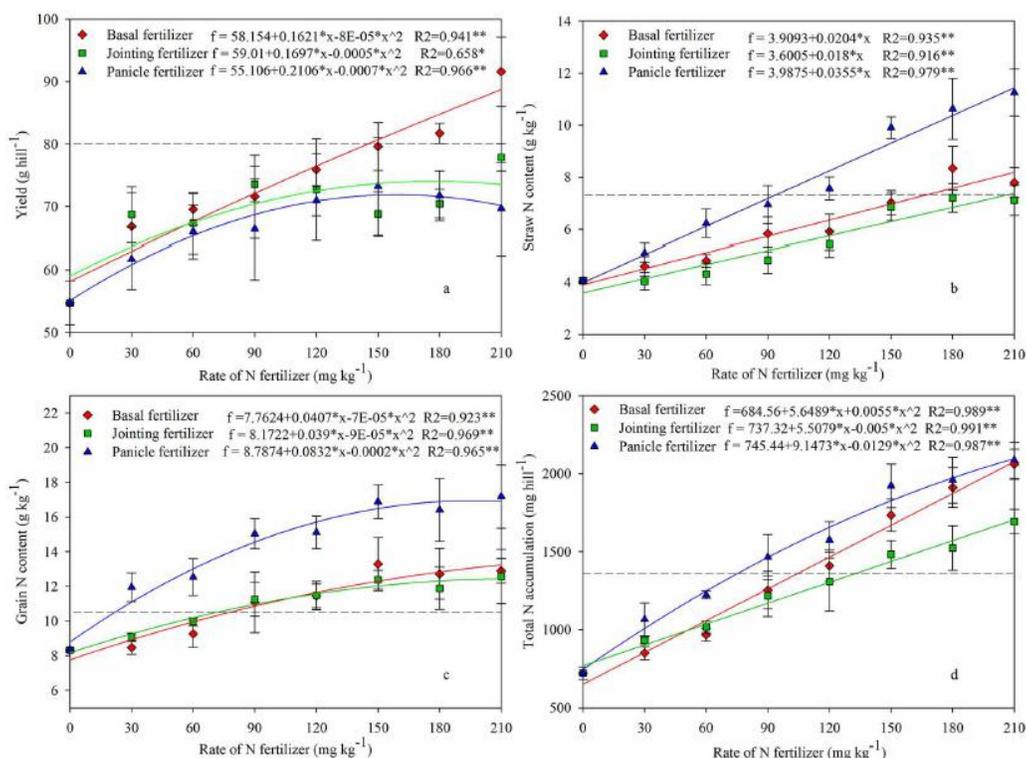


Fig.8 Dry matter production for rice (a) and wheat (b) of the different treatments in the three years

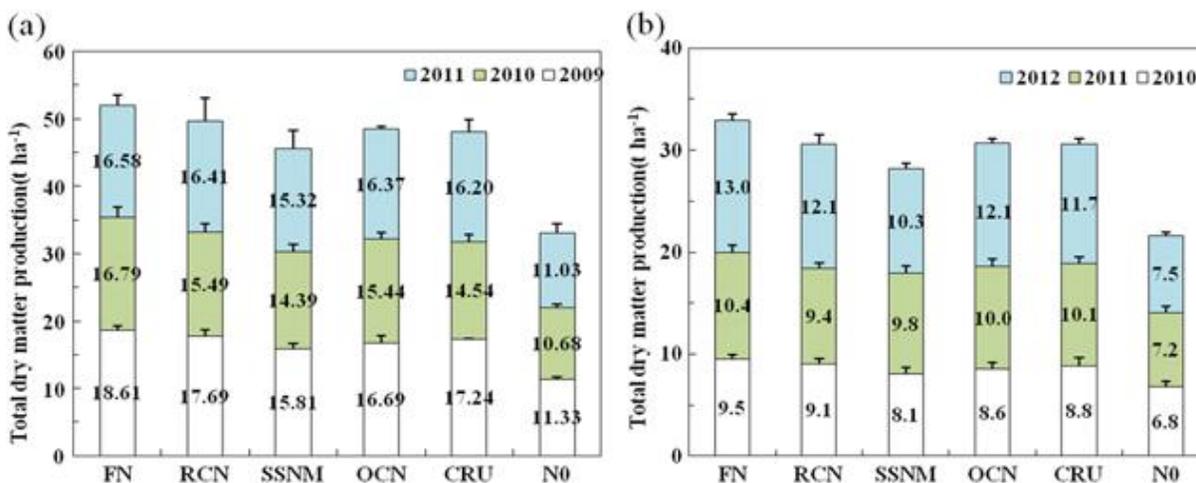
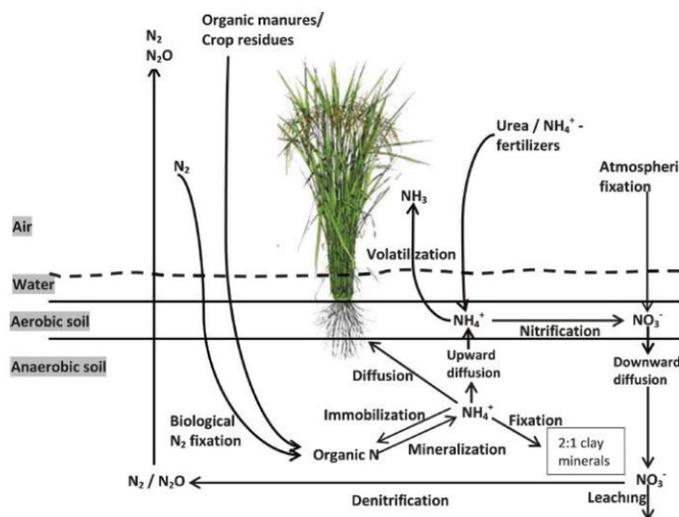


Fig.9 Nitrogen transformations in a submerged soil under lowland rice



References

Ali, T.F., 2002. Methods of zinc, iron and manganese application to rice grown under submerged conditions. M.Sc. Thesis, Fac., of Agric., Kafr El-Sheikh-Tanta Univ., Egypt.

Anonymous 2018. Agriculture statistics at a glance, Department of Agriculture and Co-operation, Ministry of Agriculture, Government of India, New Delhi.

Babiker, F.S.H. 1986. The effect of zinc sulphate levels on rice (*Oryza sativa* L.) growth and productivity. *Alexandria J. Agri. Res.* 31(1): 48-51.

Badr, M. M. Amany, 2014. Impact of organic and inorganic fertilization, quality of rice and soil fertility. Ph.D.Thesis, Fac. Agric. Kafr El-Sheikh Univ. Egypt

Cakmak, I., 2008. Enrichment of cereal grains with zinc: agronomic or genetic biofortification. *Pl. Soil*, 30(2): 1-17.

Carreres, R., J. Sendra, R. Ballesteros, E.F. Valiente, A. Quesada, D. Carrasco, F. Leganes and J.G. Cuadra, 2003. Assessment of slow release fertilizers

- and nitrification inhibitors in flooded rice. *Biol. Fert. Soils*, 39: 80–87
- Cassman, K.G., A. Dobermann and D.T. Walters, 2002. Agro ecosystems, nitrogen-use efficiency and nitrogen management. *AMBIO*, 31: 132–140
- Chaudhry, F.M. and Ali, S. 1986. Ripening of rice as influenced by micronutrients (Zn, Cu and Fe) when the nitrogen source was ammonium sulphate. *Pak. J. Sci. Ind. Res.* 29: 120-122.
- Chaudhry, F.M. and Wallace, A. 1976. Zinc absorption as affected by iron and chelate of ferrous iron. *Plant Soil* 45: 697-700.
- Chaudhry, F.M., Alarn, A. and Latif, A. 1977. Mechanism of differential susceptibility to two rice varieties to zinc deficiency. *Plant Soil* 46: 865-879.
- Chaven, A.S. and Banarjee, N.K.1979. Response of rice to Fe-Zn inter-relationship in a lateritic soil (Oxisols). *Plant Soil* 52: 311-313.
- Chen, J, Huang Y and Tang Y H 2011 Quantifying economically and ecologically optimum nitrogen rates for rice production in South-Eastern China *Agric. Ecosyst. Environ.* 142: 195–204
- Choudhury, A.T.M. and Kennady, I.R. 2004. Prospects and potential for systems of biological nitrogen fixation in sustainable rice production. *Bioferti. Soils*.39:217-227.
- Datta, S.K., Buresh, I.R.J. and Mamaril, C.P. 2010. Increasing nutrient use efficiency in rice with changing needs. *Ferti Res.* 26: 157-167
- Emilsson, T., J.C. Berndtsson, J.E. Mattsson and K. Rolf, 2007. Effect of using conventional and controlled release fertilizer on nutrient runoff from various vegetated roof systems. *Ecol. Eng.*, 29: 260–271
- Esfahani, A.A. 2014. Effect of Fe, Zn and Mn application on growth and yield of rice. *Int J Farm Allied Sci*, 3(5): 529-533.
- Ghanem, S.A., Soliman, S.M., Serafy, A.M. and Soaud, A. 1992. Productivity of Broadcasting seeds rice as affected by different application methods of some micronutrients. *Proc. 5th Conf. Agron. Zagazig*, 1(1): 71-79.
- Gomez, K. A. and Gomez, A., 1984, Statistical procedures for Agricultural Research (2/E). John Willey and Sons, New York, pp. 28-33.
- Gomez, K. A., 1972. Techniques for field experiments with rice. International Rice Research Institute, Manila, Philippines, pp. 39-45.
- Hiremath, S.M. and Hosamani, M.H. 2015. Influence of balanced fertilization on productivity and nutrient use efficiency of maize (*Zea mays*)-chickpea (*Cicer arietinum*) cropping systems. *Res. Crops* 16 (3): 479-84.
- Hossain, M.S., Hossain A., Sarkar M.A.R., Jahiruddin M., Teixeira da Silva J.A., Israil Hossain M., 2016. Productivity and soil fertility of the rice-wheat system in the high Ganges River floodplain of Bangladesh is influenced by the inclusion of legumes and manure. *Agric. Ecosyst. Environ.* 218, 40–52,
- Huang, J.L., F. He, K.H. Cui, R.J. Buresh, B. Xu, W.H. Gong and S.B. Peng, 2008. Determination of optimal nitrogen rate for rice varieties using a chlorophyll meter. *Field Crops Res.*, 105: 70–80
- Jahan, M.A.H.S., Hossain A., Sarkar, M.A.R., Teixeira, S.J.A., Ferdousi, M.N.S. 2016. Productivity impacts and nutrient balances of an intensive potato-mungbean-rice crop rotation in multiple environments of Bangladesh. *Agric. Ecosyst. Environ.*, 231(1): 79-97.

- Jahan, M.A.H.S., Timsina, A.H.J., Sarkar, M.A.R. M., Das, S., Chaki, A.K and Hossain, M.M. 2019. Productivity, nutrient balance, and economics of monsoon rice under different nutrient management practices in two agro-ecological zones of Bangladesh. *Open Agriculture* 4:24–40.
- Jawahar, S., Vijayakumar, D., Bommera, R, Jain, N. 2015. Effect of silixol granules on growth and yield of rice. *Int J Curr Res Aca Rev*, 3: 168–174.
- Kappen, H. 1929. Soil Acidity. Berlin: Springer. (In German)
- Keeping M G, Reynolds O L. 2009. Silicon in agriculture: New insights, new significance and growing application. *Ann Appl Biol*, 155: 153–154.
- Khan, A.A. 2008. Effect of Sulphure in Zinc on growth and yield and nutrient uptake of boro rice (cv. BRRI Dhan-29). *J. Soil Nature*; 2(3):10-15.
- Khawas, M.A. 1990. Effect of *Azotobacterchroococum* and *Azospirillumbrasiliense* inoculation under graded levels of nitrogen growth and yield of wheat. *Plant Soil*. 69:61-67
- Landis, T.D. Dumroese, R.K. 2009. Using polymer coated controlled release fertilizers in the nursery and after out-planting. Forest Nursery Notes, winter.5-12.M.Sc. Thesis, Fac., of Agric., Kafr El-Sheikh-Tanta Univ., Egypt.
- Liu X, Wang H, Zhou J, Hu F, Zhu D, Chen Z. 2016. Effect of N Fertilization Pattern on Rice Yield, N Use Efficiency and Fertilizer N Fate in the Yangtze River Basin, China. *PLoS ONE* 11(11): e0166002. doi:10.1371/journal.pone.0166002
- MD. L. Pasha, S. Sridevi, M.V.Ramana, P.R. R. Reddy and M. Goverdhan Influence of balanced fertilization on productivity, economics and soil fertility of rice –rice (*Oryza sativa* L.) cropping system under deccan plateau of Telangana. *J Crop Weed*, 14(1): 158-162 (2018)
- Moe, K., Htwe, A.Z., Thu, T.T.P., Kajihara, Y., and Yamakawa, T. 2019. Effects on NPK Status, Growth, Dry Matter and Yield of Rice (*Oryza sativa*) by Organic Fertilizers Applied in Field Condition. *Agriculture* 9, 109; doi:10.3390/agriculture9050109
- Moll, R.H., E.J. Kamprath and W.A. Jackson, 1982. Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. *Agron. J.*, 74: 562–564
- Naik, S.K, Das, D.K. 2007. Effect of split application of zinc on yield of rice (*Oryza sativa* L.) in an inceptisol. *Arch. Agron. Soil Sci.*; 53:305–313.
- Pack, J.E., Hutchinson, C.M., Simonne, E.H. 2006. Evaluation of controlled-release fertilizers for Northeast Florida chip potato production. *J Plant Nutr* 29:1301–1313
- Panase V.G, Sukhatme PV. 1967. Statistical methods for agricultural works. ICAR, New Delhi, Ph.D. Thesis, Fac. Agric. Kafr El-Sheikh Univ. Egypt.
- Panwar, A.S., Shamim, M., Subhash Babu, N. Ravishankar, N., Prusty, A.K., Alam, N.M., Singh, D.K., Bindhu, J.S., Kaur, J., and Dashora, L.N. 2019. Enhancement in Productivity, Nutrients Use Efficiency, and Economics of Rice-Wheat Cropping Systems in India through Farmer’s Participatory Approach, Sustainability, 11, 122; doi:10.3390/su11010122
- Pasha, L., Sridevi, A.S., Ramana, M.V., Reddy, R.R., and Goverdhan, M. 2018. Influence of balanced fertilization on productivity, economics and soil fertility of rice –rice (*Oryza sativa* L.) cropping system under deccan plateau

- of Telangana. *J Crop Weed*, 14(1): 158-162
- Patil, M.D., B.S. Das, E. Barak, P.B.S. Bhadoria and A. Polak, 2010. Performance of polymer-coated urea in transplanted rice: effect of mixing ratio and water input on nitrogen use efficiency. *Paddy Water Environ.*, 8: 189–198
- Peng, S.B, R.J. Buresh, J.L. Huang, X.H. Zhong, Y.B. Zou, J.C. Yang, G.H. Wang, Y.Y. Liu, R.F. Hu, Q.Y. Tang, K.H. Cui and F.S. Zhang, 2010. Improving nitrogen fertilization in rice by site-specific N management: a review. *Agron. Sustain. Dev.*, 30: 649–656
- Prasad, R. And Datt, S.K. 1979. Increasing fertilizer nitrogen efficiency in wetland rice. In: Philippines IRRI (ed) Nitrogen and rice. *IRRI, Philippines*, pp 465–484
- Rajini and Sen, A. 2017. Bio- efficiency of polymer coated urea on growth and yield of rice (*Oryza sativa* L.) under low land cultivation. *Int J plant soil sci.* 19(1): 1-5.
- Sharma, S.K., Jain, N.K. and Upadhyay, B. 2011. Response of groundnut (*Arachis hypogea* L.) to balanced fertilization under sub-humid Southern plain zone of Rajasthan. *Legume Res.*, 4:273-77.
- Shaviv, A. and R.L. Mikkelsen, 1993. Controlled-release fertilizers to increase efficiency of nutrient use and minimize environmental degradation - A review. *Nutr. Cycl. Agroeco syst.*, 35: 1–12
- Shoji, S. and H. Kanno, 1994. Use of polyolefin-coated fertilizers for increasing fertilizer efficiency and reducing nitrate leaching and nitrous oxide emissions. *Nutr. Cycl. Agroeco syst.*, 39: 147–152
- Singh, B., and Singh, V.K. 2017. Fertilizer Management in Rice, Chapter February 2017 DOI: 10.1007/978-3-319-47516-5_10
- Singh, R. and Sharma, M.P. 1994. Response of rice to different zinc carriers and their method of applications in partially reclaimed salt affected soil. *Fertilizer News* 39:51- 52.
- Soon, Y.K., S.S. Malhi, R.L. Lemke, N.Z. Lupwayi and C.A. Grant, 2011. Effect of polymer-coated urea and tillage on the dynamics of available N and nitrous oxide emission from Gray Luvisols. *Nutr. Cycl. Agroecosys*, 90: 267–279
- Uddin, M.J., Bhuiya, Z.H., Hoque, M.S. and Rahuman, L. 1981. Effect of rates and methods of zinc application of rice. *Madras Agric. J.*; 68:211-216.
- Varsheny, J.G. 1988. Effect of different micronutrients on the flooded rice in hilly tract of Meghalaya. *Oryza* 25:23-26.
- Wang, X.Z., J.G. Zhu, R. Gao, H. Yasukazu and K. Feng, 2007. Nitrogen cycling and losses under rice-wheat rotations with coated urea and urea in the Taihu lake region. *Pedosphere*, 17: 62–69
- Weih, M., L. Asplund and G. Bergkvist, 2010. Assessment of nutrient use in annual and perennial crops: A functional concept for analyzing nitrogen use efficiency. *Plant Soil*, 339: 513–520
- Xu, M.G., D.C. Li, J.M. Li, D.Z. Qin, Y. Hosen, H.P. Shen, R.H. Cong and X.H. He, 2013. Polyolefin-coated urea decreases ammonia volatilization in a double rice system of Southern China. *Agron. J.*, 105: 277–284
- Xu, M.G., X.F. Sun, C.M. Zou, D.Z. Qin, K. Yagi and Y. Hosen, 2005. Effects and rational application of controlled-release nitrogen fertilizer in paddy field of southern China. *J. Plant Nutr. Fert.*, 11: 487–493
- Yongjie, Yu, Meng Wu, Evangelos Petropoulos, Jianwei Zhang, Jun Nie,

- Yulin Liao, Zhongpei Li, Xiangui Lin and Youzhi Feng,. 2019. Responses of paddy soil bacterial community assembly to different long-term fertilizations in southeast China, *Sci Total Enviro.*, 10.1016/j. scitotenv. 2018.11.359, 656.
- Zhang, F.S., J.Q. Wang, W.F. Zhang, Z.L. Cui, W.Q. Ma, X.P. Chen and R.F. Jiang, 2008. Nutrient use efficiencies of major cereal crops in China and measures for improvement. *Acta Pedol. Sin.*, 45: 915–924
- Zhu, Z.L. and D.L. Chen, 2002. Nitrogen fertilizer use in China –Contributions to food production. *Nutr. Cycl. Agroecosys*, 63: 117–127

How to cite this article:

Rahul Kumar, Mohan Lal, R. K. Naresh, Mukesh Kumar, Shipra Yadav and Rajendra Kumar, M. Sharath Chandra and Pradeep Rajput. 2020. Influence of Balanced Fertilization on Productivity, Nutrient Use Efficiency and Profitability of Rice in Inceptisol: A Review. *Int.J.Curr.Microbiol.App.Sci*. 9(01): 568-590. doi: <https://doi.org/10.20546/ijcmas.2020.901.063>